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Methodology for Design of 100% Renewable Energy Transition Pathways to Meet Small Island Developing States Transport and Electricity Objectives.

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List of Acronyms and Abbreviations

AFV	Alternative Fuel Vehicles
BABSTER	Bottom-up Agent Based Strategy Test Kit for Electricity with Renewables
BAU	Business as Usual
BEV	Battery Electric Vehicle
BOE	Barrels of Oil Equivalent
CAES	Compressed Air Energy Storage
CARICOM	Caribbean Community
CCP	Charging Connection Profiles
CEESA	Coherent Energy and Environmental System Analyses
CGE	Computable General Equilibrium
ChAdeMO	Charge de Move
CO_2	Carbon Dioxide
COP	Conference of Parties
COVID-19	Coronavirus disease 2019
Cp	Coefficient of Performance
CREDP	Caribbean Renewable Energy Development Program
CWS	Chilled Water Storage
DC	Direct Current
DEEP	Desalination Economic Evaluation Program
DG	Distributed Generation
DM	Dry Matter
DME	Dimethyl Ether
DSM	Demand Side Management
DVPP	Dynamic Virtual Power Plant
EAIDT	Earnings After Interest Depreciation and Taxes
ECCB	Eastern Caribbean Central Bank
ECCU	Eastern Caribbean Currency Union
EE	Energy Efficiency
EENS	Expected Energy Not Supplied
EIR	Energy Index of Reliability
EnergyPLAN	Advanced Analysis of Smart Eenergy Systems
EnergyPRO	Techno-Economic Modelling of Energy Projects
EU	European Union
EV	Electric Vehicle
EVSI	Electric Vehicle Supply Infrastructure
FCV	Fuel Cell Vehicle
FF	Fossil Fuels
FM	Fresh Material
GAMS	Generic Algebraic Modelling System
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiation
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit

GNI	Gross National Income
GOSL	Government of Saint Lucia
GRENLEC	Grenada Electricity Services Limited
GWdc	Gigawatt Direct Current
HDV	Heavy duty vehicle fleet
HiGRID	Holistic Grid Resource Integration and Deployment Tool
HOMER	Hybrid Optimization Model for Electric Renewables
HVAC	Heating, Ventilation and Air Conditioning
ICE	Internal Combustion Engine
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IPP	Independent power producers
IRP	Integrated Resource Planning
IRRP	Integrated and Resilient Resource Planning
IRR	Internal Rate of Return
ITES	Ice Thermal Energy Storage
KPI	Key Performance Indicator
kW	Kilowatt
kWp	Kilowatt Peak
LCOE	Levelised Cost of Energy
LCR	Load Coverage Rate
LDV	Light duty vehicle fleet
LEAP	Long-range Energy Alternatives Planning Model
LED	Light Emitting Diode
LHV	Lower Heating Value
LOLP	Loss of Load Probability
LOPP	Loss of Power Probability
LPG	Liquified petroleum gas
LPSP	Loss of Power Supply Probability
LUCELEC	Saint Lucia Electricity Services Limited
MARKAL	MARKet and ALlocation Numerical Model
MATLAB	Matrix Laboratory
MEPS	Minimum Energy Performance Standards
Mesap	Modular Energy System Analysis and Planning Environment
mn	Million
MPGe	Miles per Gallon Equivalent
MSW	Municipal Solid Waste
MW	Mega Watt
MWp	Mega Watt Peak
NDC	Nationally Determined Contribution
NETS	Saint Lucia National Energy Transition Strategy
NL	Normal Litres
NPV	Net Present Value
NURC	National Utility Regulatory Commission (of Saint Lucia)
O&M	Operation and Maintenance
ODM	Organic Dry Matter

OECS	Organisation of Eastern Caribbean States
OEM	Original Equipment Manufacturer
OLADE	Latin-American Energy Organization
OTEC	Ocean Thermal Energy Conversion
Panel-VAR	Panel Vector Autoregression
p.u.	per unit
P2G	Power to Gas
PCM	Phase Change Materials
PEMFC	Proton Exchange Membrane Fuel/Electrolysis
PHEV	Plug-In Hybrid Electric Vehicle
PHS	Pumped Hydro Storage
PlaNet	Planning Network
PV	Solar Photovoltaic
PVSOL	PV Solutions Simulation Tool
PyPSA	Python for Power System Analysis
RE	Renewable Energy
REDOX	Reduction – Oxidation Reaction
RER	Renewable Energy Ratio
RETraP	Renewable Energy Transition Pathways Methodology
RETSCREEN	Renewable Energy Project Analysis Software
ROE	Return on Equity
RPS	Renewable Portfolio Standard
RTP	Real Time Pricing
SAE	Society of Automotive Engineers
SAIDI	System Average Interruption Duration Index
SAM	System Advisory Model
SCUC	Stochastic Security-constrained Unit Commitment
SIDS	Small Island Developing States
SLSWMA	Saint Lucia Solid Waste Management Authority
SOC	State of Change
SS	Substation System
SUV	Sport Utility Vehicle
SVAR	Structural Vector Auto-regression
T&D	Transmission and Distribution
TOU	Time of Use
TRNSYS	Transient System Simulation Tool
TS	Transmission System
UNFCCC	United Nations Framework Convention on Climate Change
UniSyD_IS	Systems Dynamics Modeling of Pathways to a Sustainable Transportation in Iceland
USA	United States of America
USD	United States of America Dollar
V1G	Grid to Vehicle
V2G	Vehicle to Grid
VAT	Value Added Tax

VPP	Virtual Power Plant
VRE	Variable Renewable Energy (solar, wind, et cetera)
WAREt	Weighted Average Tariff for all Generation Sources
WASCO	St. Lucia Water & Sewerage Company
XCD$	Eastern Caribbean Dollar

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Definitions

Demand – Customer electricity consumption measured in kWh (MWh or GWh).

Load – Power requirement in MW

Sector – Customer type including domestic (residential), hotel, commercial, industrial and street lighting.

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I. Thesis Structure

The report starts with Section 1 providing an overview of the country of Saint Lucia and its energy sector used as a case study for developing the energy transition methodology. Section 2 is a presentation of the state-of-the-art review of sustainable energy in the context of Small Island Developing States (SIDS) followed by a description of the research methodology in Section 3. Section 4 provides a description of the available data and sources and includes a report of stakeholder views on key energy sector related issues that are addressed in the scenario modeling. An analysis of the gross renewable energy potential of the case study island is also summarised therein. Section 5 describes and elaborates on the analytical model used for the research. Section 6 describes the development of the various scenarios evaluated in the research.

Having defined the modeling approach and the scenarios, Section 7 follows with an analysis of the scenario results to evaluate how the stakeholder objectives have been addressed. Stakeholder feedback on the scenario outputs and selection of the preferred scenario are then presented in Section 8. Section 9 presents a review of the response of the research to the research questions and a summary of the developed methodology. Finally, Section 10 summarises the key contributions and conclusions of the research work, and an evaluation of areas for future research.

II. Executive Summary

An extensive literature review was conducted in the field of transitioning SIDS to 100% renewable energy (RE) systems. Gaps were identified in the literature from which a research question was synthesized. The development of a response to the research question has followed a methodology which evolved organically as the research work progressed. The main steps included a consultation with the key stakeholders to identify their objectives for a future 100% RE system and the formulation of three scenarios using the highest priority stakeholder feedback to questions in a Delphi survey.

During this process the methodology employed was distilled into a simple procedure presented as a flow chart, for ease of reference, that can be followed by any SIDS to develop transition pathways to 100% RE systems serving all energy consuming sectors. Many interesting results were produced that can help guide

the policy making process. These contributions are presented in the body of the report. Energy use in the transport sector was integrated into the electricity system and bidirectional energy flows were factored through vehicle to grid and energy storage technologies. An evaluation was made on the potential for utilisation of mature terrestrial sources of RE and stakeholder constraints were applied to the use of these sources.

The methodology can be used to synthesize a continuum of RE transition pathways, however, the research has focused on those pathways that are most interesting to the key stakeholders identified and consulted. The three (3) key stakeholder scenarios were elaborated based on the prioritized responses from stakeholders to questions administered through a Delphi survey. The survey responses were directly inputted into an energy model designed specifically for utilizing those inputs to define the energy transition pathways.

The transition process was evaluated in 5-year intervals over a 25-year period. The results were then analysed to determine how well the stakeholder requirements were met by each scenario. This evaluation was performed using key performance indicators (KPIs) and by the stakeholders through an evaluation of the modelling outputs relative to the feedback that they provided through the Delphi survey. The research results are also compared with published works and areas for future research have been identified.

1 Section 1 Country and Sector Overview

1.1 Background

1.1.1 Overview of Country Energy, Demographic, Economic and Environmental Factors

This research is focused on a typical SIDS, the island of Saint Lucia, located in the Eastern Caribbean at 13.883°N 60.967°W and depicted in Figure 1. The country is divided into ten (10) districts and the estimated population was 165,510 (Turkheimer & Waldron, 2019) people in 2018. The land area is 616 km^2, 200 km^2 of which is forest. Saint Lucia has a tropical climate with a dry season from the months of January to April and a rainy season during the months of May to August. The island has very good insolation with global horizontal irradiation exposure of most coastal areas exceeding 5.5kWh/m^2 with on average twelve (12) hours of daylight per day. Average wind speed exceeded 7.5m/s at 10m at the Hewanorra International Airport meteorological station over the twelve (12) months of 2021 (Underground, 2022). The prevailing wind direction (more than 80% of the time) is from the north-east. The diurnal temperature range is about 8°C (maximum temperature of 30°C and minimum of 22°C in May, 2018) (Underground, 2019). Rainfall varies from 1,524 mm to 1,788 mm in the north up to 2,540 mm to 3,683 mm in the central mountainous areas of the island (Fay & Grett, 2013).

Figure 1 Map of St. Lucia Showing Districts

Saint Lucia is an upper middle-income country and an independent member state of the Organisation of Eastern Caribbean States (OECS). The primary economic activity is tourism which accounts for 65% of GDP (Turkheimer & Waldron, 2019). In 2017, the country had gross domestic product (GDP) of USD$1.74bn and gross national income (GNI) per capita was USD$12,980 (World Bank, 2019). The country's GDP has been growing with a linear trend since 1977 (USD$0.09bn) (World Bank, 2018). In 2017, the island's exports were valued at 37% of GDP whereas imports were 45% of GDP indicating a trade imbalance (World Bank, 2019). At the end of 2017, debt to GDP ratio stood at 68.5% (CDB, 2017).

The island imports about 3,000 Barrels of Oil Equivalent (BOE)/day (based on 2013 data), two-thirds of which are used to generate electricity. Energy consumption, by sector, has a distribution of 41% in the transport sector, 30% in the commercial sector, 17% in the residential sector, 4% in the industrial sector and the remaining 8% in other sectors (Espinasa et al., 2015). Electricity is reliably supplied by the monopoly provider, Saint Lucia Electricity Services Ltd. (LUCELEC), which has a concession to generate, distribute and commercialise electricity sales until June 2045. About 98% of electricity sold is generated using diesel generators.

Connected to the grid, as of December 2021, was 1.49 MW of distributed solar generation (LUCELEC, 2021) capacity including 75 kilowatts peak (kWp) at the LUCELEC Cul de Sac generation plant. In addition, the island has 3-Megawatt peak (MWp) of ground mounted solar PV generation capacity owned and operated by LUCELEC and located near the Hewanorra International Airport at Vieux Fort in the south of the island. Power is transmitted at 66kV and distributed at 11kV via seven (7) substations with 6.86%

system losses in 2017. LUCELEC distributes the generated electricity reliably with 2017 system average interruption duration index (SAIDI) of 8.89 hours (LUCELEC, 2017).

Peak demand is about 61.7 MW (2017) and average demand is about 38 MW (2015). In 2017, LUCELEC generated just over 400 GWh of electricity which was used to service around 128,000 domestic customers, 203,000 commercial customers, 18,000 industrial customers and 11,000 street lights (LUCELEC, 2017). Sales to commercial customers, including hotels, was 202,770 MWh, to domestic customers 127,732 MWh, industrial customers 18,256 MWh and to street lighting 10,896 MWh. The company has an installed capacity of 88.4 MW at its Cul de Sac power station at Castries, located in the north of the island. Firm capacity is 68 MW due to the advanced age of some of the generation units. LUCELEC maintains four (4) diesel storage tanks each with a storage volume of about 150,000 gallons to supply the diesel generators. In 2017, LUCELEC spent USD$47,525,000 on fuel and lubricants representing 44.8% of its operational costs (LUCELEC, 2017). Electricity prices are consequently high with price volatility due to exposure to world market oil prices with average tariff of USD$ 0.287/kWh in 2017. Such a high electricity tariff, which varies with the vagaries of international oil prices, has a negative impact on economic activities. In a 2010 survey of businesses, 55% of firms indicated the high cost of electricity as a major constraint to doing business in the country (World Bank, 2017a).

In order to improve economic competitiveness through reduction in the cost of electricity, the Government of Saint Lucia (GOSL) has set a target of 35% by 2025 and 50% by 2030 (World Bank, 2017a) to generate electricity from renewable sources (solar, wind and geothermal), and another target of 23% reduction in carbon dioxide (CO_2) emissions relative to a 2010 baseline of 643Gg CO_{2eq} as part of its intended nationally determined contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) (Lucia, 2015). Saint Lucia also ratified the Paris Agreement in 2016. In 2020, the NDC target was revised to 7% reduction in greenhouse gas (GHG) emissions, in the energy sector relative to 2010, by 2030 (Government of Saint Lucia, 2021). The GOSL also set a target of 20% reduction in energy consumption in the public sector by 2020 (Bunker et al., 2016). This target was not achieved.

A National Energy Transition Strategy (NETS) was developed in 2016 informed by an integrated resource plan to define the pathway for transitioning the electricity sector over the next twenty (20) years. The NETS had the goals of maintained or improved reliability, cost containment and energy independence (Bunker et al., 2016). The output from the NETS process indicated that if geothermal energy can be cost effectively developed, then it should be included as part of the energy mix.

To meet the RE generation target, the GOSL has focused its investments on the development of the geothermal energy resource. Surface exploration works and a prefeasibility study have been completed leading to the selection of sites for exploratory drilling. An environmental and social impact assessment has been completed for the proposed sites and public consultations have started. The GOSL has secured concessional financing and technical support, from international development agencies such as the World Bank and countries such as New Zealand, to finance the high risk exploratory phase of the geothermal development process along with the required regulatory reform and technical capacity building (VOICE Newspaper, 2018).

The transport sector is 100% dependent on imported petrol and diesel fuel. The fuel is imported into the Buckeye Saint Lucia Terminal Ltd. storage facility and distributed by Sol Petroleum EC Ltd. and Rubis to a network of service stations around the country via delivery trucks. As of 2016 the transport stock consisted

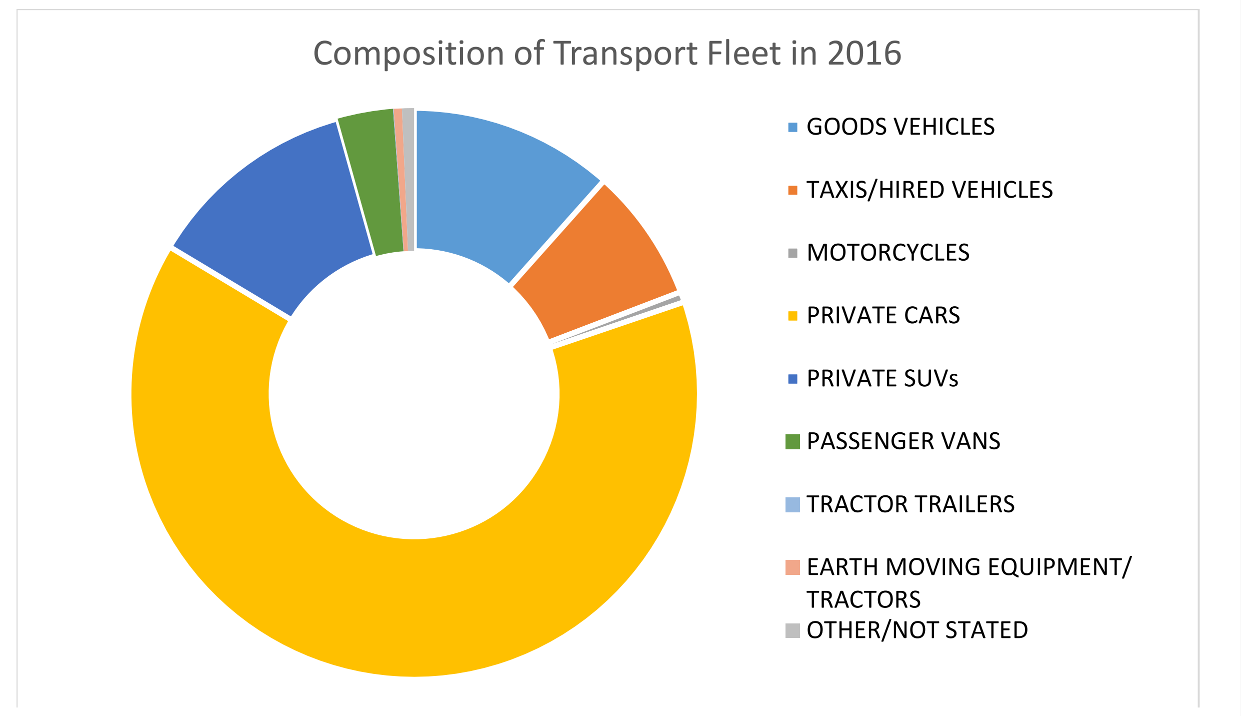


Figure 2 Composition of Transport Fleet in 2016

of about 35,700 vehicles. The composition of the transport fleet in 2016 is shown in Figure 2. For the purpose of this research, the heavy-duty vehicle fleet (HDV) consists of tractor trailers, goods vehicles and earth moving equipment/tractors. The light-duty vehicle fleet (LDV) consists of private cars, motorcycles, taxis and all other vehicle categories.

1.1.2 Review of Institutional Arrangements for Implementation of Policies

LUCELEC's concession, which gives it a monopoly on the generation, transmission, distribution and commercialization of electricity, is governed by the Electricity Supply Act of 2001. The Act which sets out the tariff setting mechanism and service standards, was revised in 2016 to provide for the regulation of the electricity supply service by the National Utility Regulatory Commission (NURC) and to allow the participation of independent power producers (IPPs) for the generation of electricity from renewable sources (*Electricity Supply (Amendment) Act*, 2016). The NURC is responsible for the regulation of the electricity sector including tariff setting and the licensing and regulation of electricity generation from RE sources. The legislation required to enable effective operation of the NURC has, however, not been enacted.

There are no differentiated tariffs for RE. Benefits from RE generation are transferred to customers as savings in the cost of purchasing fossil fuel for electricity production. The current tariff mechanism allows LUCELEC to pass fuel costs to the consumer through a fuel surcharge thereby removing fuel supply cost risk from the company and reducing incentives to invest in renewable sources of generation. The base tariff is calculated using the cost of investments and a base cost of fuel for generation. The tariff mechanism also ensures that the utility has a regulated return on its investments. The National Energy

Policy (GTZ, 2010) allows for the regulatory commission to procure RE through international tenders to meet the government set targets. No such tenders have taken place. No utility scale IPP is currently operating to supply electricity under license from the NURC. The Ministry of Finance, Economic Development and the Youth Economy sets the pricing for and oversees the import of petroleum products.

1.1.3 Other Energy Sectors

Since 2017, licensing and registration of vehicles is the responsibility of the Ministry of Infrastructure, Ports, Transport, Physical Development and Urban Renewal, and there are no regulations governing fuels or emissions in the transport sector.

Liquefied petroleum gas (LPG) is used for cooking in hotels, restaurants and private homes. Water heating is served by a combination of electric and thermal water heaters. Total installed solar thermal water heater capacity in 2014 was 20.5 MWth with a market penetration of 111.4 MWth per 1000 people (Meister Consultants Group, 2015).

2 Section 2 State of the Art Review

2.1 Introduction

Due to the global trend of rising temperatures caused by increasing greenhouse gas emissions tied to anthropogenic activities, the world community has been taking steps to curtail climate change in an effort to reduce the impacts on the earth's ecosystems. As of October 2022, the Paris Climate Agreement, coming out of the Conference of Parties (COP) 21 and coming into force on 4 November 2016 , was joined by 193 parties (United Nations, 2022). This signaled a strong commitment, of global governments, to maintain global temperature rise to less than 2ºC. Net zero targets have since become a central focus of the climate debate. 53 countries and the European Union (EU), accounting for 60-70% of today's GDP and energy related CO_2 emissions, have, as of September 2021, pledged to meet net zero emissions targets (Cozzi & Gould, 2021). The primary adaptation and mitigation strategies being employed include the increased utilisation of renewable sources of energy and energy efficiency. The following literature review gives a broad overview of the impact of RE in meeting energy service needs and points to the direction of smart energy systems as the most appropriate intervention for reducing energy costs and environmental impacts, particularly in SIDS. 145 publications have been reviewed and 95% of them were published between 2014 and 2017.

2.2 Sustainable Energy Systems

Traditionally, power systems have been characterized by a central generation facility with a transmission and distribution (T&D) system to transport the energy to customers in a one-way energy flow. Generation seeks to match demand at every point in time.

Distributed generation (DG) has been defined as an electric power source connected to the customer side of the network or to the distribution system (Zubo et al., 2016). The authors analysed uncertainty evaluation methods for integration of DG into power systems, e.g., system reliability, loss of load indices, future demand and RE generation estimations, and methods for optimal placement of DG resources using various techniques including multiple scenario generation and artificial intelligence algorithms.

A sustainable energy system may be regarded as one which considers cost efficiency, reliability, environmental and social acceptance and harmony and utilises local resources in a renewable and sustained manner (Shortall et al., 2015). (Hohmeyer, 2017) (pg. 87) highlights the need for strong stakeholder involvement and local participation to ensure high levels of wind penetration in the island of Barbados. It has also been shown by (Hohmeyer, 1988) that market prices alone will not be sufficient to drive a transition to sustainable energy as some economic benefits are external to the market process, e.g., benefits associated with environment and health.

In their work, (Timilsina & Shah, 2016) have identified three (3) requirements for successful deployment of RE in a country, viz., a long-term vision defined by goals; implemented and enforced policies, instruments and mechanisms to support the achievement of the goals; strong and effective governance structures and administrative processes for implementing the policies and instruments.

By the end of 2010, as both solar and wind energy approached and then went below grid parity in SIDS, the idea of a 100% RE supplied system started to emerge (Ciriminna et al., 2016).

A sustainable energy system should also be resilient. (Hotchkiss, 2016) (pg. 7) defines resilience as 'the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions through adaptable and holistic planning and technical solutions'. The author presents the following mitigation measures for grid resilience depending on the vulnerabilities and threats: undergrounding critical lines, demand side energy efficiency, diversifying generation, deploying distributed generation including distributed PV, micro grids, energy storage solutions and smart grids. (Burgess, Christopher; Goodman, 2018; Burgess et al., 2020; Elsworth & Geet, 2020; Stone et al., 2020) have investigated and provided various system improvement measures for hardening of PV systems to climate hazards to add resilience to electricity networks. In addition (Elsworth & Geet, 2020) provide estimates of the upfront cost premiums that can be expected for hardening of PV systems. An average snapshot of the cost of thirteen storm hardening system measures resulted in an estimate of a cost premium of 51% for a 1 MW ground mounted system and 10% for a 100kW roof mounted system (Elsworth & Geet, 2020) (pg. 41) compared to the cost of baseline systems. Though most of the measures are of a technical nature, the need for a robust quality assurance and maintenance system is of equal importance. In addition (Stone et al., 2020) have listed codes and regulations that should be implemented in SIDS to build resilience against climate hazards into solar PV projects.

A post disaster needs assessment for the Commonwealth of Dominica after the passage of hurricane Maria in 2017 found that 90% of the housing stock was damaged (Dominica, 2017) (pg. 5). 90% of the housing stock in Anguilla (UNDP, 2017) (pg. 17) was also severely damaged by the passage of hurricane Irma in 2017. This provides an indication of the proportion of the housing stock that can be expected to survive similar climate hazards in the Eastern Caribbean. Consequently, 10% is used as an approximation for the portion of the building stock that can be considered fit for installation of roof mounted solar PV systems.

2.3 Stakeholder Engagement Methods for Scenario Building

In their work looking at integrating stakeholder preferences into the assessment of scenarios for electricity production on a small island, (Chopin et al., 2019) point out that integrating the views and beliefs of stakeholders into decision-making tools can aid decision-making by focusing on the characteristics in the scenarios that best satisfy the expectations of the various stakeholders. The authors used a combination of stakeholder discussions and online surveys for administration of a questionnaire.

In developing a context-specific set of indicators for monitoring sustainable energy development that adequately reflect relevant challenges and national priorities, (Gunnarsdóttir et al., 2021) underscores the need for stakeholder engagement. This is important as decision makers are increasingly recognising the need for public participation and stakeholder engagement for effective decision-making and increased public acceptance. Additional benefits of stakeholder engagement identified include increasing comprehensiveness, building trust and acceptance, reducing bias, and increasing relevance and applicability of the affected body of work. The stakeholder engagement techniques used included interviews, focus groups and use of a Delphi survey. In a scenario development process, (Haatanen et al., 2014) engaged stakeholders through a combination of a workshop (attended by a balanced representation of stakeholder groups) and an online questionnaire. The priority stakeholders were experts and policymakers in the field under study. In their prioritization of barriers to RE development in India, (Pathak et al., 2022) used a modified Delphi method for prioritization and final selection. The modified Delphi is described as a structured way of collecting inputs from experts through group conversations and surveys. The method consists of the following steps to achieve consensus: selecting the professionals; conducting a first-round questionnaire survey; conducting a second-round questionnaire inspection; conducting a third-round questionnaire; and synthesizing the results. Some studies have suggested that eight (8) experts are sufficient to get credible results.

In a review of stakeholder inclusion in scenario planning from a European projects perspective, (Andersen et al., 2021) have provided an extensive literature review showing that the core of scenario planning is a focus on stakeholder inclusion. A key purpose of scenario planning is to shed light on future possibilities and to avoid being constrained to a single possible outcome. This is typically achieved by including diverse and sometimes unconventional views to extend the range of potential solutions to a problem or challenge. Scenario planning methods such as Delphi studies, horizon scanning and other foresight techniques have long been deployed in policy settings. Stakeholders are defined as 'all individuals who have been engaged in the scenario planning exercise and integrated into the process for their point of view or perspective' (Andersen et al., 2021) (pg. 4). Stakeholders can generally be classified under three (3) categories: subject matter experts, professionals from other organisations, agencies or communities and the general public. The authors also found that there was no consistent discipline applied to the process of choosing and inviting stakeholders in the scenario methods investigated. Three (3) typical stakeholder selection approaches are identified in the literature, viz., stakeholder analysis identifying stakeholders who are actively engaged in public debate on the subject, snowball or co-nomination and, utilising selection criteria. The authors note that the literature identified around a hundred processes or methods for stakeholder inclusion, most of which are some form of workshop, interviews or surveys, and questionnaires. The Delphi method is identified as an engagement mechanism used to include stakeholder inputs into scenario building. The Delphi method is noted to have response rates as low as 10% which can be improved by combination with a workshop or interview. Reasons cited in the literature for stakeholder inclusion in scenario planning include: to ensure an impact on policymaking; prioritising of trends and challenges identified; building scenarios; vetting preliminary scenarios to ensure they are fit for purpose in relation to possible strategies and adaptation options devised from the scenarios; and strategy or policy formulation. A variety of stakeholder functions are identified ranging from providing inputs, identifying factors or challenges from longer lists and categorising them, formulation and evaluation of qualitative scenarios and prioritizing among scenarios.

2.4 Stakeholder Analysis

In his work (Hohmeyer, 2015), on a 100% RE system for Barbados, indicates a positive impact on taxation as money saved from reduced fossil fuel imports is reused within the economy. The author indicates the need for an appropriate policy and regulatory framework to enable a sustainable energy transition; enabling local participation in the financing of RE investments to generate income and jobs for locals; and the need for participation of the population in the planning process to foster buy-in.

The authors of (Wehner et al., 2017) identified the need for strong stakeholder participation as an integral requirement for successful deployment and operation of RE systems in SIDS as new sources of employment are created and skilled worker capacities have to be developed in both the private and public sectors. The improved air quality from reduction in fossil fuel use in the electricity generation and transport sectors will also result in positive health benefits to the general population. The paper cites the lack of financial incentive schemes as a barrier to implementation of sustainable energy plans particularly for private sector investors. Weak regulatory frameworks, inadequate institutional capacity and a lack of political will are also cited as major barriers impeding the participation of local electricity utility companies and private investors in sustainable energy investments. A lack of consultation and collaboration among the energy sector stakeholders is also highlighted as a barrier to integrating new sustainable energy investments into the existing systems and accessing the required data needed for decision-making.

The following key objectives of stakeholders were identified by (Hohmeyer, 2017) (pg. 8) in an economic analysis to establish a stable price for renewable electricity in the island of Barbados, viz., reliability of the power supply, low environmental impact, low cost of power, high employment generation, reduction of imports and increased energy security. Public acceptance, local participation and domestic ownership were also mentioned by stakeholders as important objectives. In this particular case, it was evident that policymakers were the key stakeholders to make decisions around final technology choices as the agricultural sector could be significantly impacted. This highlights the need to understand the impact on stakeholders in other economic sectors that may be affected by a transition to sustainable energy. Other stakeholders engaged during the analysis included personnel at the energy Ministry, local investors, utility company, agricultural sector and the utility regulator.

(Hohmeyer, 2017) (pg. 15) identifies four (4) main mechanisms for introducing RE based electricity into the electricity market worldwide, viz., net metering, feed-in-tariffs (FiTs), renewable portfolio standards (RPS) and auctions. The report further points out that empirical evidence shows participation of a wide range of citizens in the energy transition process is best accommodated by FiTs, however, they must be adequately tailored to the local context and must be adjusted based on the technology cost trends.

As it relates to energy efficiency, demand side management (DSM) and security of energy supply, the National Energy Policy of Saint Lucia (GTZ, 2010) (pg. 14) identifies 'utility personnel, hotel developers, engineers, government ministries, e.g., Finance and Energy, electricity market participants, consumer groups and entrepreneurs as key stakeholders to be consulted to ensure sustainable programmes are developed and implemented. The government ministries and electricity utility company were key stakeholders involved in the development of the Energy Roadmap (Bunker et al., 2016). The utility and government stakeholders identified the goals of grid reliability, cost containment and energy independence (including environmental protection) for a future energy system. It can be argued that these goals reflect the interests of a limited pool of stakeholders as only 'relevant stakeholders' (Bunker et al., 2016) (pg. 14) were consulted.

In a report investigating the readiness for a transition to electric mobility solutions in Saint Lucia, (Julliard, 2015) (pg. 4) consulted with the following stakeholders: Ministry of Transport, Ministry of Energy, Inland Revenue Department, LUCELEC, car dealer association and customer association of Saint Lucia. The stakeholders identified the following top four (4) objectives, in order of priority, for transitioning to electric mobility (Julliard, 2015) (pg. 16): independence from fossil fuels; increase the use of indigenous energy sources; Government's primary interest is in the public transport fleet; and it is sufficient that transport is affordable. In a similar readiness assessment, for electric mobility in Saint Vincent and the Grenadines (Roemer & Julliard, 2017) (pg. 5 -6), the following additional stakeholders were identified: the Ministry of National Security, Air and Seaport Development; Ministry of Finance; Ministry of Foreign Affairs, Trade and Commerce; Ministry of Economic Planning, Sustainable Development, Industry, Information and Labour; Ministry of Tourism, Sports and Culture; Customs and Excise Department; Central

Water and Sewage Authority; Royal Saint Vincent and the Grenadines Police Force; Education Sector Organisations; Bank of Saint Vincent and the Grenadines; the Bureau of Standards; Private Sector Companies in the Field of RE and Private Sector Companies in the Field of Vehicle Import and Trade. The four (4) highest priority objectives identified by the stakeholders were (Roemer & Julliard, 2017) (pg. 14): reduce emissions from transport (climate protection); efficient and affordable transport/reduce costs; attract global climate finance and investment; and generate revenues from new business models/job creation. In preparing the Caribbean Community (CARICOM) Regional Electric Vehicle Strategy (REVS) (Cadmus; GIZ, 2021), additional stakeholders engaged included universities, think tanks, research laboratories, consultants, development organisations and electric vehicle service providers.

In all the cases highlighted, the stakeholder engagement process consisted of face-to-face or online discussions and interviews.

2.5 Energy Modeling Tools

Two (2) approaches are typically used for simulating of RE systems, viz., chronological simulation, which relies on the use of historical data, and probabilistic techniques that incorporate the stochastic nature of RE sources, thereby eliminating the need for historic data (Amusat et al., 2016). Of the probabilistic techniques, several numerical modeling techniques have been employed in the literature for optimization of the integration of electric vehicle (EV) charging and RE into power networks, e.g., Stochastic Security-constrained Unit Commitment (SCUC) (Haddadian et al., 2016). These techniques are, however, unable to account for the dynamic nature of hybrid systems and, as such, are not able to model energy storage which is done using chronological simulation (Amusat et al., 2016). A summary of probabilistic approaches used in the literature is provided by (Chauhan & Saini, 2014). Several other RE sizing methodologies and software packages as well as multi objective design methodologies that have been used by other researchers are indicated in the work by (Chauhan & Saini, 2014).

In order to design mini-grids and distributed generation systems, that will connect to the main grid either for energy supply or to provide other services, such as desalination, several software tools have been developed. Some of these tools include hybrid optimization of multiple energy resources (HOMER®) (HOMER, 2022), a techno-economic optimization tool for hybrid energy systems that can handle both standalone and grid connected system analysis, and System Advisory Model (SAM) (NREL, 2022), both developed by the National Renewable Energy Laboratory of the United States of America. Renewable Energy Project Analysis Software (RETSCREEN) was developed by the Government of Canada Natural Resources (Government of Canada, 2022) and is a project analysis and decision support tool for handling financial and sensitivity analyses on energy projects. Desalination Economic Evaluation Program (DEEP) (I. A. E. A. IAEA, 2000) was developed by the International Atomic Energy Agency for analysis of desalination projects (Tafech et al., 2016). H2RES (Duić, 2022) has been developed for simulating the use of hydrogen for energy storage through balancing hourly time series of water, electricity, heat and hydrogen demand as well as storage technologies in island grids (Krajačić et al., 2008). Some studies such as the work presented by (Winskel et al., 2009) have used the MARKAL linear programming model (T. C. P. IAEA, 2022) to look at prospects of hydrogen as a future vehicle fuel for buses and cars in the UK. Tools such as the transient system simulation tool (TRNSYS) (Thermal Energy System Specialists, 2022) can handle modeling of solar thermal systems whereas PV Solutions Simulation Tool (PVSOL) (PVSOL, 2022) focuses on solar photovoltaic systems (Bajpai & Dash, 2012). A comprehensive review of hybrid RE system modeling, optimization and configurations for off-grid applications has been provided by (Siddaiah & Saini, 2016) with the notable point that generally hybrid systems tend to be more cost-effective than single technology systems though dependent on available resources. The authors have also indicated that the hybridization of two (2) or more optimization methods was better at evaluating risk as it included more parameters than a single method allows.

Software tools for modeling energy systems include: EnergyPLAN (Department of Development and Planning, 2022) that was developed in Aalborg University Denmark, is capable of hourly modeling of all storage, transport technologies, RE, thermal and conversion systems (Mathiesen et al., 2015), and is used to design and model national and regional energy systems; EnergyPRO (EMD International A/S, 2022) that was developed by EMD International A/S Denmark and is used for mixed fossil fuel and bioenergy powered cogeneration and tri-generation projects along with other variable RE sources; and Long-range Energy Alternatives Planning (LEAP) (Stockholm Environment Institute, 2022) that was developed in the United States of America (USA) to analyse national energy systems with the ability to track resource utilisation, energy production and consumption, and is currently maintained by Stockholm Environment Institute. LEAP is well suited for generating energy development scenarios looking at changes in both supply and demand, and for tracking GHG emissions and has been applied both in mainland and island situations (Salehin et al., 2016). The authors of (Emodi et al., 2017) have outlined the LEAP model algorithm which was used to look at future energy scenarios for Nigeria.

The main differences (Sadri et al., 2014) between LEAP and EnergyPLAN are:

- LEAP can concurrently analyse several scenarios and provide comparative results, whereas EnergyPLAN models can only analyse one scenario at a time and cannot provide comparative results.
- LEAP can account for transmission and distribution system losses as well as specific power plant efficiencies, whereas EnergyPLAN does not have equivalent functionality.
- Though both models use a bottom-up approach, the LEAP model provides greater flexibility in energy system fuel, technology and energy demand attributes compared to EnergyPLAN.
- LEAP provides more detailed environmental reports.
- Time of use tariffs must be modelled as a separate scenario in LEAP, whereas EnergyPLAN enables this through more temporal resolution in entering loads.
- EnergyPLAN allows hourly system modeling both on demand and supply sides.
- LEAP allows greater flexibility in data input through a more flexible database of fuels and units.
- Both models focus only on technical, economic and climate factors, but do not analyse stakeholder issues or social interactions.

The impact of various RE sources, demand response programmes, electric vehicle charging and energy storage on the performance electricity grid hardware can be modelled using several software packages, inter alia, Holistic Grid Resource Integration and Deployment Tool (HiGRID) (Forrest et al., 2016) and SIEMENS PSS Sincal® (Siemens, 2022).

In the work done by (Felgenhauer et al., 2016b), the VICUS one node version of the Urban Research Toolbox: Energy Systems URBS, developed by T. Hamacher and S. Richter, simulation model was used to determine the cost optimal mix of technology options. This was done by looking at the interaction among fuel cell vehicles, battery electric vehicles and the integration of distributed RE to meet the energy needs of a community in California using a linear optimization technique.

Interactions between energy markets and alternative fuel vehicles have been modelled for Iceland using the Systems Dynamics Modeling of Pathways to a Sustainable Transportation in Iceland (UniSyD_IS) (Leaver, 2022) that can be used for policy analysis providing information for entire well-to-wheel pathways (Shafiei et al., 2015).
The analysis of stakeholder objectives is also required in the development of energy systems. The authors of (Alfaro et al., 2016) applied the Agent Based Modelling tool Bottom-up Agent Based Strategy Test Kit for Electricity with Renewables (BABSTER) as a framework for stakeholder engagement as the first step to evaluate possible energy policies. The tool can be used to narrow down many scenarios to a few promising ones for further analysis and also to identify data gaps. The authors also indicated the model verification process employed.

(MacCarty & Bryden, 2016) provided a summary of available models covering the categories energy system analyses, conceptual frameworks and multi-criteria decision analyses. A model for rural electrification system design was then developed and presented considering aspects in all these categories.

(Tsai et al., 2016) presented a comparison of forecasting models for predicting growth trends in RE consumption focusing on Grey System Theory applied to the case of China. Grey theory was selected as it has minimal data requirements and tends to have high forecasting accuracy. Matrix Laboratory (MATLAB) (Mathworks, 2022) was used to perform the calculations.

Mosaik, a framework for modular simulation of active components in smart grids, was used by (Sonnenschein et al., 2015) for evaluating control methods for distributed generation in a smart grid.

(Gils & Simon, 2017) developed a 100% RE pathway scenario with a back casting process considering cross sectoral energy flows for the Canary Islands by utilizing the bottom-up accounting framework Mesap-Planning Network (PlaNet) and the power system model REMix. The island chain belongs to Spain and, arguably, the considerations would be different for SIDS. The Mesap-PlaNet model cannot provide detailed information about the interrelationships among Variable Renewable Energy (VRE) generation, temporal balancing via storage, and the geographic interactions via the power system. Thus, REMix is used to provide an optimization of the power sector in the last year of the scenario projections with hourly resolution.

(Child et al., 2016) used the EnergyPLAN model to investigate 100% RE scenarios for the Åland Islands which have grid interconnections with Sweden and Finland. This was a technical and financial analysis performed within the constraints of the model used, e.g., only one (1) of the two (2) existing interconnections with the mainland could be modelled. One (1) of the least cost scenarios included high levels of electrification of the transport sector and at least 97% of the energy for transport came from variable RE.

Python for Power System Analysis (PyPSA) (Brown, 2022) bridges the gap between energy modelling and power system analysis and can be used to simulate and optimise electrical systems. PyPSA can also perform analyses over multiple time periods, an advantage over typical commercial power system tools such as Siemens PSS Sincal, Pandapower (Kassel, 2022) and DIgSILENT PowerFactory (DIgSILENT GmbH, 2022). (Brown et al., 2017) provides a description of PyPSA functionality, and (Electrical, 2015) presents a full list of power system analysis tools. (Teske, 2015) previously developed a model that combines energy and power system modelling and, therein, he highlights several energy and power system models that have been developed to analyse various parts of the European grid. Three (3) studies of various energy model architectures and methodologies including hybrids have been presented and evidence is provided to show that the modeling objectives define the key parameters of the model. Some of the methodologies highlighted in the work include bottom-up, focusing on the energy technologies and investments; top-down, focusing on economic data; and optimization models which optimise the operation or investment of technical systems. Two (2) general solution methodologies are also identified, equilibrium and optimization.

The literature reviewed does not contain examples of energy models for isolated SIDS that integrate multi-stakeholder objectives and investigate the interactions among various sources of generation, energy storage, electric mobility and demand-side management options.

2.6 Cost of Renewable Energy

The levelized cost of energy (LCOE) is a tool that has been widely used to compare different RE options for decision-making. This tool has certain weaknesses, e.g., the inability to account for revenues, that make it necessary to combine it with other financial tools such as Net Present Value (NPV), Internal Rate of Return (IRR), payback period and realistic discount rates (reflecting opportunity cost and weighted average cost of capital) to facilitate more comprehensive project analyses. Additionally, it has been indicated that these tools should be used within the context of the financial environment in which a project is being considered to produce meaningful results (IEA, 2016). For instance, (Tao & Finenko, 2015) demonstrated that the discount rate can have a greater impact on LCOE of a PV system than the solar irradiation. The authors also cite access to low-cost financing as a critical barrier to RE projects in SIDS.

Current auction prices for utility scale solar PV energy have been as low as US $24 per MWh in the United Arab Emirates and USD$30 per MWh in Morocco for onshore wind, however, these auction prices may not be reflective of the LCOE for the energy supplies due to the effect of benefits from RE support policies and below average cost of capital (IEA, 2016).

The lack of sufficient knowledge by investors and financers, an unstable regulatory and policy environment and lack of experience by financial institutions are all cited as reasons for higher perceived risks reflected by higher cost of capital in SIDS markets (Tao & Finenko, 2015). The higher cost of capital results in higher project LCOEs in SIDS.

In a liberalized market, energy prices reflect the short-term marginal cost based on the intersection of a merit order curve on the supply side with the demand curve (Auer & Haas, 2016). This gives the cost of energy at any point in time. The rising use of VRE has resulted in a continuous decline of the short-term marginal cost in the European context due to its zero short-term marginal cost. This in turn affects the cost of fossil fuel generation as the number of operating full load hours decreases, while the earnings must continue to cover the fixed and variable costs. Thus, the price spread in these markets increases, thereby increasing the value of storage and flexible generation. This situation can lead to negative prices during periods of high VRE penetration and low demand. It is suggested that two (2) options exist for dealing with the effects of VRE overproduction and underproduction on the residual load duration curve, viz., regulated capacity payments and competition between supply and demand side flexibility solutions, e.g., storage. The market-based approach would take into account customers' willingness to pay which is lower when marginal costs are higher. This is not the case in a regulated market working under the principle of 'supply security' which requires meeting demand at any time regardless of the cost. This is the principle under which SIDS electricity systems operate. The following flexibility factors were identified as being necessary for balancing variations in residual load:

1. A pricing system where prices indicate availability of variable RE at every point in time;
2. Establishment of a demand-side capacity market;
3. The time intervals for forecasting and trading should be as short as possible, i.e., hours or less; and
4. A portfolio of flexibility options for managing residual load including high power and high energy storage, demand-side management measures, smart grids and grid extensions.

The existing price spread is still too low to create a market for these flexibility measures in Europe. In contrast, centralised capacity payments are considered as a step back towards a planned economy resulting in higher costs to society (Auer & Haas, 2016) (pgs.1599-1600).

2.7 Energy Storage

Current, since 2017 global storage capacity is about 150GW, representing about 3% of global electricity generation capacity. Dispatchable renewables represent about three quarters of all renewables based power generation today and supply about one fifth of global electricity (IEA, 2016).

The energy storage technologies capable of providing continuous energy for 24h or more include compressed air energy storage (CAES), hydrogen for use in fuel cells, high temperature thermal storage systems and pumped hydro storage (PHS) which has the highest installed capacity worldwide (Tafech et al., 2016) with roundtrip efficiency of 70% - 80%. PHS has drawbacks in terms of availability of suitable sites, potential environmental impacts, very high capital investment costs, high technical skills requirement and lengthy permitting process some of which are tackled through the variants sub-surface PHS, seawater PHS and variable speed PHS (Yekini Suberu et al., 2014) (Komor & Glassmaire, 2012). The authors of (Gottschamer & Zhang, 2016) have highlighted the negative environmental impacts, such as eutrophication, displacement of animal habitats, GHG emissions and changes in sediment and nutrient loading of grid scale hydro energy which represents just about two-thirds of renewable supplied electricity generation worldwide.

(Akinyele & Rayudu, 2014) provided a very good overview of existing energy storage technologies for providing power quality services with discharge times ranging from seconds to minutes, bridging power services (like spinning reserve, forecast uncertainty and load following) with discharge times in the range of minutes to an hour and for energy management services with discharge times of several hours.

(Chong et al., 2016) have made a very detailed analysis of the suitability of available storage technologies to different applications with a matrix to rank the different technologies. Although mentioned, the environmental impact and social acceptability of the technologies were not included in the ranking matrix.

Flow batteries have been cited in the literature as having the capability to size for power and energy requirements separately, with the Zinc Bromide version targeted at small to medium scale applications and the Vanadium Reduction – Oxidation Reaction (Redox) Battery targeted at utility applications (Komor & Glassmaire, 2012). (Cunha et al., 2016) indicated that redox flow batteries, in particular, the vanadium redox flow battery, have a distinct advantage over lithium-ion batteries, lead acid batteries, sodium sulphur batteries, compressed air storage and pumped hydro storage in that the energy capacity is decoupled from the rated power. This makes them particularly suited to be distributed energy storage systems for transport as the electrolyte can be stored in existing underground fuel tanks, however, they remain expensive, are not considered a mature technology and have a low energy density compared to some alternatives. The particular case analysed by (Cunha et al., 2016) was found to be financially viable in the Portuguese context under the particular assumptions made.

High system cost and environmental issues centered around the very strong magnetic field are factors which act against the use of Superconducting Magnetic Energy Storage technology, whereas flywheels have a roundtrip efficiency of 80% - 85% and are well suited to high power applications (Chauhan & Saini, 2014).

The concept of using RE to produce hydrogen as an energy vector, through water electrolysis, has been investigated and studied by numerous sources (Belmonte et al., 2016). Though the water hydrolyser and fuel cell technologies are both commercial, the systems are still quite expensive (Belmonte et al., 2016) and the process roundtrip efficiency, from electricity to hydrogen back to electricity, is quite low at 20% - 30% (Komor & Glassmaire, 2012) which is due particularly to the energy requirement for hydrogen gas storage. Investigations have been done on the production of hydrogen to store excess energy in a grid with high shares of RE including base load power sources such as geothermal energy (Krajačić et al., 2008).

(Shokrzadeh & Bibeau, 2016) investigated the use of repurposed EV batteries to provide lower cost stationary storage to increase the integration of wind energy into the power grid in the Canadian context. The concept of a renewable energy ratio (RER), defined as the ratio of RE generation to the total primary energy used in a jurisdiction for a given year, was used as a sustainability indicator. The standard UL 1974 is being developed for the use of second life EV batteries as some manufacturers, such as BMW and Nissan, already have products on the market (Spector, 2016).

Generally, the current Integrated Resource Planning (IRP) process needs to be updated to include the benefits of storage technologies, particularly on the intra-hour level. One (1) study, done by the Portland General Electric in its 2016 draft IRP, has estimated the operational benefits of energy storage to be double the capacity value on their network (Driscoll, 2016) (pg.3).

Another study, cited in the work of (Forrest et al., 2016), assessed the amount of storage and DSM strategies needed to enable high levels, up to 80%, of RE penetration into an interconnected Texas grid. This study determined that there were diminishing returns to adding more than four (4) hours of dispatch time storage and that curtailment was only reduced, to below 10%, when the equivalent of one (1) day of storage autonomy was incorporated. This study, though for a specific grid situation, indicates the need to analyse each grid to determine the storage requirements for targeted VRE penetration levels.

The need for hybridization of storage systems to provide power and energy requirements for maintaining power system operational characteristics is an area of current focus with a view to enable very high VRE penetration levels and transport applications (Hemmati & Saboori, 2016). The use of such hybrid energy storage systems (Chong et al., 2016), utilizing more than one type of energy storage to meet the power and energy needs for the vehicle charging and grid services (Forrest et al., 2016), must also be considered to ensure technological suitability based on published characteristics, as provided in (Akinyele & Rayudu, 2014) and (Chong et al., 2016). Hybrid energy systems can extend the life of the storage system, reduce system cost and improve overall system efficiency by combining high energy storage systems such as batteries with high power storage systems such as super-capacitors (Chong et al., 2016).

Analogously, ancillary services for the grid, which are necessary for integrating higher VRE shares, are categorized as high power and high energy capacity depending on the time scale involved. (Lund et al., 2015) provided a breakdown of these service requirements and how they can be met with storage and DSM.

(Lund et al., 2015) pointed out that in order to reap the full benefits of energy storage and reduce inefficient and uneconomical usage, stemming from the inability to benefit from the geographical smoothing effect, where the conditions permit, storage should be used as a system level flexibility resource rather than on a single generation facility.

The levelized cost of storage, for some major technologies including Chemical Battery, PHS, CAES, Flywheel and Flow Battery up to December 2016, are reported on (Lazard & Partners, 2016). This report does not cover power to gas technologies, does not indicate any ancillary benefits to be derived from storage technologies and does not provide cost data specific to any particular market.

2.8 The Concept of 100% RE in Power Systems

2.8.1 System Performance

In order to ensure electrical system security and stability, an electric generation unit peak power must not exceed 25% of the average power in the network (Notton, 2015). VRE can be integrated into about one-quarter of the power mix in relatively strong grids in which the integration process has been carefully planned and there is sufficient flexibility in supply (Mathiesen et al., 2015). Beyond this, demand response and storage are critical elements to avoid the need for curtailment of the VRE resources during periods of high generation (IEA, 2016) in order to maintain system performance quality.

The performance of power systems is usually quantified through the use of indicators that measure system reliability, such as the loss of power supply probability (LPSP) and system performance by Expected Energy Not Supplied (EENS) and Energy Index of Reliability (EIR). These measures were applied to determine the reliability of RE systems by allowing comparison of designs in terms of both cost and performance (Amusat et al., 2016). In this work, variability of the input RE resource was also considered through the use of multiple resource profiles, all of which are different from each other, while maintaining the historical behaviour in terms of probability distributions to generate the cost optimal design. This technique has been applied for locations with high variability in input resource conditions, but is not as applicable in regions with low variability, e.g., the Tropics. Other reliability indicators that have been used in the literature include loss of load probability (LOLP), loss of power probability (LOPP) and load coverage rate (LCR), which is typically used where a high degree of reliability is required (Bajpai & Dash, 2012). A set of reliability and economic indicators and the models or techniques that can be applied to evaluate them and their respective limitations are available (Siddaiah & Saini, 2016). The study indicates that reliability-based models are good at evaluating system performance by removing the uncertainty that arises due to the stochastic nature of the RE resources.

(Verzijlbergh et al., 2014) demonstrated that at large RE penetration levels, controlled charging of EVs and interconnected transmission systems (TS) complement each other by working to reduce generation and dispatch costs as the energy from one region can be transferred to another for EV charging and controlled EV charging can partially substitute for increased transmission capacity and delay the need for transmission investment. The work also found pumped hydro storage to be a costlier option than EV charging for energy storage due to the efficiency of pumped hydro storage at 75%. The study did not consider the effects of cross-sectoral energy flow, e.g., between transport and electricity, or the cost of increasing transmission and EV charging infrastructure.

The interconnection of power systems, across borders and territories, has been put forward as one potential solution for integrating high penetrations of VRE (Verzijlbergh et al., 2014). Arguably, similar benefits may be derived by interconnecting energy sectors, e.g., electricity and transport in SIDS.

Several countries including Denmark, Portugal and Ireland have performed analyses for 100% RE share in their energy mix (Duic et al., 2016). A 100% RE analysis until 2050 was performed for Macedonia in which energy production excesses could occur, there is no mention of energy flows between economic sectors and biomass plays a prominent role (Ćosić et al., 2012). The Danish Government has set a target for a 100% RE system by 2050. Norway has also set a target to become carbon neutral and Sweden has a target of zero net GHG emissions by this same date (Graabak et al., 2016). This is set against the backdrop of the broader EU policy objective of near complete decarbonisation of the power sector by 2050 (Verzijlbergh et al., 2014). Several SIDS countries in the Caribbean Region have set targets for 100% RE in the electricity sector including Dominica, Grenada, Montserrat and St. Kitts and Nevis (Ochs et al., 2015), but so far, there are few analyses to determine how these targets can be optimally achieved.

2.8.2 The Electrification of the Transport Sector

To achieve the target of 1.5ºC limit in global temperature increase by 2040, net zero emissions have to be achieved by this date requiring all sectors to be electrified. It is critical to decarbonize the transport sector which has grown from being the second largest contributor to CO_2 emissions globally (IEA, 2016) to having the highest reliance on fossil fuels of any sector accounting for 37% of CO_2 emissions from end use sectors (Cozzi & Gould, 2021). According to (REN21, 2022) only twenty-eight (28) countries globally have targets for RE in transport. A few countries and automobile manufacturers have started implementing policies to end sales of new internal combustion engine vehicles. Sales of battery electric vehicles was found to be resilient during the Coronavirus disease 2019 (COVID-19) pandemic, which was caused by the SARS-COV-2 virus, accounting for about 4.6% of car sales worldwide. EVs are expected to be cost-competitive with internal combustion engine models in the 2020s (Cozzi & Gould, 2021). Studies including (Morvaj et al., 2016) have focused on integrating RE systems and electric vehicles into power grids and achieving GHG emissions objectives. Models have shown that a decarbonized grid along with an EV fleet can result in 48-70% reduction in GHG emissions by 2050 relative to 2015 (Nunes et al., 2016). Though the global COVID-19 pandemic resulted in a decline in energy consumption over the period 2020 to 2021, demand in the transport sector was expected to rebound to near pre-pandemic levels in early 2022 (Cozzi & Gould, 2021).

The recent World Energy Outlook Report indicated that sources of energy outside of the electricity sector can create flexibility in the energy system, e.g., the transport sector (IEA, 2016). The report states that making use of existing flexible resources, e.g., EV fleets, for energy storage is the most cost effective way to integrate VRE. VRE is also highlighted as providing increased flexibility, i.e., the ability to operate at a wide range of generation levels.

(Haddadian et al., 2016) researched aggregating EV fleets to act as stationary distributed load and energy storage facilities to enable the integration of large amounts of wind energy into the power network and demonstrate that vehicle-to-grid (V2G) systems can be used to accommodate the hourly energy demand.

V2G technology, when powered from RE sources, can provide services to the grid, e.g., load balancing, increased penetration of VRE sources, grid voltage and frequency regulation, decreased losses and reduced environmental impact (Deur et al., 2016) (Morvaj et al., 2016). If EV charging is uncontrolled, at high penetration levels, this can result in grid issues including voltage and frequency deviations, increased network peak loads, increased energy costs, reduced transformer life, high harmonic distortion levels, need for network reinforcement or expansion, and reduced reserve margins (Aghaei et al., 2016), (Ashique et al., 2016). (Ashique et al., 2016) recommend that micro-level analysis, e.g., on the distribution feeder level, be performed to determine the impact of EV charging on different points of the network as different parts of the network would have different capacities for EV integration.

(Forrest et al., 2016) have shown that increasing vehicle charging intelligence, in the case where EVs are treated as stationary for 90% of the time, can be used to achieve VRE targets without the need for stationary storage. Other authors have indicated that V2G systems may result in excessive battery degradation for vehicles involved in such a regime (Felgenhauer et al., 2016b). (Fathabadi, 2017) have demonstrated an efficient solar car port operating with V2G capability. Excess power from the PV array is exported to the grid and supplemental power is drawn from the grid as required. These functions can be substituted with onsite energy storage services.

(Nunes et al., 2016) investigated the current state-of-the-art solar PV charging of EVs at parking lots. This form of charging is very beneficial as the carbon emitted, during the manufacture of solar panels, is generally offset in about two (2) years, by the electricity produced. This means that cars charged with solar energy are virtually free of direct and indirect GHG emissions. Furthermore, it was indicated that the equivalent well-to-tank GHG emissions for an EV powered by half solar and half wind energy is 0-4 g/km.

The need for optimizing freight routes for charging and understanding EV routes is of low significance in island systems due to short travel distances, potential use of rapid charge infrastructure and limited road networks (Deur et al., 2016). (Colmenar-Santos et al., 2016) have looked at the impact of EV charging on an island grid situation, however, only home charging was considered. Their work has also revealed the need to incorporate RE generation in parallel to increasing penetration of EVs to avoid the need for more fossil fuel generation assets to meet the increased demand. (Baptista et al., 2013) also support this position.

Car manufacturers are now providing technology that, not only allows rapid charging, e.g., 22kW, but also enables managing of EV charging from the grid and home RE systems through a charge plan developed from predicted PV system output based on weather forecasts for the particular region (Eleectriccarsreport.com, 2017).

The well-to-wheel electrical efficiency of fuel cell electric vehicles has been cited as being lower than for battery electric vehicles (BEVs). Fuel cell vehicles have certain advantages over battery electric vehicles such as longer range, shorter refueling times and no limitations on vehicle classes that can be replaced, e.g., trucks and Sport Utility Vehicle (SUV) (Zhang et al., 2015) and the freight class example of the Nikola One battery and hydrogen powered truck (Electriccarsreport.com, 2016). BEVs are quickly overcoming these limitations though, e.g., with the introduction of a new Mercedes Benz 26 tonnes Urban eTruck

(Daimler, 2016) and delivery of the first Nikola Tre BEV semi-truck to customers in 2021 (Car and Driver, 2022; Nikola, 2022).

(Sadri et al., 2014) have presented a general procedure, by applying Artificial Neural Network techniques based on historical data of population and GDP, to generate forecasts of vehicle population, vehicle kilometers traveled and traffic volume for forecasting energy demand in the transport sector in developing countries with limited data. These parameters were then used as inputs into LEAP and EnergyPLAN tool models to generate possible future scenarios. The study indicates that without RE, the introduction of EVs charged during off-peak hours result in an increase in fossil fuel consumption in the form of natural gas for the context analysed.

(Gnann et al., 2018) have indicated that aggregating vehicle fleets in modelling exercises may result in overestimating the load shift potential. This tendency can be reduced by simulating each vehicle separately, however, this increases the complexity of the process and the time requirement for calculations. Additionally, most studies do not account for the possible shift in charging patterns and the change in the load curve when more charging infrastructure becomes available. The authors also point out that additional private and work charging infrastructure have an influence in increasing the number of EV stock, whereas, additional public charging infrastructure does not have this effect.

(Geske & Schumann, 2018) have identified range anxiety as a more important parameter for adoption of V2G than remuneration. The V2G strategy must be tailored to consider the mobility demands of the V2G participants. (Shirazi & Sachs, 2018) have highlighted the deleterious effects on the economics of V2G emanating from efficiency losses. These losses lead to reduced revenue and include increased battery degradation, financial losses due to battery energy losses and reductions in the maximum power availability from a fleet. The authors identified the only available empirical evidence of roundtrip V2G efficiencies quantified at 53% to 62%. (Dubarry et al., 2017) have forecasted, from modeling, that batteries that undergo V2G twice daily will induce about 20% capacity loss in about five (5) years compared to about 10% loss with no V2G. There are two (2) V2G architectures already proposed, namely: deterministic in which each EV operates autonomously and aggregative which is provided by a fleet of vehicles. (Uddin et al., 2017) outlines an experiment that shows it is possible to improve battery degradation using a smart grid and an algorithm for optimising degradation, however, the smart grid technology that allows communication with the battery BMS of the EVs does not exist today. Power fade was reduced by up to 12.1% and capacity fade was reduced by up to 9.1%, under certain operating conditions.

(Shirazi & Sachs, 2018) highlighted the shortcomings and conditions under which two studies (Uddin et al., 2017) and (Dubarry et al., 2017) yielded the published results. Both cases did not account for the full range of real-life conditions that can be expected to occur. Additionally, technologies to only maximize return on investment to the EV owner are not viable due to battery degradation. If limits are intelligently set and with the use of battery prognostic tools, however, V2G can be viable. (Steward, 2017) summarised potential costs of V2G electric vehicle supply infrastructure (EVSI) .

2.8.3 RE in Island Power Systems

More than 100,000 islands are scattered all over the Earth’s surface comprising about one-sixth of the land area. Island electricity networks not interconnected with the mainland grid are generally considered as weak since a fault in the network, e.g., a short circuit, will lead to strong voltage and frequency deviations resulting in a high possibility of network failure (Notton, 2015). This is a technical barrier for VRE integration which can be overcome.

(Zubo et al., 2016) have grouped the challenges to distributed generation into four categories: technical, commercial, environmental and regulatory. An assessment of the barriers and potential solutions to RE development in SIDS is available (Blechinger et al., 2016) and (Colmenar-Santos et al., 2013). Among the suggestions for increasing renewable penetration levels are interconnection of islands, simplification of the bureaucratic administrative processes, implementation of smart grids and storage systems and general public engagement.

The issue of technology lock-in, as cited by (Gottschamer & Zhang, 2016), is a critical factor affecting the transition to RE based electricity generation in SIDS which results in their continued dependence on imported fossil fuels for energy services and the continuation of expensive fossil fuel subsidies. This is particularly exacerbated by the institutional inertia inherent in the utility sector in operation of fossil fuel generation assets through the use of unit commitment strategies that have been instrumental in achieving, in a few cases, acceptable levels of performance indicators in island situations.

In addition to cost of energy, risk mitigation and energy security have been cited, in (Dornan & Jotzo, 2015), as primary objectives for the integration of RE in island grids. The authors also proposed that increased electricity demand in islands should be serviced by RE, with cost streams not correlated with existing technologies, to reduce generation portfolio cost and financial risk. Thus, approaches based on portfolio theory are regarded as superior to those based on least cost analysis for risk assessment. This position is further supported by a global consensus for more RE generation through distributed energy sources (Santos et al., 2017).

Traditionally, VRE sources have been unable to provide system stability and security services including inertia for voltage and frequency control due to their stochastic nature. This necessitated the requirement for conventional generation to provide spinning reserve and flexible capacity (Notton, 2015). Technological advances have improved the degree to which VRE resources can now be forecasted and controlled in real-time to the point that they can now be used to provide ancillary services to the grid including voltage and frequency control. In some cases, they even outperform conventional generators in providing these services. Many jurisdictions have not started taking advantage of these services due to outdated regulations, policies and technical standards (IEA, 2016). The kinetic energy stored in the rotating mass of wind turbine blades, for instance, can be used to provide system inertia for frequency regulation. Thus, it is possible to improve network characteristics by connecting VRE plants to weak points on the network (Erdinc et al., 2015), (Zubo et al., 2016). The cost of some of ancillary services have also been documented (Akinyele & Rayudu, 2014).

Three (3) methods have been put forward in the literature to enable higher penetrations of VRE, viz., forecasting particularly over short time intervals, the use of smart grid infrastructure for more flexible operation of the electricity network, and energy storage to enable better matching of energy availability to demand (Notton, 2015).

Furthermore, geographic distribution of VRE sources around an island has been suggested to increase diversity, smooth production profiles, enable easier forecasting and reduce the impact of a decrease in production from a single generator (Notton, 2015). (Lund et al., 2015) also discussed favorably the effect of geographical smoothing to reduce variability of VRE.

The role of energy storage, to increase penetration of RE in energy networks, has been intensely studied and demonstrated as providing services including grid angular stability, peak shaving and load leveling; fault ride through support; power reliability; unbalanced load compensation; frequency and voltage support; power quality and power reliability improvement (Zhang et al., 2015) (Akinyele & Rayudu, 2014), this is even more effective when combined with flexible resources (Santos et al., 2017). Considering these capabilities of energy storage, it is arguable that policies that restrict the penetration of VRE technologies should be revised. In some states including the Canary Islands, regulations prohibit the penetration of renewables to 100% in order to protect the stability and security of the power system by ensuring that baseload production units constitute at least 40% of the instant generation mix at all times with production of VRE above 60% being curtailed (Díaz et al., 2015). In the French Islands, VRE instantaneous penetration is limited to 30% of the total active power following which curtailment is practiced such that islands including Guadeloupe and Martinique have exceeded this limit (Notton, 2015).

(STORIES Project, 2010) proposed the valorization of RE production at the point of end use and provision of energy storage services by utilities for small customers as tools to increase penetration in island grids.

In addition to the flexibility provided by advanced electronic interfaces of VRE sources to the network, e.g., for power factor control, DSM can be used as a tool for providing frequency stabilization services, e.g., through switching on/off of air conditioning equipment. Some authors advocate the use of incentivized demand response programmes for optimal operation of grids with limited generation resources such as micro-grids, as an effective strategy to provide relief to the network (Nwulu & Xia, 2017). This is already practiced in some SIDS power grids, such as Saint Lucia, however, energy storage, though costlier, can be used to provide the same service once the network is not overloaded.

Demand response programmes can broadly fit into the two (2) categories: Time Based programmes like Critical Peak Pricing, Time of Use and Real Time Pricing (RTP) or Incentive Based Programmes like Emergency Demand Response Programmes, Capacity Market Programmes, Demand Bidding, Ancillary Services, Direct Load Control and Interruptible/Curtailment (Nosratabadi et al., 2017). Of these, RTP is cited as having the greatest potential for facilitating VRE integration at all-time scales greater than ten (10) minutes (Lund et al., 2015) (pg.788).

In the (IEA, 2016) report, a model with high temporal resolution was used to evaluate demand response based on a three-step approach: the temporal load profile for each sector analysed was assessed over a 24-hour period then the aggregate load profiles were temporally matched to the load profile of the country being anaylsed; then the flexible demand in each sector was assessed based on the product of the three (3) flexibility factors, viz., shed-ability, controllability and acceptability; and thereafter the demand-side response profile was categorized into hourly models to determine which loads could be shifted based the constraints of the market conditions in the analysed territory.

Other studies, in the Saint Lucian context, as it pertains to RE and EV integration into SIDS energy systems, have not placed considerable focus on the potential contribution of DSM (Baptista et al., 2013), (Bodley, 2016). Smart devices, capable of communicating with electrical grids and independently and intelligently shift their energy use to create operating reserves for the system operator, along with thermal storage air conditioning, make it possible to integrate higher shares of VRE without curtailment (Tuballa et al., 2016). Heating, ventilation and air conditioning (HVAC) systems contribute to more than half of total building energy consumption and are well-suited to provide nearly instantaneous, ancillary services response through a demand response programme (Cui et al., 2014). That study proposed a system for providing ancillary services for a 2-hour duration, as required by reliability rules, using a combination built active and passive cold storages. It is indicated that after a demand response event, the chillers may produce a demand spike once they are returned to normal operations. This can be avoided if the active stored energy is derived from VRE resources and the active cold thermal storage is used to maintain the building temperature. There are three (3) types of cold thermal energy storage, viz., ice thermal energy storage (ITES), chilled water storage (CWS), and phase change materials (PCM), with ITES being the preferred choice for commercial and institutional buildings where space is limited (Arcuri et al., 2016). The study assessed the viability of ITES for commercial buildings in Brazil under a Time of Use (TOU) tariff system. In this study, the storage was designed to reduce peak demand and the ice-making time is during off-peak hours. ITES was shown to generate the most savings in hotter climates where energy costs are higher, but savings depended on the cooling load profile, the adopted ITES strategy and the tariff scheme. ITES can be powered by VRE sources when available, with an appropriate tariff mechanism, to enable integration of RE into power systems while reducing peak demand.

Relative capacity and cost metrics are used to measure the impact of DSM on VRE integration (Lund et al., 2015). Positive capacity, i.e., potential for decreasing power is measured relative to the maximum and minimum total net load (total load – VRE); negative capacity, i.e., potential to increase power is measured relative to maximum VRE power feed in; virtual storage, i.e., load that can be shifted, is measured relative to the installed storage capacity; the investment, variable and fixed costs are relative to a typical fossil fuel generation asset, e.g., a typical gas turbine. The authors have also provided many examples of the use of DSM, and sometimes energy storage, to facilitate increased use of VRE including island systems with the result of an average 20% cost reduction and 10%-20% increase in VRE consumption.

(Abdmouleh et al., 2015) provide a global analysis of successful and failed RE investment policies and mechanisms, the reasons for success or failure and an indication of best practices. To level the playing field for energy costs from conventional generation technologies relative to RE technologies, subsidies similar to what was provided for the development of the fossil fuel generation plants should be provided to RE investments and the financial requirements for the environmental impacts of the fossil fuel generation, should be implemented. The required legislative aspects are classified into the two (2) categories, the power purchase agreements and facilitation of grid interconnection. The following instruments have been identified as effective tools for promoting investment in RE technologies: sustainable grants and subsidies, targeted loans, competitive bidding, FiTs, Renewable Portfolio Standards (RPS) and production tax credit to encourage efficient operations.

(Romano et al., 2017) assessed the impact of policies, in both developed and developing countries, on the adoption of RE technologies. They have analysed policy effectiveness under different situations and stage of national development. Their work shows that developed countries adopt more regulatory policies and tax incentives than developing countries although no difference is observed in the area of public investments. Additionally, it is shown that fiscal (tax) incentives are strongly correlated to increased energy generation from RE in developing countries, although regulatory and public investments do not have a conclusive impact. The factors influencing a higher investment in RE generation, in developing countries, include higher ratios of females in the population, electricity prices, energy consumption and energy efficiency. The policies identified as providing a positive influence on RE generation investment in developing countries include RPS, net metering, sales tax, efficient investment and investment tax. Public investments are shown to have a negative impact on RE investment whereas public competitive bidding has a positive impact. The authors finally suggest a three-phase policy approach to promoting investments in RE.

Ocean thermal energy conversion (OTEC) can be a key component of an energy system for island situations as both energy and fresh water can be produced, however, this is still a technology under development with high LCOE and yet unaddressed environmental and social issues (Hussain et al., 2017). Considering that only two kW scale projects, one in France and another in South Korea, are currently under development, this technology cannot be expected to achieve technological maturity in the near future.

2.8.4 100% RE States

In 2012, the island nation of Tokelau became the first in the world to transition to 100% renewable electricity using a solar PV and battery storage combination (Go100re.net, 2016c). The Samoa Islands were also cited as achieving a 100% RE electricity sector and they share an interconnection with Denmark (Díaz et al., 2015) to export the excess electricity (Kuang et al., 2016) (Notton, 2015) generated primarily from wind and biogas (Mendoza-Vizcaino et al., 2016). The sector is 80% funded by the inhabitants with the support of laws and standards set by the government to promote RE development (Colmenar-Santos et al., 2013). The Mediterranean Island of El Hierro, in the Canary Archipelago, is identified as achieving 100% of its electricity from a mixture of renewable sources (Ciriminna et al., 2016), particularly from wind and pumped hydro storage. Notwithstanding, this claim has been refuted because resultant operational data indicates unsatisfactory performance due to poor engineering design (Deign, 2016). Iceland has used its abundant hydro and geothermal resources to achieve 100% RE in its electricity sector, whereas the transport sector remains dependent on oil (Go100re.net, 2016a). However, the island is now producing hydrogen from its low-cost electricity in an effort to convert its transportation sector (Krajačić et al., 2008). The island of Bozcaada, Turkey has achieved 100% RE in the electricity sector through the use of wind, the excess production is exported to the mainland and some is converted to hydrogen (Go100re.net, 2016b). The island of Graciosa in the Azores is planning a wind, solar and lithium ion battery system that will provide 100% renewable electricity to the island (Deign, 2016). The island of Ta'u in American Samoa has just transitioned to 100% renewable electricity utilizing solar energy and lithium ion battery storage (Roy, 2016). The island of Yakushima, Japan, mainly from hydropower, has achieved 100% RE in electricity production, and has investigated hydrogen production and the use of fuel cell and electric vehicles to achieve a carbon-free energy sector (Go100re.net, 2016d). Porto Santo island in Portugal has achieved 100% RE with a combination of wind, solar and hydrogen storage (Mendoza-Vizcaino et al., 2016).

The conversion from fossil fuel-based generation to RE on islands is not so much driven by climate change mitigation pressure as it is for economic reasons (Shah & Niles, 2016). Current RE penetration levels in Caribbean SIDS are documented and the highest ranked is Belize at 65%, which is interconnected with Mexico while several countries, e.g., Saint Lucia and Antigua and Barbuda, are below 2% (Ochs et al., 2015).

2.8.5 RE in Island Transport Sectors

Plug-in and hydrogen fuel cell electric vehicles offer the opportunity to electrify the SIDS transport sector with powering from indigenous RE sources, thereby mitigating CO_2 emissions while simultaneously achieving energy security. Most EVs on the market have a range of over 100km which is sufficient to cover most commutes on small islands. Additionally, it has been established (Felgenhauer et al., 2016b) that hydrogen fuel cell vehicles consume 2.2 times more initial energy per unit distance traveled than a comparable BEV due to losses in the hydrogen supply chain. According to (Aghaei et al., 2016) plug-in hybrid electric vehicles (PHEVs) are able to reduce fuel consumption up to 70% compared to conventional vehicles and can be powered with RE sources. This makes them a good option for islands to reduce their consumption of fossil fuels in the transport sector. (Cunha et al., 2016) purported that EV use can decrease the global GHG emissions between 10%-24% compared to conventional diesel or petrol internal combustion engine vehicles.

(Krajačić et al., 2008) shows that using hydrogen as an energy vector allows for the achievement of 100% RE for both electricity and transport energy sectors in island systems. A study undertaken by (Ito & Managi, 2015) indicates that fuel cell vehicles may not be cost-competitive, with ICE technologies in the near future (<50 years), and that there is insufficient wind and solar energy capacity, in the Japanese context, to provide electricity for hydrogen production for the fuel cell vehicle fleet, in the scenarios analysed. Thus, the applicability of hydrogen and fuel cell vehicles has to be analysed for each individual island case.

(Felgenhauer et al., 2016b) concluded that hydrogen is competitive with battery energy storage and other studies indicating that it makes more economic sense to produce and sell hydrogen than to store and use for electricity production, however, the results of their work indicates that it is most cost effective to use hydrogen to power fuel cell vehicles (FCVs). BEVs are still found to be, based on cost, hydrogen use efficiency and carbon emissions, more attractive than FCVs. It is further indicated that twice the amount of PV capacity would be required for FCVs to achieve a similar CO_2 emissions reduction as BEVs for a community analysed in California, USA. (Mathiesen et al., 2015) also support the conclusion that the best use of hydrogen is not for producing grid electricity. The roundtrip efficiency of hydrogen for electricity generation is still a major issue at 35%-50% (Lund et al., 2015). Additionally, there are still problems with the storage and utilisation of hydrogen, e.g., high pressures, low temperatures and the need for special materials to prevent diffusion and leakage (Zoss et al., 2016). More research is required to solve these problems.

Fuel cells have an efficiency of 40% to 60%. Reversible fuel cells, e.g., Proton Exchange Membrane Fuel/Electrolysis (PEMFC) cells, have advantages such as high current density, high voltage efficiency, rapid system response, high gas purity and good partial load range and are well suited for coupling with distributed RE systems, although this is still quite expensive (Zhang et al., 2015). Hydrogen can be stored for months, unlike thermal storage, and can be transported for use as transport fuel or for power generation thereby bridging the transport and electricity sectors. Where it is not possible to use hydro storage, hydrogen has been demonstrated as a suitable alternative for energy storage (Martins et al., 2009).

In the World Energy Outlook Report (IEA, 2016) it has been indicated that the cost of VRE generation is going down faster than the cost of new grid investments and favours energy deployment closer to loads where new capacity is needed. This position is also supported by (Alfaro et al., 2016) and the report provided by (Siddaiah & Saini, 2016). Additionally, it takes much less time to install a solar PV system or a wind farm than to negotiate and gain public acceptance for installing high voltage interconnections between territories or installing new transmission systems. This supports a case for providing energy services for EVs near the source of generation from VRE sources. It also supports a case for interconnection of the transport and electricity sectors to maximize the use of existing resources and enable synergies between the two (2) sectors for VRE integration.

(Zeng et al., 2016) have investigated, to a limited extent, bidirectional energy flow between the natural gas and electricity sectors for RE integration. The study showed that power to gas (P2G) can reduce system power loss especially when located near a VRE source, although there was no discussion of the cost or the roundtrip efficiencies. (Thellufsen & Lund, 2016) looked at how well excess electricity can be transferred between a local and national network as a measure of the level of RE integration. The integrable excess electricity can be exchanged between the national and local systems whereas the non-integrable excess has to be handled through other means, e.g., by transfer to other energy systems.

2.9 Smart Grid, VPPs and EVs

(Dornan & Shah, 2016) have suggested that an insufficient amount of work has been done on the transport policy as the link between RE and transport has not been sufficiently expounded. Additionally, (Forrest et al., 2016) indicate that more work needs to be done to understand how high EV penetration rates will affect RE integration, particularly in the case of SIDS grids where the work on RE integration is limited (Dornan & Shah, 2016).

(Forrest et al., 2016) have built on existing work and looked into the impact of increasing levels of smart charging intelligence on the amount of stationary energy storage needed in an electric network. (Santos et al., 2017) have looked at the impact of network reconfiguration and energy storage on RE integration in distribution networks through the use of smart grid infrastructure. (Baptista et al., 2013) also discusses the need for a smart grid to manage loads on distribution networks to ensure lines are not overloaded and technical limits are respected.

Research has shown that when not driven, vehicles are generally parked at work or home for a majority of time (Forrest et al., 2016) and in the Nordic Regions this occurs above 90% of the time (Graabak et al., 2016). Researchers have explored the impact of EV charging and its use as energy storage in island systems through incorporation into the network via a smart grid infrastructure (Díaz et al., 2015). The analysis of the impact of EV charging can be very complex depending on the behaviour of owners. Some studies (Felgenhauer et al., 2016a) have limited the scope of their analysis to the community or network feeder level in order to manage this complexity. Others have considered the use of aggregators for creating virtual power plants (VPPs) from several distributed RE sources and virtual loads from EV fleets (Haddadian et al., 2016) (IEA, 2016) together with operation through a DSM mechanism, e.g., EV solar parking lots (Nunes et al., 2016). (Haddadian et al., 2016) also spoke on the reduced CO_2 emissions and possibility of lower operation costs from low tariff nighttime charging (or during periods of high RE penetration). (Lund et al., 2015) have highlighted the aggregation of distributed household PV systems and loads as a potential VPP to be controlled under a DSM strategy. VPPs are defined as information and communications technology (ICT)-aggregated distributed generation and loads not bound by geographic limits so they act as power plants. The authors also introduced the concept of dynamic virtual power plants (DVPP) which are clusters that can be configured independently from fixed control units and which cooperate only temporarily depending on market signals.

(Aghaei et al., 2016) have presented probability distribution functions for dealing with the uncertainty of how EV charging interacts with the electric network. They have also indicated that though it is possible for a central scheduling system to be used for EV charging it is not feasible because of a lack of sufficient and timely information on when the EVs need to be charged. A scalable decentralised solution, within the framework of a smart grid and suitable price signals, has been proposed to address these issues, however, the potential need for new grid infrastructure is also indicated. In this context, the use of demand response programmes along with day ahead resource scheduling and forecasting have been proposed as a potentially effective means of managing the load on networks from EV charging. (Morais et al., 2014) have investigated the impact of V2G on system operation costs and on flattening the demand curve over a 24-hour period in a distribution network with a large penetration of distributed generators using a multi-objective function. The mathematical formulation was implemented in Generic Algebraic Modeling System (GAMS) software. There has been a lot of research done in the area of micro-grids energy management and some of this work has focused on maximising benefits to customers involved in demand response programmes (Nwulu & Xia, 2017).

The concepts of aggregating VRE and EVs, to provide the needed storage, into VPPs, as discussed by (Baptista et al., 2013), is proposed with the benefits of integrating higher shares of variable renewables and reducing the required investment costs for energy storage. This concept requires the coordination of EV charging and VRE resource availability and forecasting, as an effective tool to enable efficient, economic VRE integration (IEA, 2016). (Nosratabadi et al., 2017) indicate that using aggregators to create virtual power plants from distributed energy resources can result in improvements to efficiency, cost, reliability and security of the power system as well as provide the ability to schedule. They also indicate that the most important and appropriate reliability index, in this case, is the EENS though LOLP can also be applied. The use of VPP control technology has been highlighted by (Tuballa et al., 2016) as one means of control and communication within a smart grid network.

(Baptista et al., 2013) have identified that network losses associated, under the conditions simulated, with increased energy consumption on the network due to EV charging is higher than can be mitigated by using a smart charging approach. This discovery points towards generating energy closer to the point of use for EV charging networks.

Considering the need to be pragmatic and to provide reliable information that can be used by decision-makers, an effort must be made to ensure that RE technologies, that are environmentally, economically and socially non-feasible for the associated energy situation, are eliminated through a rigorous selection process. This effort is necessary as some authors (Mendoza-Vizcaino et al., 2016) have pointed out this deficiency, in some methodologies, adversely impact the economic and financial parameters and significantly affect investment decisions (Akinyele & Rayudu, 2014).

Attempts must be made to evaluate both mature and commercial technologies including those that allow bridging of the power and transport sectors, e.g., through the use of versatile energy carriers like hydrogen and synthetic methane. This has been highlighted as having high potential for RE integration into both the energy and transport sectors (Forrest et al., 2016) and (Franzitta et al., 2016).

(Graabak et al., 2016) have shown that low energy price-based charging, as a DSM strategy, can lead to high peak demand where a valley existed in the demand curve. Uncontrolled charging can lead to increases in daytime and nighttime peaks. This can lead to other issues such as overloading of the network and the need for new transmission system infrastructure investment. The study does not include the impact of fast-charging and considered only private cars. Distributed charging systems with integrated energy storage can be a possible solution to these problems especially in the case of SIDS where power generation, transmission and distribution systems are generally run using outdated and inefficient equipment (Shah & Niles, 2016).

The impacts of EV deployment, on the environment, energy system and economy, have generally been mathematically modelled due to a lack of real-world data because of low adoption levels and to apply available data to new scenarios that may not coincide with the conditions under which the original data was collected. (Daina et al., 2017) have undertaken an in-depth analysis of the modeling methods used in research to predict EV adoption. The techniques reviewed include adapting EV use to existing vehicle travel patterns, adapting usage to availability of charge opportunities and optimising EV travel routes. The cited reasons for this include infrastructure availability, vehicle range, tariff structures and costs, however, most of these reasons are moot in a SIDS context. The models of charging behaviour in the literature are regarded as strongly theoretical and lacking of validation from actual situations, however, no method has looked into charging from locations based on existing fueling infrastructure.

There are three (3) main bodies competing to become the standard for EV charging technology, viz., Charge de Move (ChAdeMO) which allows power output up to 50kW and 80% state of charge within half an hour (Cunha et al., 2016)), Society of Automotive Engineers (SAE) and the International Electro-technical Commission (IEC) (Ashique et al., 2016). (Ashique et al., 2016) indicate that it has been shown that 14%-50% of the transportation energy needs of a Swiss city can be met with solar energy in parking lots and that it is cheaper in a micro-grid to charge from grid connected solar than from a standalone solar PV system. Their work provides a detailed overview of the current state-of-the-art DC fast-charging. The use of fast-charging infrastructure requires allocation of expensive grid services due to the high energy demand. Additionally, charging may coincide with daytime peak demand. These issues can be addressed by decoupling the energy requirement for charging from the grid services through the use of energy storage systems and distributed RE systems. Some of the advantages cited include lowering of peak power demand and, therefore, demand charges, and use of low-price energy under a time-of-use tariff system. Generally, these opportunities are not existent in SIDS grids. A third benefit, which is particularly important in the island situation, is to facilitate the integration of VRE into the transport and electricity systems, though this was not considered in the presented work.

(Nunes et al., 2016) indicate that more work needs to be done to understand the benefits of V2G in a smart-grid environment, however, the use of Grid to Vehicle (V1G) (unidirectional power flow) can be easily accommodated with current technology and could result in both EV user and grid benefits.

(Sonnenschein et al., 2015) have outlined three (3) different control methods, in order of increasing levels, of distributed generation in a power grid under a smart-grid regime. This work shows that grid constraints on the low voltage distribution system can be adequately addressed through central control of smart-charging of EVs from decentralised PV systems to ensure maximum usage of locally produced PV energy. V2G control compared to V1G and uncontrolled charging showed the best results for utilising the maximum amount of energy from PV system generation. It also minimises energy feed into the grid, resulting in a reduction of the distribution system transformer load and a reduction in the peak load compared to without EV charging. The control methodology employed, however, entailed a high level of computational complexity. Self-organizing household device clusters have been simulated for reducing the peak demand on a network by shifting consumption.

2.10 The Smart Energy System Approach

Most of the work focusing on the integration of VRE have taken a sectoral approach focusing on the electricity sector rather than looking at a redesign of the entire energy system. The smart energy system approach, first introduced by the strategic research project Coherent Energy and Environmental System Analyses (CEESA) can lead to improved solutions relative to sectoral approaches (Mathiesen et al., 2015). In such systems, cross sectoral energy flows are enabled through the use of storage, other enabling technologies and the exploitation of synergies. The authors indicate that storage should not be the primary means of integrating large amounts of variable RE due to high energy losses and costs compared to alternatives. Storing electricity for returning to the grid is indicated as not cost effective due to roundtrip efficiency losses compared to conversion of the electricity for the end uses. It is also indicated that the transport sector should be electrified to the largest extent possible to facilitate a transition to RE with battery electric vehicles being identified as the most suitable option for achieving this. Due to limitations in the bioenergy resource and conflicts with food production, land use and deforestation, the use of renewable fuels produced by electrolysis, such as Dimethyl Ether (DME), synthetic methane and methanol, are suggested if all transport needs cannot be met with electricity. Three sets of smart infrastructure are identified: smart electric grids, smart gas grids and smart thermal grids. A smart energy system is a combination of these grids to create synergies and benefits that could not be achieved by a single system. The CEESA study revealed that overproduction of electricity could be reduced to zero through heat and gas storage and connecting the transport sector. The paper also points out that carbon capture and sequestration, CCS, is not a suitable option if high levels of RE penetration are to be achieved.

The smart energy system needs to simultaneously address several requirements as explained by (Dincer & Acar, 2016) including exergetically sound, energetically secure, environmentally benign, economically feasible, commercially viable, socially acceptable, integrable and reliable. Consequently, such systems can result in improvements to employment, social welfare, economies, productivity, energy security, health and environment. The issue of linking smart targets such as better efficiency, better cost effectiveness, better energy security, et cetera. with the development of smart energy systems is highlighted. Since the characteristics of a smart energy system depend on the locational characteristics, economics, et cetera, different methodologies are needed for transitioning to such systems for different jurisdictions (Dincer & Acar, 2016). In an analysis considering efficiency, emissions, renewability and multigeneration potential, the sources of renewable generation were ranked with geothermal the highest followed by biomass and solar for quad-generation, i.e., cold, heat, electricity and hydrogen, and wind showed the best ranking for emissions.

(Shafiei et al., 2015) have made a comparison of hydrogen, biofuels and electricity for sustainable transport in an Icelandic renewable based energy system. The need for fueling infrastructure is cited as a critical determinant for successful adoption of alternative fuel vehicles (AFV). Their results indicate that hybrid and biogas fueled vehicles are the preferred alternative for LDV up to 2050 as they have lower purchase price and fuel cost per km compared to conventional internal combustion engine, ICE vehicles. Applying an initial supply push by making the necessary fuel infrastructure available results in higher uptake of the AFV technologies. In this work, the EV scenario was found to be the most beneficial in terms of energy system cost and CO_2 emissions as electricity is being produced from renewable sources whereas a hydrogen future results in the least benefits and biofuels are least cost from the consumer's perspective due to low-cost vehicles. Thus, electricity was identified as the preferred development pathway due to mitigation cost, fuel demand reduction and fuel supply economic benefits.

The production of DME from renewable hydrogen produced from solar and wind resources and CO_2 has been conceptually evaluated by (Martín, 2016). DME can be used both as a replacement for diesel fuel and Liquified Petroleum Gas (LPG) generally used for cooking in SIDS. The cost of producing DME from solar and wind is still very high in comparison to using biomass or fossil sources as the technology is not yet mature.

Renewable hydrogen can also be used to produce methane (synthetic natural) gas via the methanation reaction and the Sabatier process to avoid the hydrogen storage and handling issues mentioned previously. Unlike hydrogen infrastructure which is yet to reach maturity, industrial applications of the methanation process exist since 2008 (Zoss et al., 2016) and the use of methane, in the forms of natural gas and biogas is very mature. The methane so produced can be used in several applications, including power generation and transport. The efficiency of renewable power to methane production is stated at 46%-75% and methane to power efficiency can be up to 60% with a roundtrip efficiency of about 36%. Additionally, the required storage volume of methane is 4-5 times less than for hydrogen. Thus, excess VRE energy can be stored through the production of methane which can then be used across sectors to meet energy demand. The authors of (Zoss et al., 2016) have explored the use of carbon dioxide in biogas from anaerobic digesters to produce additional methane through mixing with hydrogen from an electrolyser and then treatment in a methanation reactor for the Baltic states.

(Bailera et al., 2017) provide a structured overview of the power to gas technologies currently in development and commercialized for the storage of excess VRE particularly the production of methane to take advantage of existing natural gas infrastructure in many countries. The technologies reviewed range from methane production through a catalytic process to biological methanation, e.g., direct injection of the renewable hydrogen into anaerobic digesters to improve the methane yield, both processes having projects in the MW scale. Considering the range of projects existing in eleven countries around the world, this technology can be expected to reach maturity at least by 2025. Hybrid energy storage can also be effected through chemicals that use hydrogen and CO_2 in their production, e.g., methanol, ethylene, DME and other liquid fuels.

2.11 Economic Impacts of Sustainable Energy

The steps typically followed by an analyst in evaluating the economic impacts of energy efficiency and RE initiatives are to: determine the method of analysis and level of effort required for the case under consideration; quantify the direct costs and savings associated with the initiatives; and, using the selected method, apply the costs and savings to estimate the macroeconomic impacts.

Five (5) methods of estimating impacts are discussed by (U.S. Environmental Protection Agency, 2018). ‘Rules of Thumb’ provide first order approximations of the direction (positive or negative) and magnitude of the economic impact and are generally used for screening and to develop preliminary estimates. Though rules of thumb have the advantage of efficiency and convenience, the underlying assumptions and limitations must be understood before use. ‘Input and Output Models’ or multiplier analysis models can provide more rigorous analysis of the short-term economic impacts of energy efficiency and RE initiatives. Input and output models depict the relationships and interdependencies among industries in an economy and are driven by changes in demand for goods and services due to policy analysis. Whereas this method can reveal the high-level economic effects of a change in demand for a product or service, it represents only a snapshot of the economy at a given point in time. 'Macroeconomic Models' use mathematical and statistical techniques to find relationships in the macro economy and use those relationships to forecast future economic impacts. Macroeconomic models can be used for the short- and medium-term to provide sectoral and regional detail not possible with the previous two (2) methods. They are dynamic and provide a high level of detail and flexibility, however, they rely heavily on historical data to predict future behaviour. 'Computable General Equilibrium (CGE) and Hybrid Models': CGE models use a framework based on the tenets of microeconomic general equilibrium theory through equations to solve supply, demand and price equations across a specific set of markets. They are best used for long-term analyses. Hybrid models combine aspects of CGE with macroeconomic models. They can be complicated and are the most expensive to use (U.S. Environmental Protection Agency, 2018).

Demand-side energy efficiency can lead to direct costs and savings including cost of purchase and installation of more energy-efficient equipment, costs associated with administering the energy efficiency programme, energy cost savings and flow of money to energy-efficient equipment suppliers and away from electricity utilities. The direct costs and savings of RE and distributed generation include construction, installation and operating costs and programme administration cost savings from reduced operation of fossil fuel assets. Some additional savings from avoided costs include avoided health care costs due to reduced pollution and avoided electricity system costs including losses and system upgrades (U.S. Environmental Protection Agency, 2018).

A fiscal multiplier obtained from input and output modelling will be used in the research economic analysis as it is not overly complicated and can be linked to energy models. In their book (Batini et al., 2014) (pg. 2), the International Monetary Fund (IMF) defines a fiscal multiplier as the ratio of the change in output (ΔY) to a discretionary change in government spending or tax revenue (ΔG or ΔT). There is little consensus on the size of fiscal multipliers in the literature due to the difficulty of isolating the effect of fiscal measures on GDP because of the two-way relationship between these variables.

Tax and public spending multipliers provide a measure of change in output due to a unit of tax increase or increase in government spending. A multiplier greater than one (1) indicates an increase in output greater than the initial increase in input whereas a multiplier less than one (1) indicates the initial increase in output is eroded by effects that counteract the initial unitary input. Counteracting effects are usually due to crowding out of productive private sector activities and partly due to the impulse generating an increase in imports that do not increase output. Taxes are generally expected to have a negative effect on GDP. In an IMF publication, (Schipke et al., 2013) undertake an evaluation of the fiscal multipliers for the OECS/Eastern Caribbean Currency Union (ECCU), of which Saint Lucia is a member, based on a structural vector auto-regression (SVAR) model using panel data. This method is appropriate as members of the ECCU share many characteristics that facilitate the pooling of data including high levels of public indebtedness, broad government economic participation, and similar exposure to exogenous economic and natural shocks. Consequently, the use of pooled data allows a sample size that would be much larger and more reliable than if any single member of the union was evaluated, particularly due to lack of data. Three (3) fiscal multipliers are evaluated corresponding to shocks in tax revenue, government consumption and investment expenditure with 95% confidence intervals evaluated from Monte Carlo simulations.

Fiscal multipliers can be evaluated by considering the effect of a single fiscal variable on output or by considering all the interactions that may arise among the fiscal variables with GDP. This can be done by using multivariate panel-VAR models. Both methods were used by (Schipke et al., 2013), with the result that the impact multiplier of government consumption expenditure and tax revenues were found, over a 6-year period, to be statistically no different from zero (0) when the confidence intervals are considered. Both methods resulted in an impact multiplier statistically different from zero (0) for government investment expenditure. The more complete picture of the effects of fiscal shock, taking into account contemporaneous and dynamic interactions among fiscal variables and with GDP obtained from multivariate VAR models, indicates that the government investment expenditure multiplier ranges from 0.59 and 0.63 based on the order of the variables used in modelling (Schipke et al., 2013) (pg. 223). Consequently, a fiscal multiplier of 0.59 will be used over the first six (6) years of an investment from both government and private sector in the economic analysis.

A fiscal multiplier can be estimated for the cumulative effect that consumer savings can have on the economy. The effect, M, of the savings to a household, T, may be estimated with the formula from (Filc, Gabriel; Medellin, 2019) in Equation 1:

Equation 1 Formula for calculation of consumer fiscal multiplier

$$Y_i = MT_i$$

Where: $M = \frac{1}{1-c(1-t)+m}$

T_i – the money transfer mode to sector i

c – marginal propensity for consumption

m – marginal propensity for importation

t – marginal propensity for taxes

The effect of the savings on the economy is short-term and the potential increase in productive capacity, that is the accelerator effect, is not accounted for. This would further increase the multiplier effect.

The results of the analysis are proved at Table 1 for the case of Saint Lucia:

Table 1 Calculation of fiscal multiplier

XCD$ mn	2019	2018	2017	2016	2015	
Private Consumption	2,895	3,057	3,161	3,200	2,799	
Nominal Gross Domestic Product	5,700	5,600	5,400	5,000	4,900	
Import of Goods and Services	2,513	2,634	2,586	2,498	2,259	
	2019	2018	2017	2016	2015	Average
Marginal Propensity to Consume (c)	0.51	0.55	0.59	0.64	0.57	0.57
Marginal Propensity to Import (m)	0.44	0.47	0.48	0.50	0.46	0.47
Pay as you earn income tax	0%	for chargeable income <XCD$5,000				

Fiscal Multiplier	1.11

Data was obtained from (Moody's Analytics, 2022). The estimated fiscal multiplier to be applied to consumer savings is 1.11.

2.12 Summary of Research Gaps

SIDS in the Eastern Caribbean are focused on providing power from geothermal energy for base load power thereby limiting the future potential for VRE penetration. There has also been consideration given to interconnection with other islands either through a natural gas pipeline or subsea power cables.

To this point non-interconnected islands that have achieved 100% RE for power generation have done this by leveraging the most abundant indigenous RE resources available along with energy storage. Interconnected islands exchange energy with mainland energy systems to achieve 100% RE integration. In some islands P2G has been used as a bridging technology to allow energy flows from the electricity to the transport sector. Power to fuels has also been explored in mainland territories to enable the greater utilisation of cheap VRE.

Bi-directional energy flows between the electricity and gas sectors and between two (2) interconnected electricity systems have been investigated in the literature to increase the VRE share. Though bi-directional energy flow is possible with P2G technology, it is not currently recommended due to efficiency losses. Electrification of the transport sector and the use of BEVs has been described as the most effective means of transitioning to RE.

The literature reviewed has looked at the potential of distributed solar energy to provide power for EV charging at car ports and the potential for solar to power transport in one (1) Swiss city has been evaluated. The link between transport and RE has not yet focused on the use of distributed generation to provide significant power for the transport sector in island systems using electric mobility. The literature points in the direction of distributed generation as the most effective means of providing energy for BEVs. The literature also indicates controlled V2G with a real-time pricing policy, under a DSM strategy, as an effective means of integrating higher VRE shares into the energy system. There is no work looking into the relationship between available VRE, geographical distribution of demand and supply, and temporal energy requirements for EV charging to provide 100% transport energy needs in SIDS.

No systematic approach or methodology has been evaluated for connecting the two (2) primary SIDS energy sectors, electricity and transport, to reap the benefits of interconnection and reduce the variation in residual load that can occur from high VRE penetration. This could make it possible to build larger and more economic energy plants to provide dispatchable RE especially from geothermal sources and would make it possible to effectively use BEVs energy storage potential to provide ancillary grid services.

There has been no work in the reviewed literature focused on the relationship between distributed generation and energy service needs in islands with a view to increase VRE shares. There is no methodology to evaluate storage of energy at the point of use in the form in which it is required, i.e., to provide energy services, in order to minimise the needed system level flexible stored electrical energy needed for an island energy network.

There is no methodology for planning energy system development scenarios for SIDS that considers demand response, V2G, VRE, energy storage, environmental, social through multiple stakeholder objectives, reliability, climate resilience and financial evaluations to achieve a 100% RE system integrating all energy use sectors. The impact of DSM on facilitating the transition to 100% RE utilising VPPs has not been explored in the SIDS context.

No evaluation of system reliability has been performed for interconnected energy systems in an island situation for 100% RE through energy exchanges between the transport and electricity sectors.

A methodology, taking the above-mentioned factors into consideration, would generate solutions dependent on the particular stakeholder objectives and available resources. It would also provide much needed information for policy direction in terms of transitioning to a future sustainable energy system.

2.13 Key Results of Literature Review and Conclusions for the Research to be Conducted

Some of the key results from the literature review focused on the SIDS context are presented below:

- Bidirectional energy transfer between sectors can be used to enable higher VRE penetration levels.
- Power to gas/fuels is a good sector bridging technology but still has high efficiency losses. This technology is not yet mature and will not be investigated in the research.
- Electrification of transport and use of BEVs is a sound strategy for transition to RE. Energy transfer between the transport and electricity sectors is of interest in SIDS and will be investigated. EV batteries may be used to store excess VRE and the energy from these batteries can be released when there is a deficit of RE generation on the grid.
- Controlled V2G energy transfer with real time pricing policy can be effective for integrating high levels of VRE into the grid.
- DG is the most effective means of providing energy for BEVs. The potential and impact on supplying energy to transport and other sectors through use of DG will be evaluated.
- Stakeholder engagement is necessary to identify inputs to be incorporated into scenarios for transitioning energy systems to ensure social harmony, resilience and other stakeholder objectives are addressed.

2.14 Literature Review – Gaps Specific to SIDS

The following SIDS specific gaps have been identified from the literature review:

- The potential of DG and V2G to enable 100% RE in the electricity, transport and other energy sectors has not been investigated in any of the literature reviewed.
- The link between geographic distribution of available VRE and temporal energy demand for EV charging, to enable a 100% RE system, has not been reported on.

- A systematic approach and methodology to investigate the interconnection between the electricity and transport sectors for the reduction of residual load in enabling a 100% RE system has not been investigated.
- A methodology for evaluating the potential for storing excess VRE as ice for providing cooling needs at the point of use and to reduce the need for system-level electrical storage for SIDS has not been discussed in the reviewed literature.
- A SIDS methodology for stakeholder-steered development of scenarios for transitioning to 100% RE interconnected transport and electricity systems, inclusive of addressing financial, environmental and technical objectives identified and prioritised utilizing the Delphi survey method, has not been discussed in the reviewed literature.
- The potential of VPPs to enable the achievement of 100% RE systems in SIDS has not been investigated in the literature.
- Evaluation of expected system reliability in a 100% RE interconnected transport and electricity system has not been evaluated. This investigation is out of the scope of the planned research.

2.15 Hypothesis

Based on the identified gaps relevant to SIDS, the following hypothesis can be formulated.

A methodology can be developed for designing energy system transition pathways in Small Island Developing States (SIDS) to enable the use of 100% Renewable Energy (RE) to power an interconnected transport and electricity system while achieving multiple stakeholder objectives through the use of mature enabling technologies.

3 Section 3 Research Methodology

3.1 Overview

The research undertaking was motivated by the need to determine what actions can be taken to influence policymakers to make a quicker and effective transition of SIDS to 100% RE supplied systems considering the currently very slow adoption rate in Caribbean SIDS. The researcher was also interested in understanding how this transition could encompass not just the electricity sector, but also transport and other energy use sectors while addressing key stakeholder objectives.

3.2 Conduct Literature Review

To obtain an in-depth understanding of what has been done in this subject area, a literature review was undertaken. Given that it is impossible to review every related research work in the various interrelated fields around sustainable energy in SIDS, it was necessary to establish research boundaries that would make the review management more effective. The following constraints were applied in selecting articles for review:

a. Articles had to be peer-reviewed and published in international journals;
b. Articles had to be published over the period 2008 to 2022; and
c. The topic of the articles had to fit within the general RE fields, energy storage and stakeholder engagement in SIDS.

To perform the study, the ScienceDirect Library was used as this source provided access to the latest peer-reviewed papers on RE matters in islands subject area. In addition, similar PhD papers from students within Flensburg University and other institutions were reviewed. Several studies in the subject area developed by consultants were also reviewed.

Some of the major key words and areas searched included: energy in SIDS; sustainable energy; stakeholder inclusion; energy modelling; energy storage; 100% RE; energy and transport; islands and energy, smart energy systems and stakeholder inclusion. The first 50 search results were scanned for relevance and the available articles were obtained. Articles were reviewed and key learnings noted in the literature review.

The literature review covered islands that already achieved 100% RE powered systems and how that transition was achieved. The technology options that can be used to enable high penetrations of RE were also investigated.

The current situation in the target research country was investigated. The details of the energy sector and overall state of the economy were reviewed.

3.3 Develop Research Question

In an analysis of the literature reviewed, gaps were identified in the area of the transitioning of SIDS to sustainable energy systems. Based on the evidence uncovered in the research and the identified gaps in the available information, a hypothesis was deduced that if held true could address the research gaps and provide solutions for SIDS wishing to transition to 100% RE systems. The hypothesis was then converted into a research question to which the following research work would seek to find answers.

Methodology for design of 100% renewable energy transition pathways to meet SIDS transport and electricity objectives. - Europa-Universität Flensburg

In order to find answers to the research question, a typical SIDS country was selected which currently has a very low penetration of RE in its energy mix, i.e., less than 10% of installed capacity. As it is established that SIDS are very similar in terms of their development status, it is postulated that a single representative country is sufficient for investigating the research question. Giving due consideration to familiarity with energy sector stakeholders, access to data and familiarity with the energy sector, the author selected his home country of Saint Lucia as the test case for the hypothesis.

3.4 Research Methods

The worldview (also known as paradigm) is the philosophical assumption that provides a foundation for the chosen research topic or problem. Worldviews directly affect the assumptions made about reality and how knowledge is obtained (Creswell, John W.; Clark, 2011). Four (4) main worldviews are identified in research, viz., positivism, post positivism, constructivism and pragmatism. Positivism, which is associated with quantitative research methods, believes that knowledge is based on natural phenomena which is unbiased and not affected by the researcher's subject view. Post positivism tries to correct for bias introduced by the researcher's subject view. Alternatively, constructivism is a world view that constitutes the understanding and meaning of phenomena formed through the researcher and their subject view. Constructivism is associated with qualitative research methods. Pragmatism evolved as a solution that resolves the conflict between positivism (and post positivism) and constructivism. Pragmatism is problem-oriented and postulates that a method that can solve research problems is a good method. The mixed methods research method is associated with pragmatism (Zou et al., 2018).

Quantitative research is described as the systematic empirical enquiry of observable phenomena by statistical, mathematical or computational techniques (Given, Lisa M., 2008). This method is associated with the collection of numerical data by various means including experiments, records and surveys through a standardised and repeatable process. Some weaknesses of quantitative research methods have been identified including the need for large samples to ensure accuracy and representativeness of the results, inability to quantify some variables and lack of information on why the results are happening (Zou et al., 2018).

Qualitative research is described as an interpretative naturalistic approach to studying things in their natural settings, with phenomena interpreted based on the meanings people ascribe to them. Qualitative research is usually conducted at the early stage of study to develop a systematic understanding of the research subject through discussion, open-ended answers and explanations shared by participants. Some of the weaknesses associated with qualitative research include being subjective such that it can be influenced by the researcher and arguably limited samples used cannot represent a population (Zou et al., 2018).

Both qualitative and quantitative research methods were utilised, i.e., the two methods (a mixed methods approach) were used to strengthen the research outcomes (Creswell, 2009). The mixed method is appropriate as the research will integrate an analysis of the technical energy system parameters that will be modified based on qualitative stakeholder requirements. The application of each approach to this work is described below. (Zou et al., 2018) identified the mixed method approach for performing interviews, combined with modelling simulation, as a good method used to investigate the impact of building occupant behaviour patterns on energy use. The research to be undertaken similarly looks at stakeholders influence on a future energy system and utilised the same mixed method.

3.5 Qualitative Research

In recognition of the democratic governance system of most SIDS countries and the importance placed on public participation in the decision-making process, a review of stakeholder integration in the decision-making process was investigated. The various methods of stakeholder inclusion were evaluated and considering the available resources for performing the research, particularly financing, a survey method was selected to obtain the required stakeholder perspectives.

The Delphi method was selected over a simple survey as this method has the added benefit of prioritising responses and guiding stakeholders to agree on common objectives. The alternative method of stakeholder inclusion to allow for conscious building, on common objectives, is a workshop, however, this would require a significant budget and for stakeholders to be gathered in a single location for at least a day and more than once. This was particularly difficult during the research period considering the then legislated social distancing protocols to control the spread of the COVID-19 disease.

The Delphi method was therefore considered the most effective method for stakeholder engagement under these circumstances. In addition, to improve the level of stakeholder participation, it was decided that the survey questions would be shared with stakeholders via email. Only stakeholders with a minimum of tertiary level education were selected to improve the likelihood of sufficient understanding of the subject matter and, therefore, improve the quality of feedback. Stakeholders were then required to provide responses either via recorded voice messages, which the author would then transcribe, or by email. All responses were received via email.

The second round of the survey in which stakeholders prioritised all responses, was administered again via email and responses were also obtained via email. Each round was administered within a four-to-six-week period.

The prioritised stakeholder responses, based on the Delphi survey application, were ranked and then used to generate scenarios that would provide responses to the research question. The research question asked whether a methodology was available and if SIDS could identify alternate pathways for transitioning to 100% RE systems. This question does not seek a single solution, but alternatives that can be considered and that respond both to the research gaps and the stakeholder requirements identified in the Delphi survey. Consequently, scenario building is well-suited to provide alternate solutions to problems that can have multiple solutions.

The results from the scenarios were shared with the stakeholders who were then required to rank the output of each scenario, by question, based on how well the output responded to the stakeholder feedback received via the Delphi survey. These stakeholder rankings were aggregated and the final scenario rankings were obtained indicating the stakeholders’ choice in selecting a scenario that best addressed their objectives.

3.6 Quantitative Research

Both primary and secondary data sources were used to describe the current energy system in Saint Lucia. The resource potential of the various forms of RE available on the island was investigated. Some of the resource assessments, e.g., for hydropower, had already been thoroughly researched by consultants. The data from these reports was utilised. In the case of wind energy, although some data had been collected and were available, data for one (1) site belonged to private sector interests and could not be accessed. In this case, as well as with solar energy, Meteonorm software was used to generate site-specific data to account for geographic variations. In other cases, in-depth assessments done for other Caribbean SIDS was available. The key data in those assessments were adapted to the Saint Lucia context under investigation. This data was used as inputs into the custom-built energy system model.

3.7 Energy System Model

Modelling is described as a research approach that uses physical, mathematical or logical representation of a system, phenomenon or process which is the basis of simulations to generate information for decision-making (Zou et al., 2018). The research model had to have the capability to include all energy use sectors of the economy. It was, therefore, necessary to collect qualitative data for all energy sectors which was used to calibrate the model and determine growth trends for the various sectors. Energy demand data was collected from available online sources and personal GOSL contacts. Other sector data were collected from online sources and government ministries, e.g., Ministry of Transport and government agencies including the Water and Sewerage Company of Saint Lucia. The data was used to develop the current baseline picture of the energy system.

The research model was used to generate energy sector demand using a bottom-up approach, in which demand was generated using the various sector energy profiles along with projected peak demand. It was necessary to calibrate the model by comparing the generated demand for the base year against actual published demand data for that year.

Growth projections were prepared for each economic sector and used as an input into the research model to calculate the energy system demand over the analysis period. This provided a business-as-usual baseline scenario to which the stakeholder scenarios were compared.

A suitable simulation model was required to generate solution options to respond to the multiple stakeholder requirements obtained from the Delphi survey. The literature was reviewed to understand the modelling tools currently available. As there was no budget for the research work, only the available free tools could be considered. This is also a consideration for SIDS that tend to have very limited budgets and available financing for research work. The investigated tools were diverse, some of them targeted to very specific uses and others more general in their application. Therefore, the use of free tools was a good fit both for the current research and the financial situation in most SIDS. The model also had to merge both the qualitative and quantitative data to generate information for decision-making.

In addition, though based on experience of the energy sector in the research SIDS country, the author had a general idea of what the stakeholder requirements might be which could not be confirmed until the Delphi survey was completed. Based on the wide range of anticipated stakeholder requirements, it was felt that either a combination of existing tools, which may not be free for use, or a custom tool would be required. The author opted to create a custom model that provided full flexibility to vary inputs and calculations as needed.

The overall Research methodology as described in the foregoing sections is summarised in the flow chart at Figure 3.

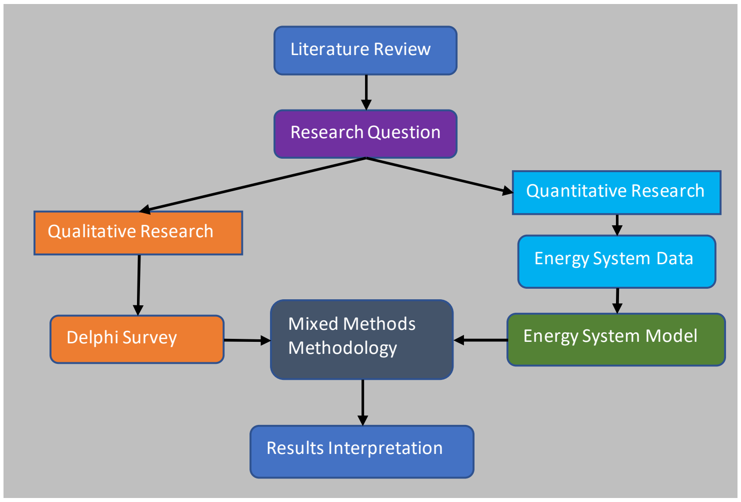


Figure 3 Flow chart of research methodology

3.8 Scenario Generation

Having calibrated the research model to ensure it was outputting acceptable generation information, relative to the selected base demand year for which data was available, the stakeholder inputs were integrated to adjust the calculation parameters to simulate the stakeholder defined future scenarios. With this addition, it was possible to generate different scenarios based on stakeholder input/output information obtained from a Delphi survey.

3.9 Key Performance Indicators

To facilitate easy comparison of scenarios, key performance indicators (KPIs) were chosen to represent the key stakeholder requirements, identified by the researcher, based on the information received through the Delphi survey and the literature review. The KPIs were designed to be very specific, measurable, achievable, realistic and timely. In the KPI selection process, stakeholder requirements were reviewed to determine the variables that were most important. The most suitable measurement parameters for the chosen variables were then selected as the KPIs. Another key requirement was that the model had to calculate the KPI or it had to be easily calculated from the modeling results. The KPIs were also selected to evaluate how effectively the scenarios responded to the stakeholder requirements.

3.9.1 Sustainability and key performance indicators

Based on the literature review, (RER) defined as the ratio of renewable energy generation to the total primary energy used in a jurisdiction for a given year, is used as a sustainability indicator. A second measure of sustainability is the overall economic impact of the transition scenario. The more positive the impact on the economy, the more sustainable the transition is. A third measure of sustainability is the energy tariff which determines affordability of energy. These sustainability indicators are used as the KPIs.

3.10 Stakeholder Evaluation of Results

The scenario results were shared with the Delphi survey participants. The stakeholders were asked to prioritize the scenarios in the order that scenario outputs best respond to their feedback provided via the Delphi survey. Using the individual stakeholder prioritizations, a final prioritization of scenarios was determined and the scenario most responsive to the stakeholder requirements was identified. The scenarios were also evaluated against the research question to determine how well they responded.

3.11 Policy and Mechanisms

Having defined the most appropriate transition pathway, some suggestions are made regarding the existing policy instruments and mechanisms that could be implemented to achieve the results projected by the defined transition pathway. Since much work has already been done in this area and the purpose of the research is to develop a methodology for defining the transition pathways, considerable attention was not given to this area.

3.12 Definition of RETraP

All the steps in the research methodology were reviewed and a suitable framework was identified that adequately categorizes them within an accepted industry standard process. In this way, the Renewable Energy Transition Pathways Methodology (RETraP) was defined. Fitting RETraP into an industry standard framework lends more credence to the methodology so that it can be adopted for use.

The research author has determined that the methodology steps would fit neatly within the standard Quality Problem Solving Framework which is integral to product quality management systems. This framework relies heavily on personal experience (Xu & Dang, 2021) (pg.1). It, therefore, complements the Delphi method of stakeholder engagement which also relies on the experience of stakeholders to predict possible future states of the energy sector. The steps are generally:

1. Analyse and define the problem;

2. Identify the root causes;

3. Formulate solutions; and

4. Define RETraP solution (a newly added step).

These general steps are adapted in the following report sections to generate the methodology for designing transition pathways that respond to multi-criteria stakeholder objectives. The methodology is summarised in Figure 4 and is described below.

3.12.1 Analyse and Define the Problem

– Sections 3.14 and 4.1:

A literature review was undertaken and key stakeholder requirements were identified. Delphi survey questions were formulated based on the key requirements. The Delphi survey was administered to stakeholders identified through a stakeholder analysis.

3.12.2 Identify the Root Causes

– Sections 4.3 to 6.2**:**

The responses from the Delphi survey define the root causes driving the need to transition the energy system. These responses were prioritised, then analysed and converted into modelling inputs and outputs. The modelling inputs were integrated into the energy system model.

All required energy sector demand, supply and energy efficiency data were collected and projections prepared for the transition period. The data was entered into the energy model and a baseline scenario was generated for business as usual.

3.12.3 Formulate Solutions

– Sections 6.3, 7 and 8**:**

In this step, the new desired state of the energy system is generated based on the prioritised individual stakeholder responses to the Delphi survey. Both qualitative and quantitative responses were received out of the Delphi survey. The prioritised responses were used as input or output requirements to generate scenarios to achieve the stakeholder requirements and, therefore, respond to the research question.

To maximise flexibility of integrating the stakeholder feedback into the scenario modelling process, a custom chronological simulation model was built in Microsoft Excel. Though building this model was more time consuming and demanding than utilizing an existing model, it provided the advantage of full flexibility in defining how calculations were performed. The energy model was flexible enough to receive the multi-criteria stakeholder inputs. The model performed calculations in quarter hourly time intervals for the selected SIDS island to evaluate the research questions.

Using the stakeholder requirements for predefined time intervals of five (5) years, scenarios were built addressing the three (3) highest priority responses to each of the survey questions. The first priority response to each of the questions together were used to generate the first scenario (A), second priority responses for the second scenario (B) and, similarly, third priority responses were used to generate the third scenario (C). Suitable tools were built in Microsoft Excel to perform economic, financial and other analyses of the results from the scenarios generated. Sensitivity analyses were also performed on the scenario results.

The KPIs were calculated and used to rank the scenarios. Stakeholders were provided with the outputs from the scenarios and asked to rank them based on the responsiveness of the outputs relative to the Delphi survey responses that they provided. A stakeholder ranking of the scenarios was generated from the stakeholder feedback and was compared with the KPI ranking.

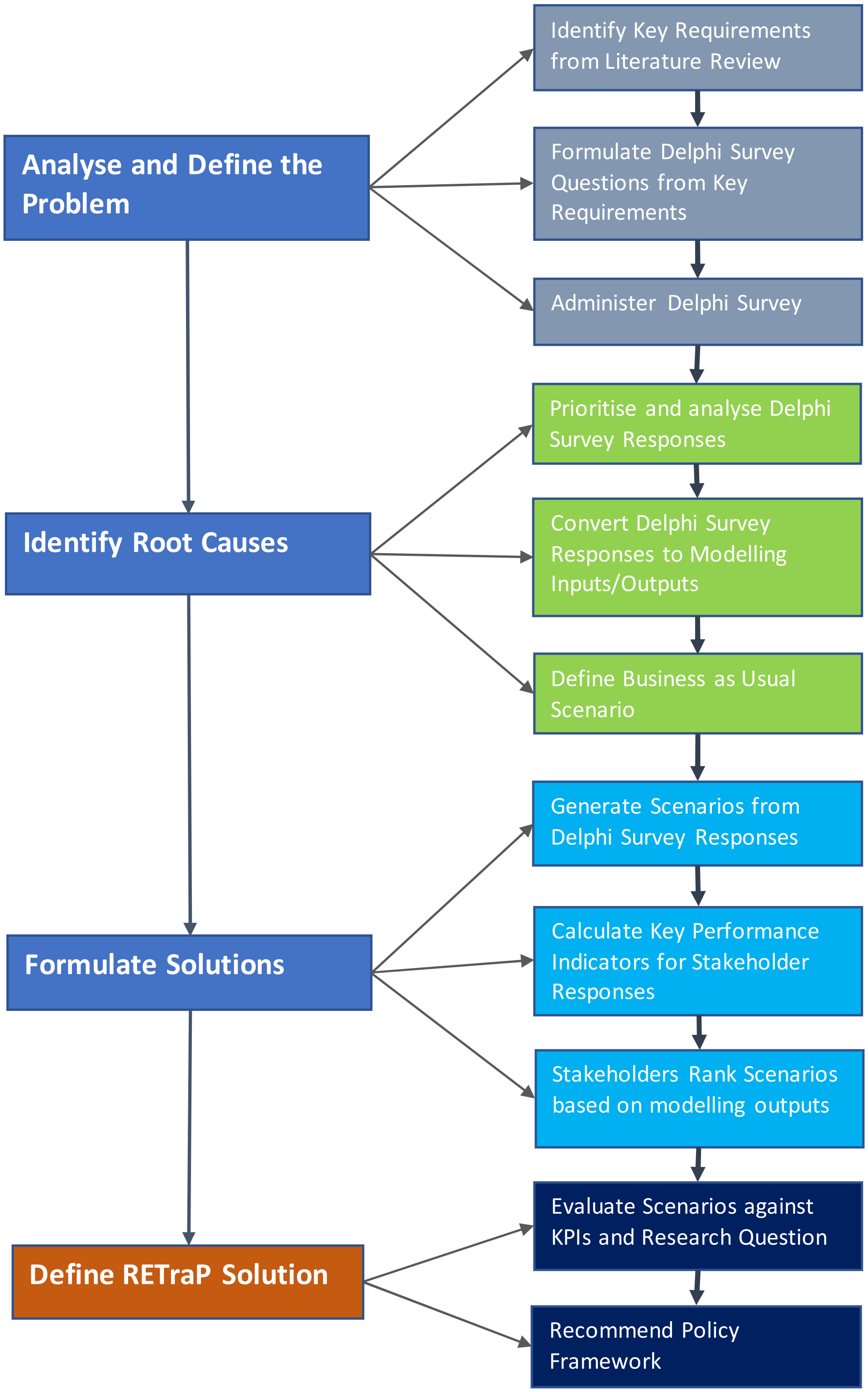


Figure 4 Renewable Energy Transition Pathways (RETraP) Methodology for Developing Transition Scenarios

3.12.4 Define RETraP Solution

– Section 9.

The scenario outputs were evaluated against the KPIs and the original key requirements, which in this case was the research question. Some policy recommendations were then suggested.

The results of the scenarios developed using the methodology are projections of future states of the energy system aiming to achieve the stakeholder objectives. Consequently, in applying this methodology it is very important that the stakeholders be carefully selected and sufficiently informed to adequately represent the opinions of the society.

It can be argued that the objectives of future stakeholders may differ from today's stakeholders. The RETraP methodology is intended to be applied in a regular cycle to ensure that the stakeholder-selected transition pathway remains aligned with stakeholder objectives. A 5-year cycle has been suggested, however, this should be as often as deemed necessary by the implementing SIDS country. It can also be argued that future stakeholders may have climate change as their primary objective. All of the scenarios are already aligned with climate change mitigation by transitioning from fossil fuel generation to RE. A future iteration of the methodology may also focus on climate change adaptation, in which case the energy mix may vary to place a focus on adopting more technologies that have a lower risk of being impacted by climate change events, i.e., that are more resilient. Such a scenario would likely include objectives of strengthening and protecting grid infrastructure and may also place a focus on building micro-grids. The final stakeholder selected scenario may look different from the scenarios generated in this research work. It is, therefore, important to repeat the methodology and revise the transition pathways on a regular basis to address the needs of stakeholders as those needs evolve.

3.13 Business as Usual Scenario

A business-as-usual scenario was developed for comparison to the stakeholder defined scenarios. The following steps were followed in developing this scenario.

- The electricity, transport and other terrestrial energy sectors consumption data for at least two (2) years were obtained. As much as possible, disaggregated demand data was collected.
- The historical growth trend was determined and used to project the business-as-usual future growth trend for both transport and electricity sectors for the next twenty-five (25) years.
- A business-as-usual scenario was developed to produce results for comparison with the stakeholder generated scenarios.

An additional step undertaken was to evaluate potential problems of the selected scenario at Section 10.2. These steps ultimately should result in a scenario that can be implemented by policymakers.

3.14 Research Questions

The primary research question arising out of the hypothesis can be posed as:

Can a methodology be developed to design pathways for transitioning to a 100% RE system in a SIDS country by interconnecting the transport and electricity sectors while providing various benefits through simultaneously meeting multiple stakeholder objectives using mature enabling technologies?

The sub-questions arising from the primary question are:

1. What methodology and tools can be used to provide a systematic framework for designing an interconnected electricity and transport system powered by 100% RE?
   - 1.1 What are the economic, environmental and other sustainability objectives to be satisfied from transitioning to an interconnected transport and electricity energy system powered by RE?
   - 1.2 How will the system operate to control cross-sectoral energy flows to achieve continuous energy balance?

The first sub-question is focused on defining the combination of methodology and tools that can be used to provide a framework for analysing the energy system and the transition options. The tools must be selected so that the social, economic and sustainability impacts can be evaluated for all energy sectors of the economy. The tools and framework must also enable evaluation of multi-criteria stakeholder objectives and must facilitate the required energy flows to enable system demand/supply balancing. This will provide an insight into the smart-grid characteristics that may be required in such an energy system.

2. What are the 100% RE system configurations that can achieve the energy sector transition objectives?
   - 2.1 What is the timeframe during which an energy system transition can be achieved and what are the expected costs and benefits?
   - 2.2 What role can distributed generation (DG) play in the energy system transition?

This question is required to define scenarios that will lead to 100% RE system configurations. It is intended that a sense of the transition timeframe, as well as costs and benefits from transitioning, will be investigated. As DG is becoming increasingly cost-competitive, it is anticipated that DG will play a role in the transition process. It is intended that this role will be investigated to the degree possible. Finally, the impact of stakeholder objectives on the transition pathways will be investigated.

3. Can interconnection of the transport and electricity sectors result in energy system benefits and synergies?
   - 3.1 What economic and sustainability performance levels can be expected in an interconnected transport and electricity system?

In this question, we seek some insights on how the interconnection of energy consumption sectors, particularly transport and electricity, can result in benefits to the overall energy system. These benefits are to be investigated in economic and sustainability terms as well as in responding to the stakeholder requirements.

4. What are the stakeholder objectives that can be achieved by a transitioned energy system?

4.1 What are the modalities by which stakeholder objectives are addressed in the proposed transition pathways?

As explained in Sections 2.3 and 2.4, stakeholder inclusion is a key consideration for defining energy transition scenarios and determining objectives for such a transition. This is, therefore, a key question to be explored in the research process.

4 Section 4 Energy Data, Sources and Systems

4.1 Identification of Key Requirements

A Delphi survey was administered to obtain critical stakeholder feedback for developing three (3) transition scenarios. The survey method was found to be the most cost effective approach for identifying and prioritizing stakeholder objectives. The Delphi method is described in Section 2.3 and two (2) survey rounds were administered.

Based on the literature review, four (4) key requirements were identified for an energy system transition. Questions were formulated addressing the needs under each key requirement. A simple stakeholder analysis was conducted by the author to identify which stakeholders may be impacted by the answer to each question (See Table 2). A list of stakeholders was compiled and then separated into three (3) categories, based on the literature review, as shown in Table 3. The Delphi survey was then administered to representative stakeholder groupings.

The following describes the question formulation process and connects each question to the relevant key requirement identified in the literature review.

4.1.1 Key Requirement 1: Smart and Sustainable Energy System

To develop a Smart Energy System (Dincer & Acar, 2016), and a Sustainable Energy System (Shortall et al., 2015), the following questions should be answered:

- What should be the national priorities for improving energy security in the energy sector (electricity, transport, cooking, et cetera)?
- What environmental aspects should be considered when making decisions on investments in the energy sector?
- Should government continue to provide financial support for investments in the energy sector or should all energy investments be financially viable on their own?
- Are there any sources of RE that may not be socially acceptable? If so, please list.
- What benefits to the county would you like to see from sustainable energy investments?
- What forms of electricity generation should receive priority for development in the electricity sector? Why?

4.1.2 Key Requirement 2: Long-term Vision

To identify the long-term vision for the energy sector, as highlighted by (Timilsina & Shah, 2016), the following questions should be answered:

- The GOSL has set a target of 35% by 2025 and 50% by 2030 for the generation of electricity from RE sources. Are you in agreement with this vision? If not, suggest an alternative.
- The GOSL has set a target of 7% reduction in GHG emissions in the energy sector relative to 2010, by 2030. Are you in agreement with this vision? If not, suggest an alternative.
- The GOSL has set a target of 20% reduction in energy consumption in the public sector. Are you in agreement with this vision? If not, suggest an alternative.

- What economic sectors should receive priority support for improving efficiency of energy consumption, i.e., achieving the same output with less energy?

4.1.3 Key Requirement 3: Resilience

Based on the definition of resilience by (Hotchkiss, 2016), the following question should be answered:

- What should be the objectives of developing a resilient energy system in Saint Lucia?

4.1.4 Key Requirement 4: Democratisation of Energy

To enable increasing penetration of RE, by involvement of the general public (Blechinger et al., 2016) in the sustainable energy transition process, the following question should be answered:

- What are your objectives for transitioning the energy sector to sustainable energy (RE and energy efficiency)?
- How should the general public participate in a transition to sustainable energy?

Table 2 provides a stakeholder analysis based on key requirements and the research question.

Table 2 Stakeholder analysis

Key Requirement 1	Related Research Question	Questions	Stakeholders
Smart Energy System (Dincer and Acar, 2016), a Sustainable Energy System (Shortall, Davidsdottir and Axelsson, 2015) *Description*: The smart energy system needs to simultaneously address several requirements (Dincer & Acar, 2016) including exergetically sound, energetically secure, environmentally benign, economically feasible, commercially viable, socially acceptable, integrable and reliable. *Description*: A sustainable energy system may be regarded as one which considers cost efficiency, reliability, environmental	No. 1 - What methodology and tools can be used to provide a systematic framework for designing an interconnected electricity and transport system powered by 100% RE? No. 2 - What are the 100% RE system configurations that can achieve the energy sector transition objectives?	What should be the national priorities for improving energy security in the energy sector (electricity, transport, cooking, et cetera)? What environmental aspects should be considered when making decisions on investments in the energy sector? Should government continue to provide financial support for investments in the energy sector or should all energy investments be financially viable on their own? Are there any sources of RE that may not be socially acceptable? Please list.	LUCELEC; Ministry of Energy; Regulator; Energy Companies; Ministry of Sustainable Development; Bureau of Standards; Ministry of Finance; Business Operators; Financial Institutions; Supplier and Consumer Associations; Students; Teachers; Farmers;

and social acceptance and harmony and utilises local resources in a renewable and sustained manner (Shortall et al., 2015).		What benefits to the country would you like to see from sustainable energy investments? What sources of energy, for electricity generation, should receive priority for development in the electricity sector? Why?	Trade Union; Minibus and Taxi Associations
Key Requirement 2	Related Research Question	Questions	Stakeholders
The long-term vision for the energy sector (Timilsina & Shah, 2016). *Description*: (Timilsina & Shah, 2016) identified three (3) requirements for successful deployment of RE in a country, viz., a long-term vision defined by goals; implemented and enforced policies, instruments and mechanisms to support the achievement of the goals; strong and effective governance structures and administrative processes for implementing the policies and instruments.	No. 3 - Can interconnection of the transport and electricity sectors result in energy system benefits and synergies? No. 4 - What are the stakeholder objectives that can be achieved by a transitioned energy system?	The GOSL has set a target of 35% by 2025 and 50% by 2030 for generation of electricity from renewable sources. Are you in agreement with this vision? If not, suggest an alternative. The GOSL has set a target of 7% reduction in GHG emissions in the energy sector relative to 2010, by 2030. Are you in agreement with this vision? If not, suggest an alternative. The GOSL has set a target of 20% reduction in energy consumption in the public sector. Are you in agreement with this vision? If not, suggest an alternative. What economic sectors should receive priority support for improving efficiency of energy consumption, i.e., achieving the same output with less energy?	Energy Companies; Business Operators; Financial Institutions; Hotels; Taxi and Minibus Associations; Concerned Citizens; Ministry of Transport; Minibus Association; Taxi Association; and Hotels
Key Requirement 3	Related Research Question	Questions	Stakeholders
Resilience (Hotchkiss, 2016).	No. 2 - What are the 100% RE system configurations that	What should be the objectives of developing a	LUCELEC; Ministry of Energy; Energy

Description: (Hotchkiss, 2016) (pg. 7) defines resilience as 'the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions through adaptable and holistic planning and technical solutions'.	can achieve the energy sector transition objectives?	resilient energy system in Saint Lucia?	Companies; and Business Operators
Key Requirement 4	Related Research Question	Questions	Stakeholders
To enable increasing RE penetration by general public involvement in the sustainable energy transition process (Blechinger et al., 2016). *Description*: An assessment of the barriers and potential solutions to RE development in SIDS was presented by (Blechinger et al., 2016) and (Colmenar-Santos et al., 2013). Among the suggestions for increasing renewable penetration levels are… and involvement of the general public.	No. 4 - What are the stakeholder objectives that can be achieved by a transitioned energy system?	What are your objectives for transitioning the energy sector to sustainable energy (RE and energy efficiency)? How should the general public participate in a transition to sustainable energy?	Ministry of Finance; Ministry of Transport; Entrepreneurs; Bureau of Standards; Students; Farmers; Business Operators; Consumer Associations; Trade Unions; and Concerned Citizens

4.1.5 Stakeholder Selection and Delphi Survey Process

The participating stakeholders are categorized and listed in Table 3. A heterogenous group of stakeholders was selected reflecting a broad spectrum of interests. As Saint Lucia, like most SIDS, is a very small country, in which information spreads very quickly via social media, it is expected that despite their varied backgrounds, some stakeholders are likely to share similar perspectives in the responses provided. The Delphi survey was adapted as a two (2) round process as it is likely that stakeholders will lose interest and become less participative if further rounds are administered. In addition, there are very few subject matter experts available in the country and they would be concentrated in the local utility company and the Ministry of Energy. If only this homogenous group was targeted, it is likely that the survey results would not be representative of the general population and the number of participants would be too low for effective implementation of the Delphi survey method. To achieve more nationally representative survey results, a heterogenous stakeholder grouping was found to be more suitable.

A downside to this is that there may be a wide variation in the stakeholder understanding of the subject matter ranging from experts to individuals with little knowledge of the energy sector. To address this issue stakeholders were encouraged to research the subject matter of the questions if necessary. In addition, the opinions of a regional energy expert and a non-expert professional were sought regarding the ease of understanding and effectiveness of the information sources at providing clarity of the subject matter prior to administering the survey. Further subject matter research may also be necessary as the discussion of sustainable energy has been occurring, to a limited extent, in the news media and social networks over the last few years focused primarily on geothermal energy.

The questions in the survey were a mix of technical energy related and social questions, e.g., social acceptance of different types of RE technologies. The technical questions would be within the expertise of the energy sector experts whereas the social questions can be answered by any stakeholder.

In the first round, stakeholders were encouraged to be liberal with their responses and to use publicly available sources of information and to research the issues, for further clarity, if necessary. A list of Delphi survey questions was shared with each identified stakeholder (see full listing in Appendix A – Delphi Survey Questionnaire) via email. Stakeholders were asked to submit their responses via voice note to facilitate ease of responding or via email. All stakeholders chose to respond via email.

The author compiled all answers and administered the second survey round in which respondents were asked to rank, in order of priority, their first four (4) choices of responses to each question. Respondents were also asked to provide any new or different feedback that was not included in the collated responses from the first round. The full second round survey is presented (see Appendix A-2 – Feedback Survey). The result from this round was then analysed to identify the stakeholder objectives in order of priority.

Based on results from the second Delphi survey round, the highest ranked responses, from all stakeholders, were used as inputs/outputs for the generation of Scenario A. The second ranked responses were used for building scenario B and the third ranked for scenario C. Since only two (2) rounds were used, the level of consensus building in the Delphi survey is likely lower than if more rounds were used. This is, however, mitigated by the limited possibilities in a very small energy sector on an isolated island state.

A final feedback survey was conducted in which stakeholders were provided with the outputs from the scenario modelling and asked to rank them in order of priority based on how well the objectives identified from the Delphi survey were met. Results of all three (3) scenarios were summarised and shared with stakeholders, along with stakeholder prioritised responses, from the second round of the Delphi survey. The stakeholders were asked to rank the scenarios in order of priority based on achievement of their objectives. The full feedback round survey is provided in Appendix A-2 – Feedback Survey. The prioritized stakeholder feedback for the second round is provided in Appendix A-2 Feedback RND2.

In all survey rounds and the feedback round, stakeholders were constantly reminded, using follow-up text messages and phone calls, to ensure that they responded to the surveys. This resulted in response rates over 70% for each survey round. Stakeholder participation in each survey round is provided in Appendix B – Table of Delphi survey stakeholders. Stakeholders who were contacted in all three (3) rounds but did not respond in any round are not identified in the table.

Table 3 List of represented stakeholders

Stakeholder Category	Represented companies/disciplines
Subject Matter Expert	LUCELEC; National Utilities Regulatory Commission; Ministry of Infrastructure, Ports, Energy and Labour; Sustainable Development and Environment Division;
Professionals from other Sectors	Windward Islands Gases Ltd.; OECS Commission; Saint Lucia Bureau of Standards; Bank of Saint Lucia Limited; Goddard Enterprises; Armana Consult; Export Saint Lucia; Innov8 Engineering Solutions; Ministry of Agriculture; Human Resources Specialist
General Public	Project Manager; Secondary School Principal; Farmer; Auto Specialist; C'Ton Tours (Eco-tourism operator); School Teacher; Retired Laboratory Services Specialist; Private Consultant

4.2 Modelling Scope, Limitations and Assumptions

4.2.1 Scope

The research will evaluate only the energy flows required from sources of generation to loads in sectors that consume energy on the island of Saint Lucia. Only terrestrial sources of indigenous energy and imported fossil fuels will be considered. The research will not investigate the details for implementation and enforcement of the suggested transition pathways.

4.2.2 Limitations

Load flow calculations have not been performed. Though the analysis evaluates substation transformer upgrades that will be required, other network upgrades, e.g., lines, switch gear and protection equipment are outside of the scope.

Availability of data, particularly in the transport sector was a constraint. LUCELEC also declined to provide firsthand electricity data. Consequently, published data sources were used in the research.

4.2.3 Assumptions

It is assumed that all new water heating demand is met using solar thermal collectors. This is not modelled in the research as it operates outside of the electricity system.

It is anticipated that the developed methodology can be utilised in any SIDS country considering the many similarities in the energy sector and the consultative process generally used in the decision-making process.

It is assumed that the government and implementing agencies will invest in the required capacity to implement the required interventions suggested in the transition pathways. An analysis of the additional capacity requirements has not been performed.

It is further assumed that a unified political decision can be taken and sustained during the transition period to transform the energy sector and the taxation system to take advantage of new sources of revenues as suggested by the results of the analyses.

Electrification of the transport sector assumes that the necessary environmental regulations will be enacted to ensure recycling of batteries, automotive hardware and RE system hardware at end of life.

It is assumed that biodiesel can be sourced locally or imported to replace petroleum-derived diesel during the latter stages of the transition. Though biodiesel has been modelled, other biofuels may also be substituted for the generation of electricity based on availability.

It is also assumed that LUCELEC will maintain its diesel storage facilities throughout the transition period, as storage for biodiesel or another biofuel substitute.

Due to a lack of information on the transport sector, it is assumed that geographical fuel consumption patterns mirror consumption patterns in the electricity sector.

4.2.4 Energy System Model Design

An energy system model was developed and each scenario was simulated. Energy flows among sectors, control algorithms, alignment with stakeholder objectives and benefits to the country were assessed.

4.2.4.1 Establishing a realistic case for scenario adoption

- A business case financial analysis of the required investment was developed for each scenario. This analysis simulated the investment conditions in the selected SIDS country.
- A balance of payments economic analysis was performed for each scenario.
- A sustainability evaluation was performed for each scenario. The impact of community participation in the energy system transition was investigated through distributed generation and local investment.
- An operation methodology was suggested to minimise the required smart-grid intelligence for managing the cross-sector energy flows to enable complete supply from RE.

4.2.4.2 Methodology defined from the research process

The process used to design the scenarios, incorporate the stakeholder objectives and evaluate the results was distilled and summarised. The results of the research were evaluated and key findings presented. The findings were compared to the stakeholder requirements obtained from the Delphi survey.

4.3 Data Collection Methods, Sources, Quality and Limitations

4.3.1 Power Sector

Original data was not directly available from LUCELEC. Other data sources were used including LUCELEC's Annual Reports, raw data used in the analysis for producing the Master's Thesis report 'A 100% RE electricity system in Saint Lucia' (Bodley, 2016) and data available from the LUCELEC company website (https://lucelec.com/). Historic electricity demand and system operational parameters are well documented in the LUCELEC annual reports.

Half hour load data for the years 2013 and 2015 were obtained from the indicated sources. Peak load per substation and demand, disaggregated by sector, data were available from the Developing Saint Lucia

Energy Roadmap (NETS) (Bunker et al., 2016) analysis files. Sector (customer type) load profiles, based on 2016 historic data, were obtained from the NETS analysis data files.

4.3.2 Transport and other sectors

The Latin-American Energy Organisation (OLADE) supported the GOSL in producing energy balances for the period 2010 to 2012 (Carrera et al., 2014). This study provided most of the available information on fuel imports and consumption, particularly in the transport sector. Data was also obtained from the Central Statistical Office of Saint Lucia's website (https://stats.gov.lc/). Original data was obtained from the Ministry of Infrastructure on the size and composition of the transport fleet.

Water reservoir volumes and energy consumption data were obtained from the St. Lucia Water & Sewerage Company (WASCO).

4.3.3 Renewable Energy

Several studies were conducted by the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) financed Caribbean Renewable Energy Development Program (CREDP) on development of wind farms in Saint Lucia. Wind data and reports used in these studies for the Sugar Mill and Anse-Canot sites were obtained from CREDP staff before the programme ended in 2017. The wind data was combined with synthesised data produced for various sites using Meteonorm® software.

Solar data was synthesised for each substation location evaluated using Meteonorm® software.

The most recent information on the geothermal resource was used in the research. As the source of data and most up-to-date data are both confidential and the resource has not been proven by drilling, the production capacity and parameters used in the analysis are the best estimates available based on geological and magneto-telluric analyses done during 2015 and 2016.

A technical evaluation of the run-of-river hydropower potential was commissioned by the CREDP (Fay and Grett, 2013). The results of this work were used in the modelling to follow.

Waste characterization and volume information were obtained from the Saint Lucia Solid Waste Management Authority (SWMA) website (http://sluswma.org/category/reports/).

4.3.4 Cost of fossil fuels

The future trend in fossil fuel costs follows the projection for crude oil provided by the World Bank and released on January 24, 2017 (World Bank, 2017b). The cost of diesel fuel to LUCELEC is discounted based on historic trends calculated from data available in the company's annual reports. Figure 5 illustrates the fuel cost projections utilised.

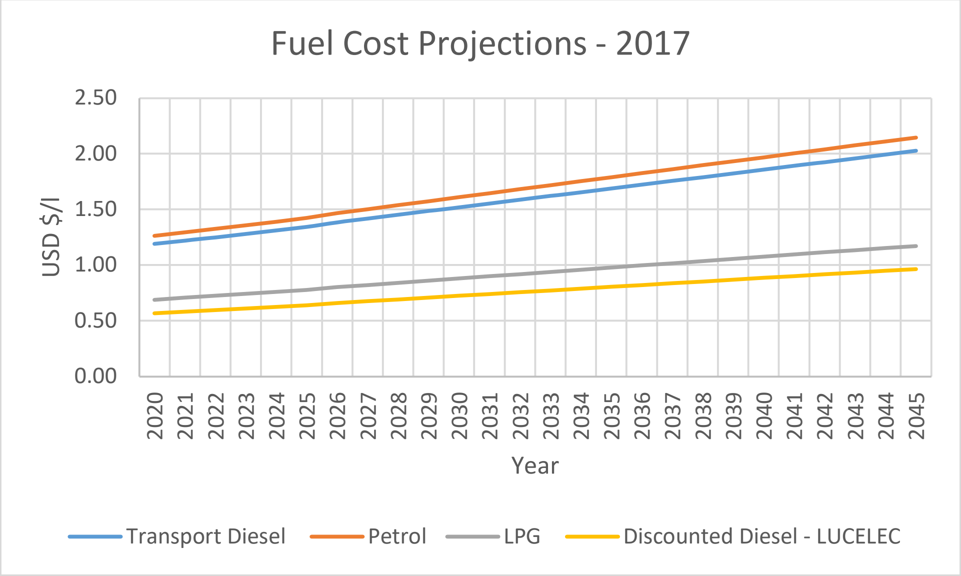


Figure 5 Projected cost of fossil fuels

4.3.5 Distribution of Electricity System Substations and Feeders

A single line drawing of the electricity network is provided in Figure 6 and the associated data table in Table 4. The distribution system nodes used, in the research analysis, were based on the seven (7) substations shown. Substation transformer capacity information is provided on the drawing and in the table.

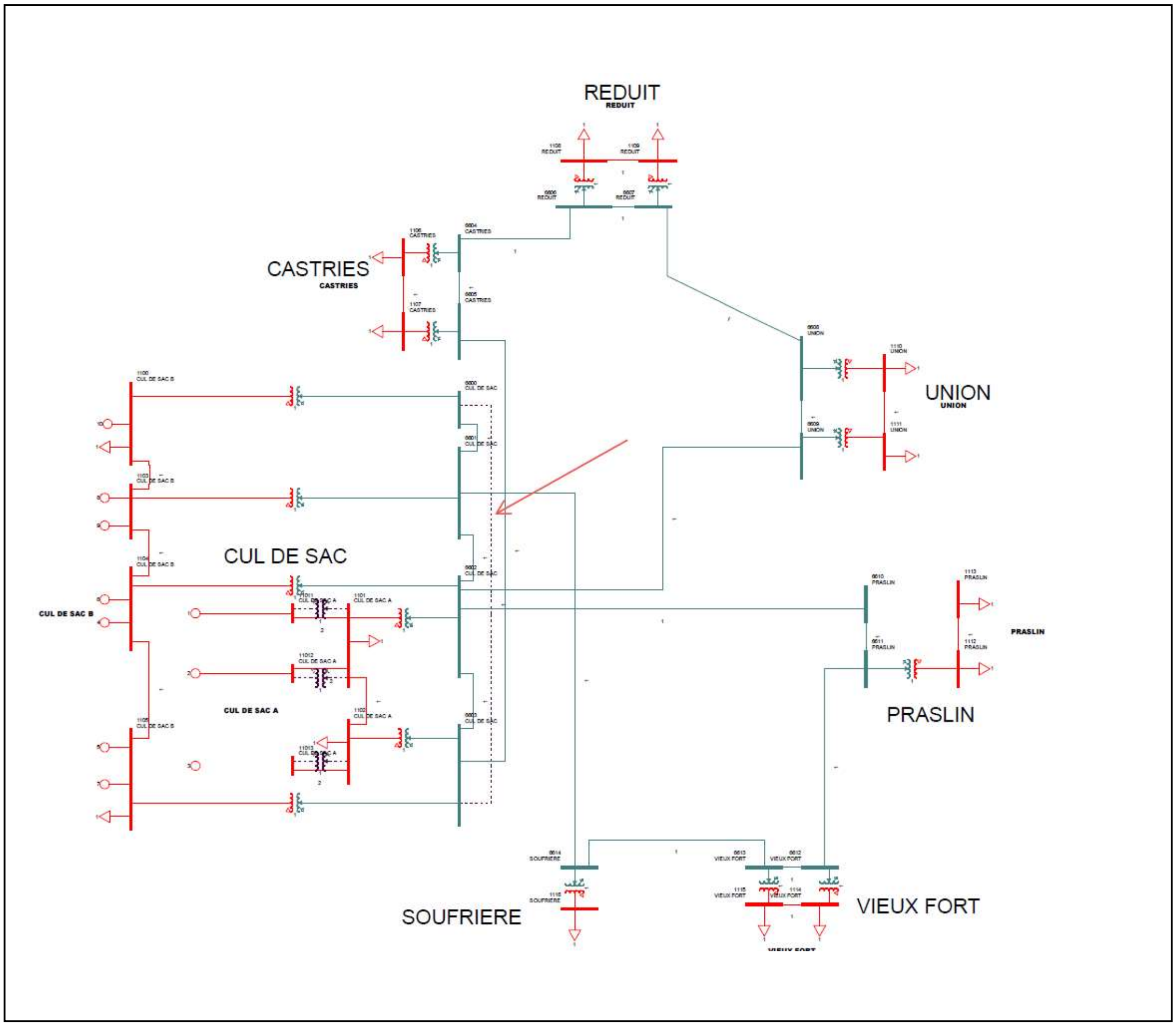


Figure 6 LUCELEC Network Single Line Drawing

Table 4 Data table for LUCELEC network single line drawing

Designation	Substation	Transformer Rating
CDS_G1	Cul De Sac	8 MVA
CDS_G2	Cul De Sac	8 MVA
CDS_G3	Cul De Sac	9 MVA
CDS_T1	Cul De Sac	22.5 MVA
CDS_T2	Cul De Sac	22.5 MVA
CDS_T3	Cul De Sac	37.5 MVA
CDS_T4	Cul De Sac	37.5 MVA
CDS_T5	Cul De Sac	37.5 MVA
CDS_T6	Cul De Sac	37.5 MVA
CSS_T1	Castries	15 MVA
CSS_T2	Castries	15 MVA
RED_T1	Reduit	15 MVA
RED_T2	Reduit	15 MVA
PRA_T2	Praslin	8.5 MVA
SFS_T1	Soufriere	6.667 MVA
USS_T1	Union	15 MVA
USS_T2	Union	15 MVA
VFS_T1	Vieux Fort	15 MVA
VFS_T2	Vieux Fort	15 MVA

4.3.6 Scenario development for transport and electricity sectors

4.3.6.1 Transport Sector

- All scenarios included the transitioning of the transport sector to electric mobility. The energy needs for each scenario were assessed.
- Sources of RE, locations and delivery methods for the needed energy were evaluated. This included distributed generation, EVs, energy storage (stationery and EV batteries) and biogas from municipal solid waste. The location of distributed charging stations for EVs, on the selected island, were evaluated based on the location of existing infrastructure.

- All EVs connected to the charging network were evaluated as one (1) aggregated VPP for providing V2G energy services.

4.3.6.2 Electricity Sector

- All scenarios were developed with transitioning fossil fuel energy use from all sectors to the electricity sector.
- DSM was included through use of the thermal storage in refrigeration and water pumping and storage in the water sector.
- Thermal VRE storage, at hotels and commercial sites as ice to be used for air conditioning, was evaluated as a second VPP.
- The research considered the overall energy balance of the modelled energy system. The impact of the distributed RE systems and V2G energy transfer on enabling 100% RE in both electricity and transport sectors was investigated.
- Bidirectional energy flow between the transport and electricity sectors was investigated. Excess energy from the transport sector was exported to the electricity sector and vice versa.
- The scenarios investigated maximum possible VRE shares and options for energy storage technologies including batteries, PHS with fresh water storage and on-site thermal storage applications.

4.4 Demand Projections

4.4.1 Electricity demand growth projection

Load growth projection methodology is taken directly from the NETS as the methodology used in that process has been vetted and accepted by GOSL, LUCELEC and other stakeholders. Population growth data from World Bank reported historic data and GDP growth was obtained from the Eastern Caribbean Central Bank (ECCB) for the period 2005 to 2014. Using the historic GDP and electricity consumption data from LUCELEC, elasticity, in average demand per customer sector, was calculated for each sector (Equation 2). Likewise, using the historic population growth data from the World Bank and the number of customers per sector from LUCELEC, elasticity in average number of customers per sector was calculated (Equation 3).

Equation 2 Demand Elasticity

$$DE = \prod_{2}^{10} \left(\frac{CYC}{PYC}\right) / \prod_{2}^{10} \left(\left(\frac{gGDP}{P}\right) + 1\right)$$

Where DE – demand elasticity

CYC – current year consumption (kWh)

PYC – previous year consumption (kWh)

gGDP – growth in GDP compared to previous year

P – population growth compared to previous year

Equation 3 Elasticity in Number of Customers

$$CE = \prod_{2}^{10}(\frac{CYN}{PYN}) \,/\, \prod_{2}^{10}\left(\frac{CYP}{PYP}\right)$$

Where CE – elasticity in number of customers

CYN – number of customers in current year

PYN – number of customers in previous year

CYP – current year population

PYP – previous year population

During the forecast period up to 2035, population and GDP growth are estimated based on World Bank, ECCB forecasts and historic data and are held constant at 0.75% and 1.63% respectively per annum. The growth in GDP per capita was first calculated then multiplied by the elasticity in average demand and then multiplied by the average demand for the previous year to estimate the average demand for the current year for each sector.

The elasticity in average number of customers was multiplied by the population growth and then multiplied by the number of customers for the previous year to estimate number of customers for the current year for each sector. The calculated average demand is then multiplied by the calculated number of customers to estimate the total demand per sector for the year under consideration (Equation 4).

Projected average demand was then multiplied by projected number of customers per sector to estimate baseline growth in demand per sector per year up to 2035.

Equation 4 Calculation of Demand Projections

$$CYD = gGDPc * DE * PYD$$

$$CYN = CE * PG * PYN$$

$$BDG = CYD * CYN$$

Where CYD – average demand for current year

gGDPc – growth in GDP per capita

DE – demand elasticity

PYD – previous year average demand

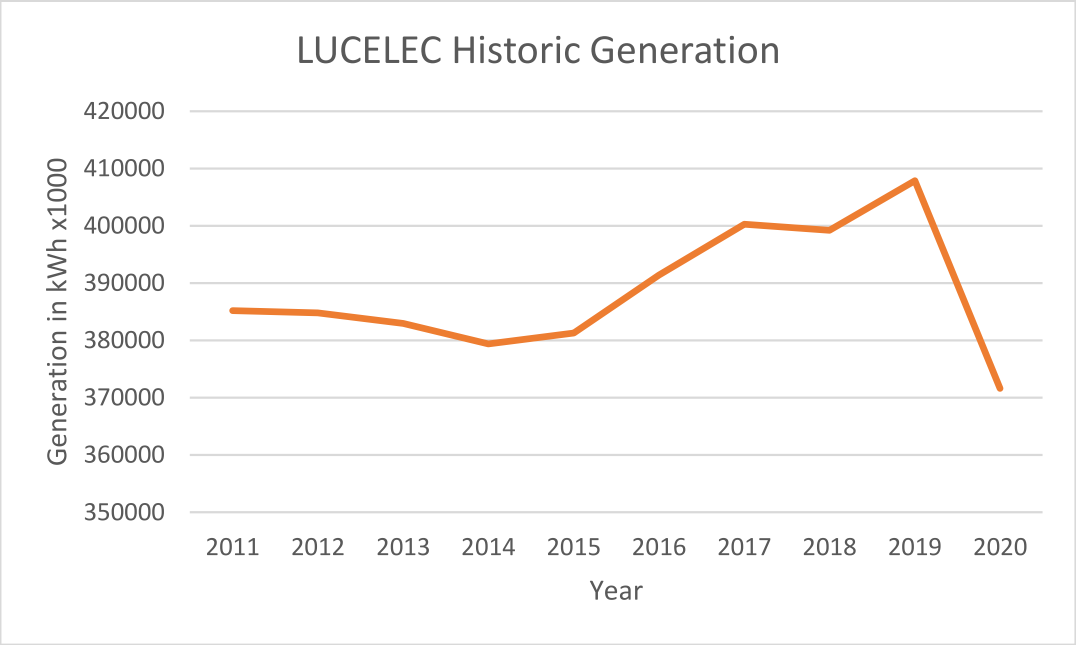
CYN – number of customers for current year

CE – elasticity in number of customers

PG – population growth

PYN – number of customers in previous year

BDG – baseline demand growth



Historic Demand

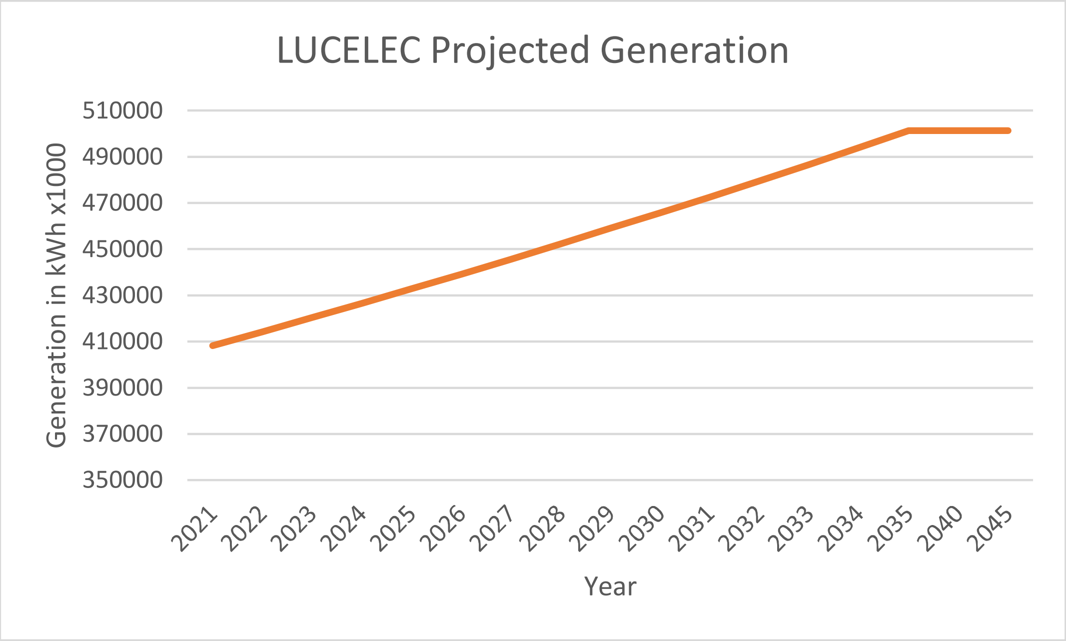
x1000kWh	2020	2019	2018	2017	2016
Power Station	13059	12325	12288	13196	13770
Losses	22067	26658	25317	27450	29432
Generated	371599	407921	399228	400300	391431
%Power station and losses	9.5%	9.6%	9.4%	10.2%	11.0%
x1000kWh	2015	2014	2013	2012	2011
Power Station	13715	13918	14706	14511	14599
Losses	30013	33574	33791	36948	37234
Generated	381268	379431	382976	384783	385208
%Power station and losses	11.5%	12.5%	12.7%	13.4%	13.5%

Figure 7 Historic electricity demand curve and data

The projected average demand for all sectors was summed and the transmission losses (8.7%) and self-consumption by LUCELEC (average of total of 11.3%) were factored in. The result was divided by the number of hours in the year accounting for the expected load factor (71.1%) to arrive at a projected system peak load for the current year (Equation 5).

The historic demand growth curve and historic demand data are provided in Figure 7. A drop in the energy demand is observed between 2019 and 2020 due to the impact of the COVID-19 protocols which reduced in country economic activity. Full economic recovery in terms of power consumption is assumed to occur beyond 2022 as the world learns to live with the SARS-COV-2 virus which causes COVID-19.

The projected demand curve assumes growth becomes stagnant between the years 2035 to 2045. The combined historic and projected demand curve assumes an S-curve characteristic. This is because the economy is assumed to become mature during the period 2035 to 2045 (for the purpose of this study).



Forecast Demand

Forecast x1000kWh	2021	2022	2023	2024	2025
Sales	366784	372177	377653	383213	388859
Generation	408267	414269	420365	426554	432838
Forecast x1000kWh	2026	2027	2028	2029	2030
Sales	394591	400412	406322	412324	418418
Generation	439218	445698	452276	458957	465740
Forecast x1000kWh	2031	2032	2033	2034	2035
Sales	424606	430889	437270	443749	450328
Generation	472628	479622	486724	493936	501259

Figure 8 Forecast electricity demand curve and data

The average growth rate until 2035 is 2% per annum. Forecast data is provided in Figure 8.

4.4.2 Energy efficiency

Three (3) energy efficiency (EE) targets linearly projected in 5-year increments over a 20-year period as indicated in Table 5 were analysed. They include the GOSL set EE target of 20% applied to all sectors, a higher target estimated from MEPS energy consumption data (Energy Dynamics Ltd, 2016) and commercially available equipment specifications and a lower target taken as half of the GOSL set EE target.

Table 5 Energy savings by sector and year

			Energy Efficiency % Reduction			
			Maximum by Sector			
Year	Target	Minimum	Domestic	Hotel	Commercial	Industrial
Year 5	-5%	-3%	-6%	-6%	-5%	-6%
Year 10	-10%	-5%	-11%	-12%	-10%	-12%
Year 15	-15%	-8%	-17%	-17%	-15%	-18%
Year 20	-20%	-10%	-23%	-23%	-20%	-23%
Year 25	-20%	-10%	-23%	-23%	-20%	-23%

A check was done to ensure that the level of savings projected was technically possible. To ensure a realistic estimate was used, average annual consumption data per customer by sector were calculated using consumption data (LUCELEC Annual Reports and NETS Data) from 2004 to 2015. An average breakdown of the typical energy consumption, by usage and equipment in the Caribbean Community (CARICOM) states, was obtained (Energy Dynamics Ltd, 2016) and is provided in Table 6. Thus, a baseline for equipment consumption was estimated using load factors to match to the expected CARICOM average. Energy-efficient equipment was then substituted for inefficient equipment and a maximum possible energy savings was calculated. The calculations are shown in Table 7.

Table 6 Breakdown of Energy Consumption in CARICOM

Breakdown of energy consumption in CARICOM (Energy Dynamics Ltd, 2016)	
Air conditioning	48.1%
Lighting	10.4%
Refrigeration	9.1%
Pumps	13.8%
General Equipment	15.1%
Water heaters	3.1%
Other	0.4%
	100.0%

Table 7 Calculation of Maximum Energy Savings

Average annual consumption per domestic customer - (NETS data)	2,051	kWh						
Domestic Sector	BAU Annual consumption in kWh	Unit rating in kW	No of units	Load Factor	Annual consumption in kWh	EE Unit rating in kW	Annual consumption in kWh	Savings in kWh
Air conditioning	987	1.00	1	0.11	964	0.69	667	296
Lighting	213	0.04	1	0.6	210	0.008	42	168
Total					1,174		709	465
% Savings								23%
Average annual consumption per hotel customer - (NETS data)	1,127,599	kWh						
Hotel Sector	BAU Annual consumption in kWh	Unit rating in kW	No of units	Load Factor	Annual consumption in kWh	EE Unit rating in kW	Annual consumption in kWh	Savings in kWh
Air conditioning	542,375	1.00	103	0.6	541,368	0.69	374,793	166,575
Lighting	117,270	0.04	478	0.7	117,244	0.008	23,449	93,795
Total					658,612		398,242	260,370
% Savings								23%
Average annual consumption per commercial customer - (NETS data)	17,811	kWh						
Commercial Sector	BAU Annual consumption in kWh	Unit rating in kW	No of units	Load Factor	Annual consumption in kWh	EE Unit rating in kW	Annual consumption in kWh	Savings in kWh
Air conditioning	542,375	1.00	103	0.6	541,368	0.69	374,793	166,575
Lighting	117,270	0.04	478	0.7	117,244	0.008	23,449	93,795
Total					8,357		4,820	3,537
% Savings								20%
Average annual consumption per industrial customer - (NETS data)	169,985	kWh						
Industrial Sector	BAU Annual consumption in kWh	Unit rating in kW	No of units	Load Factor	Annual consumption in kWh	EE Unit rating in kW	Annual consumption in kWh	Savings in kWh

Air conditioning	81,763	1.00	11	0.87	83,833	0.69	58,038	25,795
Lighting	17,678	0.04	72	0.70	17,660	0.008	3,532	14,128
Total					101,493		61,570	39,923
% Savings								23%

The calculated percentage savings in the last row of each sector section in Table 7 is an estimate of the maximum savings possible from the sector using the projected consumption. The calculations assume that all customers use air conditioning which is an overestimation, however, customers may achieve savings by switching to other efficient devices not accounted for in the calculations, e.g., more efficient pumps. All customers use lighting.

LUCELEC is gradually replacing the existing HPS streetlights with energy-efficient light emitting diode (LED) lights. It is assumed that all streetlights will be replaced with LED lights for an overall savings of 55% during the period covered by this research.

4.4.3 The Transport Sector

Using vehicle registration information obtained from the Ministry of Transport for the years 2009 to 2016, an average annual growth rate of the transport fleet of 3% was calculated. The projected number of vehicles in the transport fleet over the 25-year transition period considered in the research is provided in Table 8.

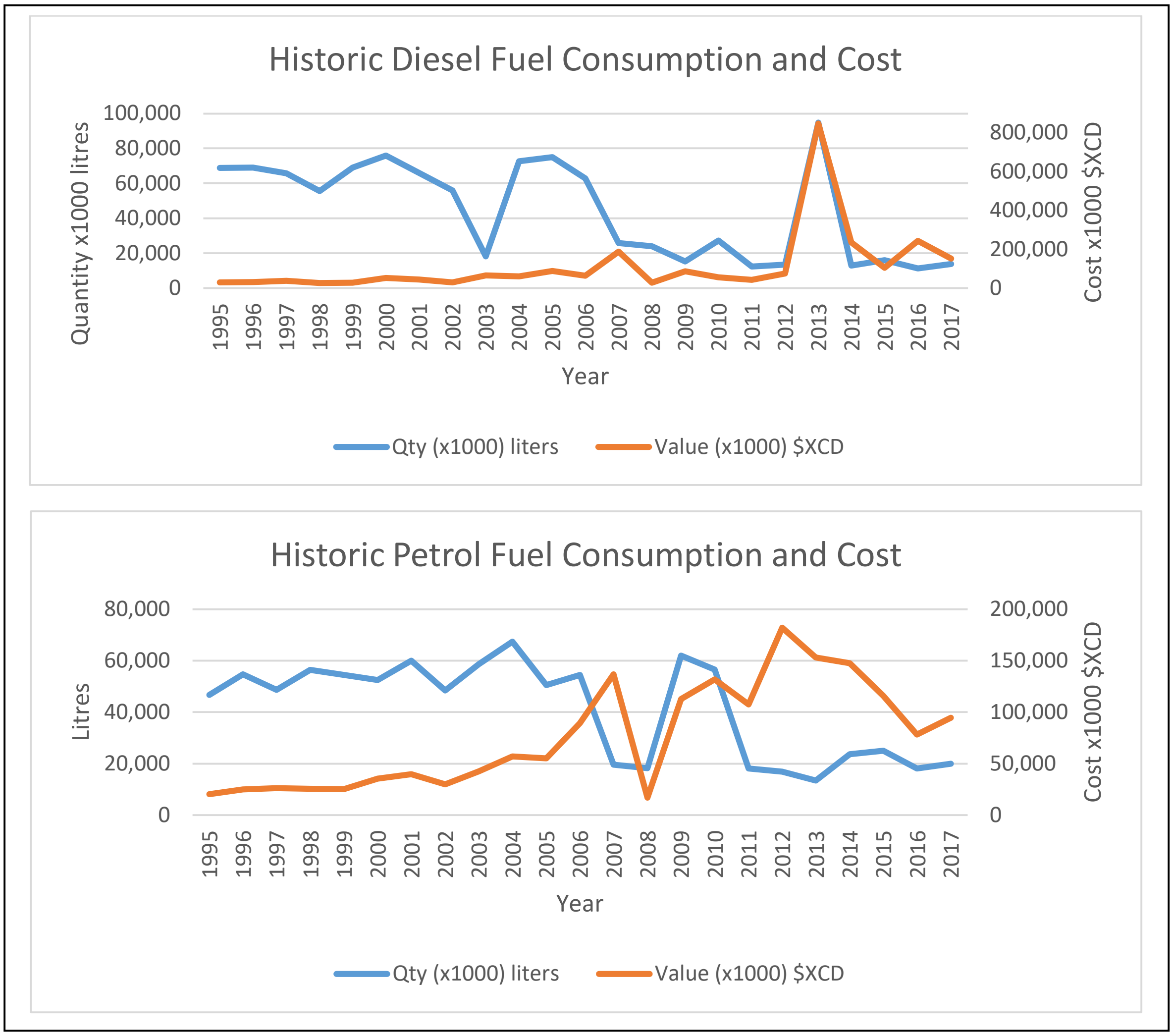


Figure 9 Historic fossil fuel consumption and cost data

Table 8 Projected number of vehicles in the transport fleet

Totals	LDV&Cars	HDV	Public Transport	Farming	Total
Year 5	33534	5337	4635	197	43505
Year 10	38875	6188	5370	231	50433
Year 15	45067	7173	6226	264	58466
Year 20	52245	8313	7216	308	67774
Year 25	60563	9635	8365	356	78563

Historic petrol and diesel fuel import data was obtained for the all sectors except power generation (Government, 2022). Consumption and cost data for the period 1995 to 2017 are provided in Figure 9. The consumption data would normally be expected to follow an S-Curve, however, the observed form of both graphs resemble a reverse S-Curve. It can be inferred from the cost information plotted alongside the consumption data that the observed cost increase over time is driving down the fuel consumption trend. As both consumption curves appear to be relatively flat from the period 2007 to 2017, a linear projection is assumed for the 25-year analysis period. The historic and projected consumption data are provided in Table 9.

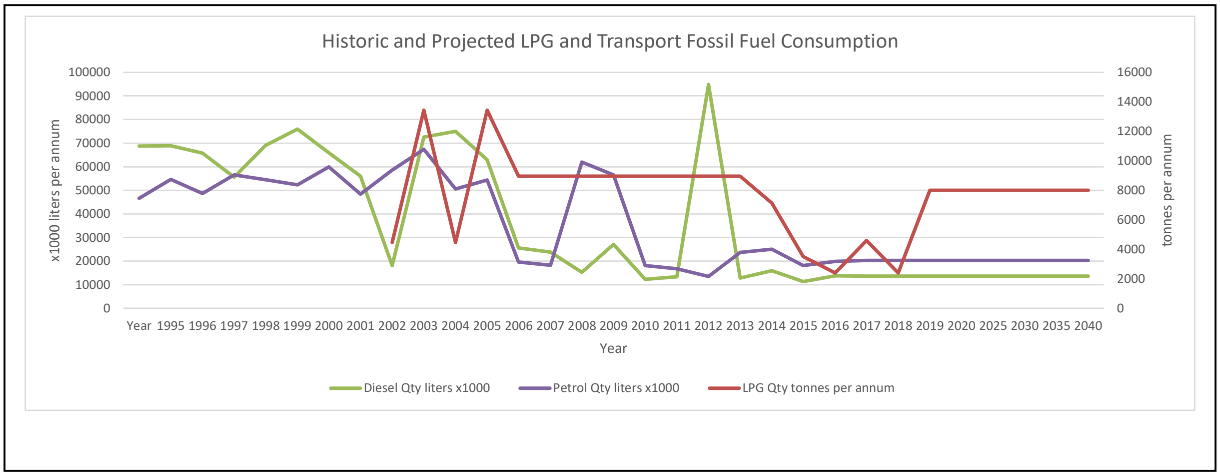


Figure 10 Historic and projected LPG and transport fossil fuel consumption

4.4.4 Sector Fossil Fuel Consumption

LPG import data was obtained (EIA, 2022; Government, 2022) for the period 2003 to 2019. Neither source contained data for the period 2013 to 2015 for LPG so information for this period was generated by linear interpolation. As with the diesel and petrol fuel consumption, for sectors other than power generation, the form of the historic consumption curve resembles a reverse S-Curve. As the price of LPG follows the same trend as other liquid fossil fuels, it can be inferred that consumption is also suppressed by rising costs. The historic and projected consumption data are provided in Table 9. A linear projection is used for consumption over the period of analysis in this research with demand remaining constant. The data is plotted in Figure 10.

Table 9 Fossil fuels historic and projected import quantities by year

Year	*LPG Qty tonnes*	*Diesel Qty litres x1000*	*Petrol Qty litres x1000*
1995		68824	46677
1996		68916	54676
1997		65702	48602
1998		55546	56442
1999		69004	54462
2000		75960	52394
2001		65872	59932
2002		55921	48442
2003	4475	18125	58606
2004	13425	72599	67397
2005	4475	75058	50507
2006	13425	62866	54376
2007	8950	25682	19568
2008	8950	23858	18261
2009	8950	15284	61931
2010	8950	27132	56504
2011	8950	12348	18150
2012	8950	13404	16821
2013	8950	94873	13519
2014	8950	12819	23649
2015	7133	15959	25015
2016	3500	11282	18117
2017	2400	13753	19907
2018	4600	13603	20309
2019	2400	13603	20309
2020	8018	13603	20309
2025	8018	13603	20309
2030	8018	13603	20309
2035	8018	13603	20309
2040	8018	13603	20309
2045	8018	13603	20309

4.4.5 Electric Vehicle Fleet Demand

Historical minibus public transportation information was available from the Ministry of Transport. The information included the number of minibuses in operation, the routes served by the minibuses and the number of trips made per route daily by each minibus. This information was used to estimate the total distance travelled daily by each minibus.

Specifications for an electric bus, from the company Proterra, were used to estimate the electricity consumption for converting to an electrified bus fleet. The specific energy consumption of 1.336 kWh/km was used to estimate the electricity consumption for running the bus routes and the total battery capacity is 84kWh. The number of full charges needed daily by the fleet and the number of hours needed to charge at an average charge power of 14kW were estimated. The number of hours to charge versus the fraction of the full fleet charging was then evaluated. The results are presented in Figure 11 for the HDV. This represents the percentage of the total fleet that has to be connected and charging to provide the required electricity consumption to replace the fossil fuel demand due to actual driving of the fleet each day. It does not represent the amount of electricity that will be needed to fully charge the fleet batteries each day.

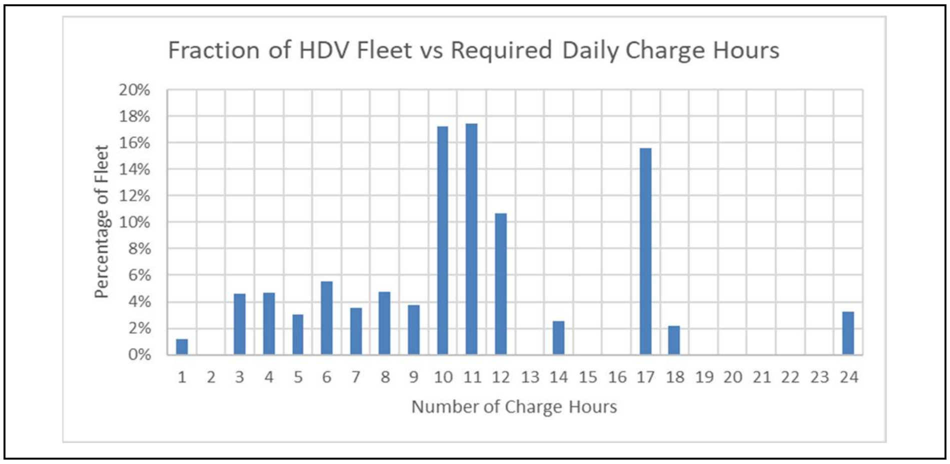


Figure 11 Estimated electricity demand of electrified HDV fleet based on historical use

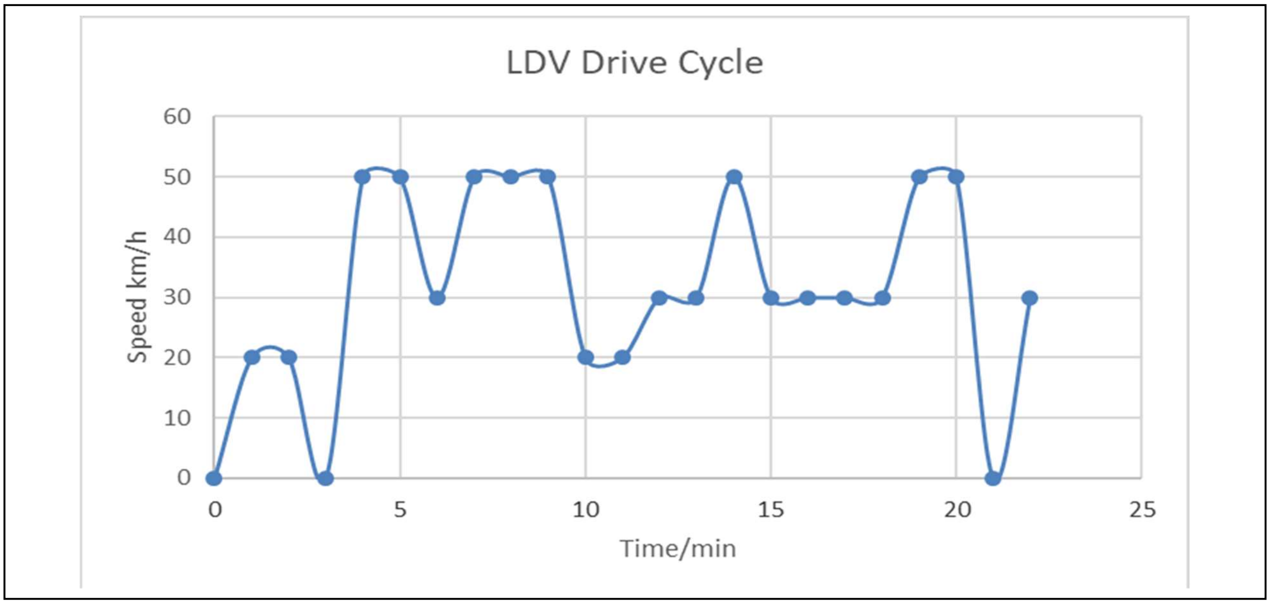


Figure 12 Assumed LDV 12km drive cycle

The sum of the product of the required charge time in hours and the percentage of the fleet charging is 10.88 hours. This total value was kept the same for all the charge connection profiles developed and presented later for the electrified fleet.

Usage data was not available for the LDV transport fleet. In this case, a daily average drive cycle was assumed for the fleet. 70% of the fleet was assumed to drive 24 km per day, representing a roundtrip from the northernmost town of Gros Islet to Castries capital city center. This route represents the traffic flow in the most densely populated section of the island. The remaining 30% of the fleet is assumed to drive 112 km per day, representing the roundtrip from the southernmost town of Vieux Fort to Castries and back. The typical 12 km drive cycle assumed is provided in Figure 12.

For the 24 km roundtrip, it is estimated that 13% of the 30kWh battery pack charge is consumed and 60% charge is consumed for the 112 km roundtrip. The sum of the product of percentage of fleet by required charge time is estimated to be 1.22 hours at an average charge power of 6.6kW. 1.22 hours is kept as the total product of percentage of fleet multiplied by charging time for all charge connection profiles developed and presented later in this report for the LDV.

4.5 Potential for Mature RE Technologies

In assessing the RE potential that can be exploited, using mature technologies, the gross resource potential of the island was analysed noting the relationship as illustrated in Figure 13 and adapted from (EERE, 2019). The technical potential was assessed by applying various technologies for converting the gross resource potential into electrical energy. An economic analysis was then performed for each site to ascertain whether it makes financial and economic sense to invest. Finally, deployment potential would be determined by availability of financing and the existing investment environment.

In the following evaluations, all forest reserves and built areas were considered unavailable and were excluded from consideration (except for DG solar on buildings).

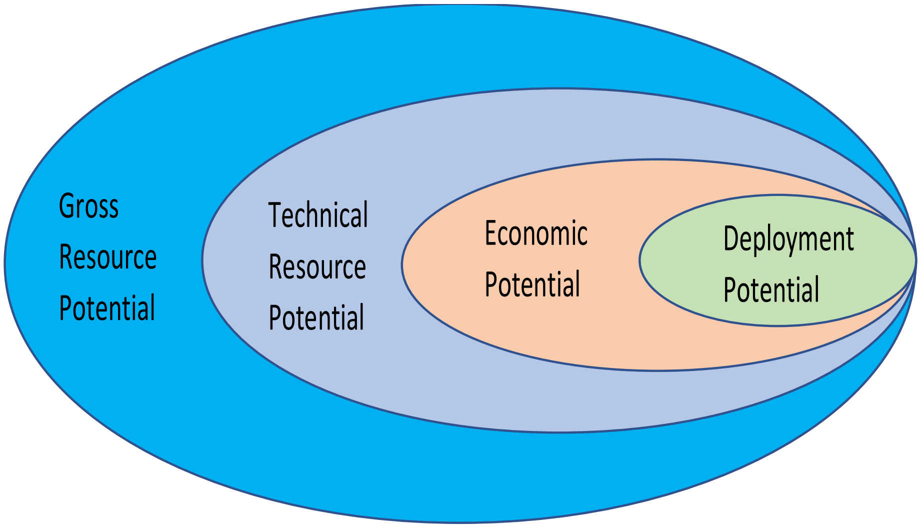


Figure 13 Assessment of Renewable Energy Potential

4.5.1 Pumped Hydropower Storage

An evaluation of potential sites for pumped hydro storage was undertaken using Google Maps contour map and Google Earth. One site in the Vieux Fort district was identified where a swamp already exists at near sea level and elevated suitable flat land is nearby for locating the upper reservoir. The potential site is shown in Figure 14.


Measure distance
Click on the map to add to your path
Total area: 135,011.76 m² (1,453,254.48 ft²)
Total distance: 1.47 km (4,806.82 ft)

Measure distance
Click on the map to add to your path
Total area: 137,056.66 m² (1,475,265.61 ft²)
Total distance: 1.71 km (1.06 mi)

Terrain
View topography and elevation

Images
Street View
Photo Sphere
See inside

Measure distance
Click on the map to add to your path
Total distance: 2.71 km (1.68 mi)

Figure 14 Proposed Pumped Hydro Storage Location in Vieux Fort (Top left: Lower Reservoir; Upper Right: Upper Reservoir; Bottom: Linear Distance Between Reservoirs)

The proposed lower reservoir is a naturally occurring swamp which fills up during the rainy season and partially dries off during the dry season. The estimated area of this lower reservoir using Google Maps is 135,011 m^2. A 10 m depth was assumed for the analysis. This gives a full volume of approximately 1,350,000 cubic meters.

The upper reservoir can be located at the relatively flat top of a nearby hill at an elevation of 300 m. The linear distance between the two (2) reservoirs is approximately 3 km. The estimated area of the upper reservoir, using Google Maps and staying approximately within the 300 m contour, is 137,056 m^2. A depth of 10 m was assumed for this reservoir. This gives a full volume of 1,370,000 m^3.

The potential stored energy can be calculated using the formula shown in Equation 6:

Equation 6 Calculation of PHS Stored Energy

$$E = \rho * g * h * V$$

Where E - Energy

ρ - density of water, 1000kg/m^3;

g - gravitational acceleration, 9.81m/s^2;

h - elevation head, 300 m;

V - volume, 1.35×10^6 m^3

The estimated stored energy is 3.97×10^{12} Joules or 1,103,625 kWh.

A freshwater reservoir can also be added to provide drinking water to the population in Vieux Fort. Based on the proposed location, shown in Figure 15, the minimum volume would be:

130,196 m^2 x 1 m depth = 130,196 m^3

Figure 15 Fresh Water Storage for Vieux Fort PHS

The freshwater reservoir is sited at 2 km from the upper PHS reservoir.

A second potential PHS system can be setup with the John Compton Dam in Roseau, Anse la Raye district, as a lower reservoir. The dam has a design capacity of 3,000,000 m^3 (Amadio, M., Dell'Aquila, V. and Mysiak, 2014) and is currently being dredged as siltation has reduced its capacity by half. The dam is located at an elevation of 120 m above sea-level and the proposed upper reservoir can be located at an elevation of 400 m above sea-level, as shown in Figure 16.

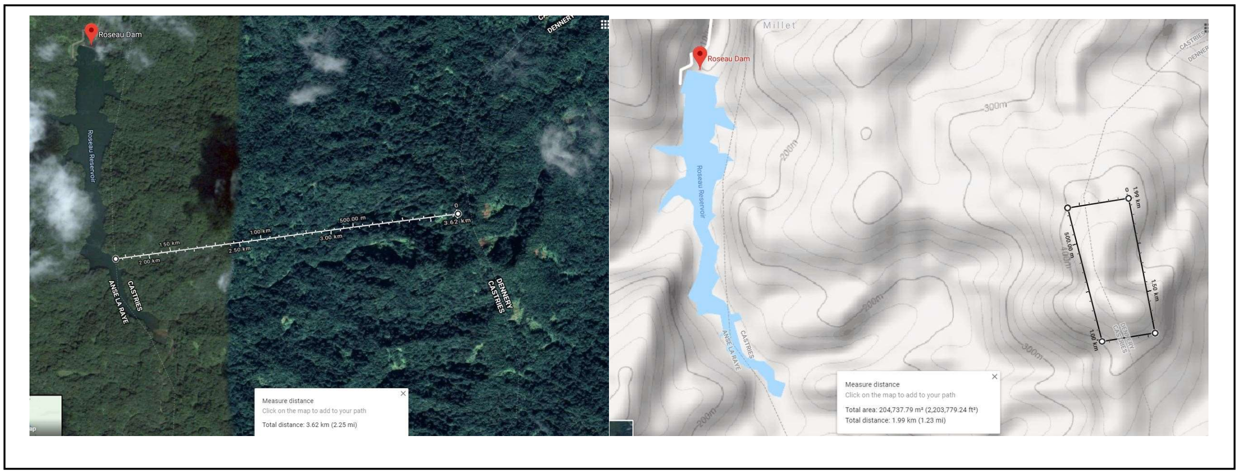


Figure 16 Roseau John Compton Dam Proposed PHS Site

For this case, the stored energy potential can be calculated using h = (400 – 120) m = 280 m;

At an upper reservoir depth of 5 m, V = 204,738 m^2 x 5 m = 1,023,690 m^3

The estimated stored energy = 2.81 $x10^{12}$ Joules, or 781,075 kWh

The total estimated PHS potential = 1,103,625 + 781,075 = **1,884,700** kWh

4.5.2 Solar Energy

The cost of solar PV continues to decline with installed costs for utility scale crystalline silicon PV, as of November 2018, between USD$0.040 to USD$0.046 per kWh in the United States (Lazard, 2018). In addition, a 2016 auction for RE in Jamaica saw a winning bid for 33.1 MWp of solar PV at USD$ 0.0854 per kWh (ZARIPOVA, 2019). Considering the changes being made to the regulatory environment, more investments in solar PV can be expected in Saint Lucia. Consequently, an evaluation of the potential for solar PV in the country was undertaken. The analysis focused on the technical resource potential.

Utility Scale: The evaluation of potential for utility scale solar PV considered the total available undeveloped flat land in the country located using Google Maps and paid no attention to zoning or land ownership considerations. An example of the evaluation in the Micoud district is provided in Figure 17. The full evaluation is provided in Appendix C – Renewable Energy Resource Potential.

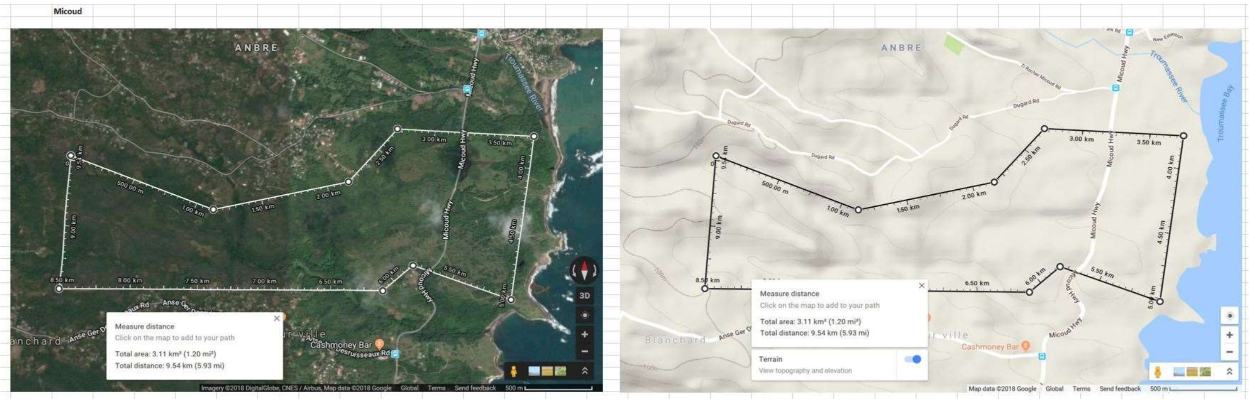


Figure 17 Evaluation of flat land available in the Micoud District

Data for solar farms installed since 2016 in the CARICOM Region was used to estimate an average installed power density as provided in Table 10.

Table 10 Installed Power Density for Solar PV in the Caribbean Region

Country	Utility	Solar PV in MWp	Area in Acres	Area in Hectares	Area in m^2
Saint Lucia	LUCELEC	3	15		60703
Anguilla	ANGLEC	1.1	4.1		16592
Antigua	APUA	3	3.9		39000
Barbados	BL&P	10	42		169968
Average power density		0.062869	kWp/m^2		

Using the average power density, the available land is translated to an installed solar PV potential as provided in Table 11. The total utility solar PV potential is estimated at just over 380 MWp.

Table 11 Utility Scale Solar PV Potential by Location

Location	Area available in m^2	Gross Utility Scale Solar Potential in MWp
Desruisseux	60,9748	38.33
Desruisseux 1	319,160	20.06
Mahaut	378,398	23.79
Anse la Verdure	359,919	22.63
Micoud	3,110,000	195.52
Micoud 1	1,270,000	79.84
	Total	380.18

Utility scale solar PV electricity production was modelled using solar irradiation data generated for the Sugar Mill site using Meteonorm® as it is likely that this site will be used for both wind and solar PV installations as it contains large areas of flat land.

4.5.3 Pumped Hydro Storage (PHS) Reservoir Surfaces

The available surface area and solar PV potential, on proposed and existing water reservoir surfaces for PHS use, are provided in Table 12.

Table 12 Utility Scale Solar PV Potential on Reservoir Surfaces

PHS Location	Area in m^2	Solar Potential in MWp
Vieux Fort Lower Reservoir	135,011	8.49
Vieux Fort Upper Reservoir	137,056	8.62
Vieux Fort Water Storage	130,196	8.18
Roseau Dam Lower Reservoir	73,925	4.65
Roseau Dam Upper Reservoir	204,738	12.87
	Total	42.81

The total available potential for utility scale solar PV is, therefore, estimated at 423 MWp.

4.5.4 Transport Sector

The evaluation of distributed solar PV potential focused on the transport sector (for servicing LDV), the commercial sector and the hotel sector. It is assumed that existing fuel stations can use their roof space and commercial centers can use their parking areas to install solar PV if the regulatory conditions are conducive. An assessment of these spaces was made to evaluate the potential for servicing the LDV.

Fuel station roof space was estimated based on the number of pairs of pump stations installed. Each pair of pump stations represents a roof area of approximately 25 m^2 (based on on-site and Google Maps observations). The PV potential was evaluated using a typical commercial solar carport installation requirement of 70,513 square feet per 1,000 kWp (0.1526 kWp/m^2 (Solar Electric Supply, 2019)). The results are provided in Table 13.

Table 13 Solar PV Potential of Fuel Stations

Sub station	Number of fuel stations	Number of pairs of pumps	Available roof area in m^2	Potential Solar PV capacity in kWp
Vieux Fort	8	9	1800	275
Soufriere	3	4	300	46
Praslin	6	6	900	137
Cul de Sac	6	8	1200	183
Castries	6	7	1050	160
Union	1	1	25	4
Reduit	2	2	100	15
Total	32	37	5375	820

Methodology for design of 100% renewable energy transition pathways to meet SIDS transport and electricity objectives. - Europa-Universität Flensburg

An evaluation of the available parking spaces in commercial centers was done using Google Maps and the solar PV potential was estimated using a commercial carport power density of 0.1526 kWp/m^2. The results are provided in Table 14.

Table 14 Solar PV Potential of Commercial Parking Spaces

Substation	Name of Business	Parking Space Area in m^2	PV Potential in kWp	Total LDV PV Potential (Fuel stations + parking spaces) in kWp
Vieux Fort	Gablewoods South; Bus terminals	900	137	412
Soufriere	none			46
Praslin	none			137
Cul de Sac	Massy Stores	400	61	244
Castries	none			160
Union	Caribbean Cinemas, Massy Mega	2,800	427	431
Reduit	JQ Mall	200	30	45
Total		4,300	655	1,475

4.5.5 Hotel Sector

As of 2020, there were 62 hotels in operation in Saint Lucia (Department of Finance, 2021). The locations of the hotels were identified using Google Maps and the potentials summarised in the table below. The solar PV potential of hotels depends on several factors including the design of the roofs, size, energy demand and aesthetic requirements. To estimate available roof space an evaluation of the available and observable roof area of a sample of hotels ranging in size from very small to the very large was measured using Google Maps. The results are provided in Table 15.

Table 15 Sample estimate of available hotel roof space

Hotel	Estimated roof space in m^2	No of rooms	Area per room in m^2
The Royalton	4,000	166	24.1
Sandals Grande	6,400	301	21.3
Coconut Bay	6,000	250	24.0
Mystique Saint Lucia by Royalton	2,500	96	26.0
St. James Morgan Bay	6,000	343	17.5
Bay Gardens Inn	500	33	15.2
Auberge Seraphine	300	28	10.7
Bay Gardens Marina Haven	350	35	10.0
Ladera Resort	750	37	20.3
Anse Chastanet	600	49	12.2
		Average	18.1

In 2017, there were 4702 available hotel rooms (UN Environment & BMU, 2017) in 61 hotels (Department of Finance, 2021). The Royalton was added in 2020. Using the average of 18.1 m^2 per room, there is approximately 88,244 m^2 of hotel roof space available for installation of solar PV systems. The estimated available rooftop area per hotel for installation of PV systems is 1,423 m^2. The housing stock in Barbados is very similar to Saint Lucia. According to (BREA, 2016), a 3 kWp PV system requires 24 m^2 of roof space, i.e., 8 m^2 per kWp. With this information, the solar PV potential per substation for the hotel sector is estimated in Table 16.

Table 16 Solar PV Potential in the Hotel Sector

Sub station	Number of Hotels	PV potential - kWp
Vieux Fort	4	712
Soufriere	8	1,423
Praslin	1	178
Cul de Sac	3	534
Castries	3	534
Union	2	356
Reduit	41	7,294
Total	62	11,031

4.5.6 Commercial Sector

As of 2017, LUCELEC had 6,995 commercial customers. The commercial operations are of various sizes and have a wide distribution in terms of location. The highest densities are in the town centers. Using a method similar to the hotel sector, Google Maps was used to estimate the land area in the urban areas where commercial customers are densely located. 50% of the measured area was estimated as occupied by commercial buildings. As indicated in the literature review, only 10% of the housing stock in Dominica and Anguilla survived the category 5 storms of 2017. Consequently, it is assumed that 10% of the building stock would be suitable for installation of PV systems, i.e., a total area of 5% (50% x 10%) of the available space. The results of this evaluation are provided in Table 17.

Table 17 Commercial Sector PV Potential

Substation	Urban area in m^2	5% Suitable area in m^2	PV potential in kWp at 8m^2 per kWp
Vieux Fort	300,000	15,000	1,875
Soufriere	450,000	22,500	2,813
Praslin	0	0	0

Cul de Sac	13,000	650	81
Castries	600,000	30,000	3,750
Union	30,000	1,500	188
Reduit	200,000	10,000	1,250
Total	1,593,000	79,650	9,956

Praslin is a residential area so the number of commercial centers is set to zero.

4.5.7 Domestic Sector

An evaluation was also done on the solar PV potential of the domestic (residential) sector, again, assuming that residential customers are distributed according to the substation load distribution. As of 2020, LUCELEC had 61,850 domestic customers with an average energy consumption of 2,207 kWh per annum. Using a specific output of 1,450 kWh/kWp, on average a 1.5 kWp solar PV system can meet the annual electricity demand of a domestic customer. A typical low-income house in Saint Lucia, as defined by the National Housing Authority, has a footprint of roughly 83.6 m^2 (900 square feet) (Louis, 2015). At 8 m^2 per kWp roughly 12 m^2 of roof space would be required for an installation. A summary of maximum distributed solar PV potentials is provided in Table 18, assuming that only 10% of the housing stock will be suitable for installations based on housing stock survival of the 2017 category 5 hurricanes in Dominica and Anguilla. This table is used to provide inputs for substation calculations in the model.

Table 18 Total Distributed Solar PV Potential

Substation	LDV in kWp (Fuel stations)	LDV in kWp (Parking Lots)	Commercial in kWp	Hotel in kWp	Residential in kWp
Vieux Fort	275	137	1,875	712	1,638
Soufriere	46	0	2813	1,423	607
Praslin	137	0	0	178	326
Cul de Sac	183	61	81	534	2,006
Castries	160	0	3,750	534	1,459
Union	4	427	188	356	1,422
Reduit	15	30	1,250	7,294	1,958
Total	820	655	9,956	11,031	9,416

Total distributed solar PV potential is estimated at 31,878 kWp.

4.5.8 Wind Energy

To estimate the technical wind energy potential, a Google Maps contour map was visually surveyed for elevated sites within close proximity to the road network. The transmission system runs parallel to the road network. Turbines were then located at potential sites using circles of six (6) rotor diameters to ensure minimum turbine spacing both in cross wind and main wind directions (Energypedia, 2019). The Enercon E-70 E4 2.3 MW, 71 m rotor diameter, 98 m hub height, wind zone III (DIBt locations near to the coast) and wind class IEC/EN IA (16% turbulence at 10 m hub height and gust speeds of 70 m/s for hurricane conditions) and IEC/EN IIA with a cut out speed of 28-34 m/s was used to evaluate the wind power potential. An example of one (1) location is provided in Figure 18 with the full evaluation provided in Appendix C – Renewable Energy Resource Potential.

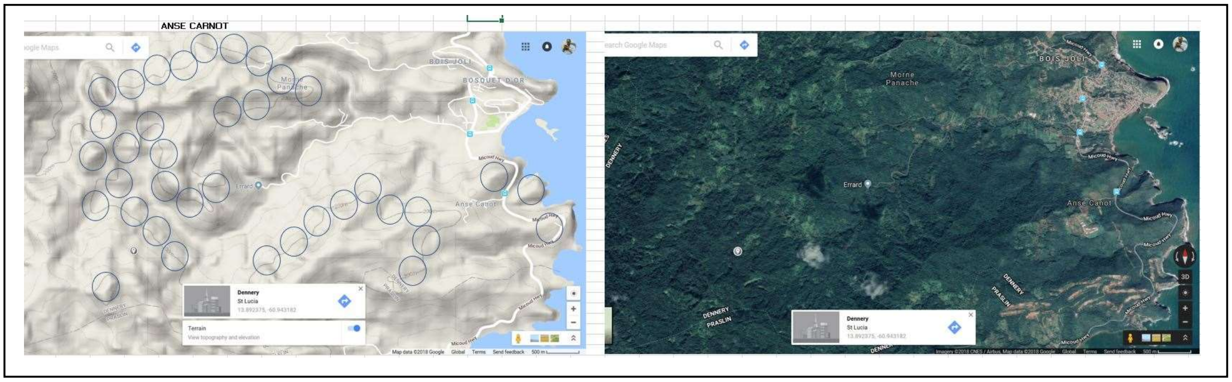


Figure 18 Wind Turbine Visual Siting at Anse Canot Dennery District

Utilising the described methodology, a technical wind potential in the table below has been estimated.

Table 19 Wind Power Potential by Location with 2.3 MW Enercon Wind Turbine

Location	No. of Turbines	Total potential/MW
Dauphin	5	11.5
Dauphin 2	11	25.3
Dauphin 3	8	18.4
Dauphin 4	11	25.3
Dennery	25	57.5
Anse Canot	37	85.1
Rouame	16	36.8
Londonderry	3	6.9
	Total	266.8

Two (2) representative sites, both on the east coast of the island, exposed to the prevailing trade winds and where investments have been made into wind data collection, for the development of wind farm projects, were selected for analysis. 15-minute wind speed data at 10 m height for the Anse Carnot site was generated using Meteonorm® as the data collected for that site by LUCELEC is not publicly available. Hourly data was available at 10 m for the second site, Sugar Mill, located at Rouame in the Micoud district. This data was merged with 15-minute data generated using Meteonorm® for the same site. As a simplification of the modelling, all turbines representing the full estimated wind energy potential are spread evenly between these two (2) sites. This assumption is reasonable as 97% of the estimated 116 turbines, that can be sited on the island, are located at east coast sites with the exception of three (3) located at Londonderry in the southwest district of Laborie. The parameters used for turbine spacing are provided in Table 20. With this data, onshore wind installation density is approximately 1,700 m^2 per MW.

Table 20 Parameters for wind turbine spacing

Parameter	Length in m	Rotor Diameters
Rotor diameter	71	x1
Recommend cross wind spacing	355	x5
Recommended main wind direction spacing	426	x6
Circular boundary used	400	x5.6

4.5.9 Hydropower – Run of River

A technical evaluation of the run-of-river hydropower potential was commissioned by the GIZ CREDP and performed by (Fay & Grett, 2013). In their work, a geographic information systems database, utilising both measured and calculated information, was used to determine hydropower potential for the rivers on the island. The virtual intake on the river, for each of the assessed VPP was located 1 km upstream. Thus, a river can have several potential power plants. The analysis assumed that only 75% of the available river flow was used at any time, in order to preserve the local aquatic eco-systems. Plant efficiency is assumed to be 80%. The installed capacity takes into account discharge with an exceedance probability of 30% minus ecological minimum flow and factors in the head and plant efficiency. The equation used for calculation of hydropower potential is provided in Equation 7:

Equation 7 Equation to calculate hydropower potential

$$P = \left(h_{geo} - h_{loss}\right) * (Q - Q_{eco}) * g * \rho * \eta$$

Where P – Power in watts

h_{geo} – geodetic head between virtual intake and virtual powerhouse (m)

h_{loss} – friction loss from penstock (m)

Q – long-term mean stream flow rate at virtual intake (m^3/s)

Q_{eco} – minimum water flow rate to be maintained in the river for ecological reasons (m^3/s)

g – gravitational constant (9.78 m/s^2)

ρ – density of water (1,000 kg/m^3)

η – plant efficiency (%)

The assumed efficiency was 80% and the friction loss was assumed as 0.5 m per 100 m of penstock length. The hydropower potential for each associated river is provided in Table 21.

Table 21 Hydropower potential as evaluated by CREDP

River	Total Hydropower Potential in kW	Approx. penstock length in km
Grand Rivière du Mabouya	108.9	3
Fond River	203.3	4
Troumassée River	591.3	8
Canelles River	192.5	5
Grand Rivière du Vieux Fort	254.5	6
Piaye River	38.7	1
Dorée River	390.2	6
Soufrière River	234.0	6
Canaries River	200.0	4
Grand Rivière de L'Anse La Raye	23.07	1
Millet River	94.0	3
Ravine Souffre	13.2	1
Total	2343.7	48

The total run of river hydropower potential is, therefore, estimated at 2,344 kW.

4.5.10 Geothermal

Results of a 2015-2016 geological and magneto telluric survey indicated a potential of approximately 30 MW in the exploitable geothermal zones. The steam resource is expected to be between 150°C-300°C. The results of the survey remain confidential; however, the above information was shared to provide reliable basic data for this research. Table 22 provides assumptions used in the geothermal energy calculations.

Table 22 Assumptions used in Geothermal Energy Modelling

Parasitic load	7%
Max output as % of capacity	97%
Min output as % of capacity	20%
Ramp rate	20% of total nominal output per minute
Ramp time	5 minutes

4.5.11 Waste to Energy

There are no large-scale biogas or biomass plants in Saint Lucia. There is also no biomass industry in the country. There is one (1) rum factory which distills product in batches so does not provide a continuous stream of liquid waste for anaerobic digestion. The liquid waste is discharged into the ocean. There is also a brewery which treats its liquid wastes using aerobic processes and a wastewater treatment plant. A sewer system is operational in the city. The untreated liquid waste from the sewer is discharged into the harbour. There is limited information available on these waste streams and they are not analysed in this research.

Along with the annual reports available on the Saint Lucia Solid Waste Management Authority (SLSWMA) website (SLSWMA, 2022), sufficient information was available to estimate the biogas potential of the biological fraction of the municipal solid waste (MSW). Also, based on the historic waste volume trends at the two (2) landfill sites, Vieux Fort and Deglos, it can be inferred that growth, in waste volume, has stagnated over the past five (5) to ten (10) years suggesting that we have reached saturation on the growth S-curve as illustrated in Figure 19. Historic data is provided in the blue section of the curve. Microsoft Excel was used to generate a linear projection from the period 2020 to 2030. The 95% confidence intervals continue to expand indicating lower uncertainty as we project into the future. The projected volume is kept constant between 2030 to 2045. The data is provided in Table 23 and was obtained from (SLSWMA, 2019a, 2019b).

Table 23 Historic and Projected Waste Quantities

	Vieux Fort (VF) Landfill				Deglos Landfill		
	Historic		Projected		Historic		Projected
Year	Qty in tons	Year	Qty in tons	Year	Qty in tons	Year	Qty in tons
2005	22,285	2020	21,793	2005	48,061	2020	57,493
2006	19,301	2021	21,995	2006	53,127	2021	57,493
2007	18,677	2022	22,197	2007	55,609	2022	57,493
2008	18,422	2023	22,400	2008	61,502	2023	57,493
2009	16,937	2024	22,602	2009	61,591	2024	57,493
2010	16,637	2025	22,804	2010	61,839	2025	57,493
2011	18,385	2026	23,006	2011	58,971	2026	57,493
2012	16,084	2027	23,208	2012	47,283	2027	57,493
2013	17,212	2028	23,410	2013	52,743	2028	57,493
2014	20,354	2029	23,612	2014	53,505	2029	57,493

Methodology for design of 100% renewable energy transition pathways to meet SIDS transport and electricity objectives. - Europa-Universität Flensburg

2015	20,227	2030	23,814	2015	51,587	2030	57,493
2016	21,948	2035	23,814	2016	52,254	2035	57,493
2017	21,375	2040	23,814	2017	61,289	2040	57,493
2018	22,256	2045	23,814	2018	51,184	2045	57,493
2019	21,591			2019	58,092		

Municipal Solid Waste anaerobic digestion using a continuous stirred tank reactor (CSTR) digester to produce biogas for electricity production was, therefore, modelled in the research. The maximum historic waste volumes were held constant for the two (2) landfills over the research timeframe. 40% of the waste going into the Vieux Fort landfill and 50% of the waste going into the Deglos landfill in the Castries district

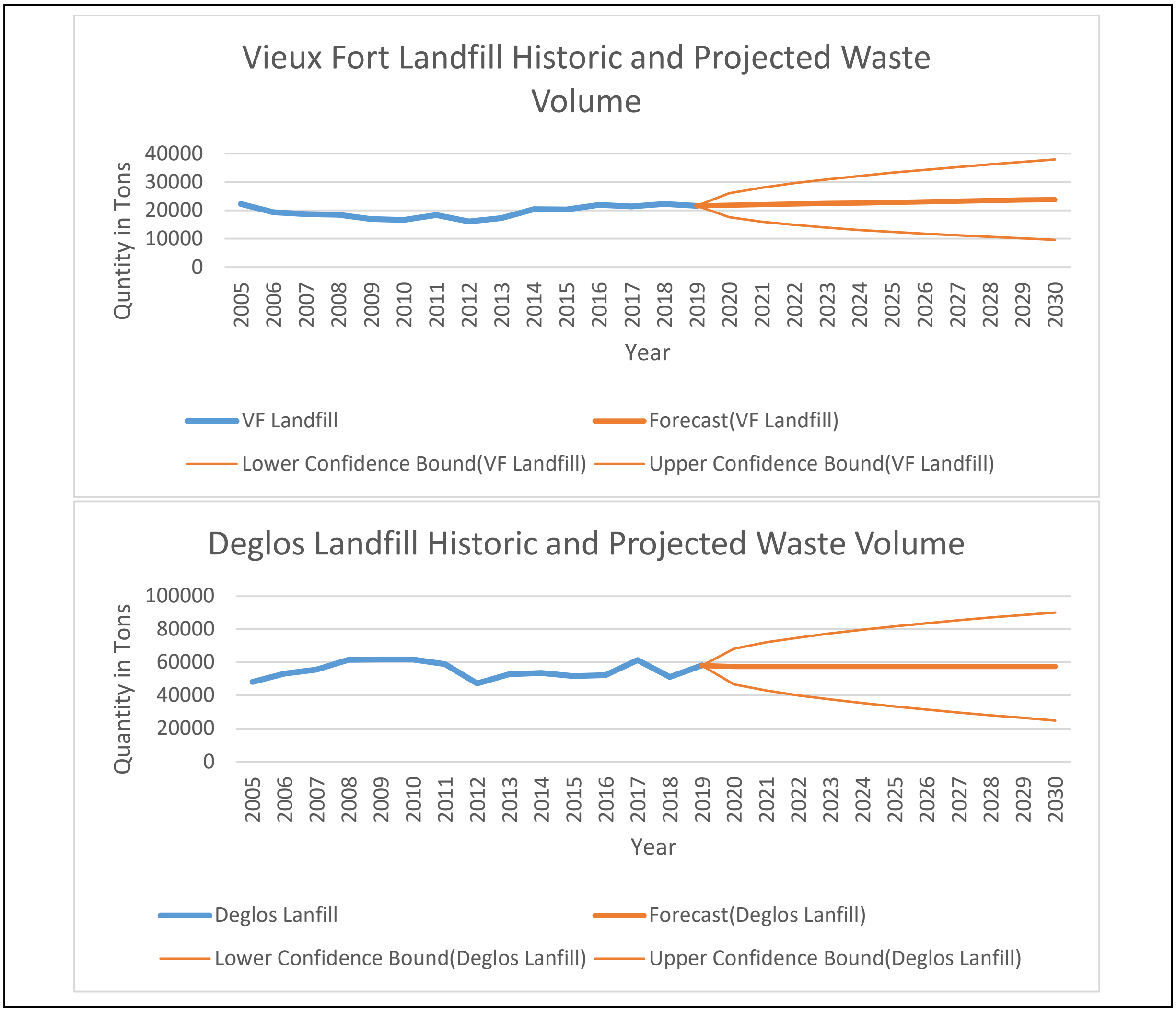


Figure 19 Historic and Projected Waste Volumes at the Two Landfills

are organic materials consisting of food waste, agricultural crop residues and yard waste. Biogas potential based on waste composition data was obtained from (Spurk et al., 2016). The organic waste composition for year 25 is provided in Table 24.

Table 24 Organic waste composition of municipal solid waste in year 25

	Vieux Fort Landfill	Deglos Landfill
Total Solid Waste in kg	21,603,704	52,156,787
% organic fraction	40%	50%
Amount of organics in kg	8,641,481	26,078,394
Breakdown of organics		
Food waste	55%	69%
Agricultural crop residue	9%	7%
Yard waste	36%	24%
Breakdown quantities		
Food waste in kg	4,752,815	17,994,092
Agricultural crop residue in kg	777,733	1,825,488
Yard waste in kg	3,110,933	6,258,814

The biogas potential of the waste is provided in Table 25. The estimated biogas yield is provided in Table 26.

Table 25 Biogas production potential

Waste Type	% Fresh Material (%FM)	Dry Matter content %	Organic DM Content %DM	CH4 Content %	Methane Yield Nl/kg oDM	Specific Biogas Yield Nm^3/t FM
Seasonal fruit Waste in kg	1%	15%	76%	60%	420	80
Bulk green waste in kg	5%	35%	90%	53%	318	189
Organic Household in kg	16%	37%	69%	56%	238.7	107.5

In the table, DM is dry matter, Nl is normal litres, oDM is organic dry matter and FM is fresh material.

Table 26 Estimated biogas yield for year 25

Waste Type	VF Landfill Annual CH4 Yield Nm^3 CH4 per annum	VF Landfill Annual Biogas Yield Nm^3 per annum	Deglos Landfill Annual CH4 Yield Nm^3 CH4 per annum	Deglos Landfill Annual Biogas Yield Nm^3 per annum
Seasonal fruit in kg	228,164	380,273	863,824	1,439,707
Bulk green waste in kg	77,906	146,992	182,859	345,017
Organic household in kg	185,664	334,529	373,532	673,031
Total	491,733	861,793	1,420,216	2,457,755

It was assumed that biogas plants can be constructed at or near the landfill sites to process the sorted biological fraction of the waste destined for the landfill. Waste sorting facilities would be required to facilitate this. The formulae used for calculating required reactor size and organic loading rate are provided by Equation 8.

Equation 8 Equations for calculating biogas reactor size

$$V = HRT * Q$$

$$OLR = F/V$$

Where V – Reactor volume in m^3

Q – Daily substrate volume in m^3 per day

OLR – Organic loading rate in kg of organic dry matter (volatile solids) per m^3 per day

F – Organic feed rate per day in kg organic dry matter per day

A CSTR digester, with design organic loading rate of 2.5kg organic dry matter (volatile solids) per m^3 per day, was selected as this technology is suited to co-digestion of household and commercial mixed waste (Labatut & Pronto, 2018). 10% was added to calculated reactor volume for accommodation of some biogas storage. Using the data at Table 25 and Table 26 a maximum reactor volume of 1,907 m^3 for Vieux Fort landfill and 5,110 m^3 for the Deglos landfill were calculated.

A combined heat and power generator set was assumed with electrical self-consumption by the biogas plant of 9.3% (Zepter et al., 2021). The reactor is assumed to operate at mesophilic temperatures with a hydraulic retention time of up to 40 days. The estimated maximum biogas electricity potential from MSW for the Vieux Fort landfill is 207 kW and for the Deglos landfill is 589 kW using an electricity generation efficiency of 35% (Biogas World, 2022). Specifications for a 200 kW biogas generator model KE-MBG 200-BS from GENTEC (GENTEC, 2022) was selected for simulating power output in modeling.

4.6 Demand Side Management

4.6.1 Residential (Domestic) DSM

To model the domestic DSM potential, consumption of suitable loads within domestic dwellings will be deferred for a suitable time period to reduce demand when there is insufficient RE availability. Refrigerators, modelled as the thermal storage, provide a buffer for the short period during which consumption will be deferred. The assumptions provided in Table 27 were used for this evaluation. The estimated annual energy consumption of 583 kWh is similar to the value of 455 kWh obtained for an Energy Star rated 18.3 cubic feet Top Freezer Whirlpool refrigerator (Energy Star, 2022). As the available data is for conditions in the United States, where average ambient temperatures are lower, a slightly higher consumption is assumed for Saint Lucia. Only domestic customers are included in the refrigerator DSM analysis since hotel and commercial customers would have more stringent requirements for maintaining refrigerator temperatures and would be less likely to participate due to perceived higher risks. Consequently, the highest potential deferrable load is estimated 4,813 kW for 72,272 domestic customers.

Available refrigerators are turned on or off by the aggregator, as an aggregated group, for a maximum of fifteen (15) minutes when there is insufficient RE generation to meet demand. In actual implementation, only refrigerators that have achieved the set point temperature would be turned off, however, the analysis assumes that all refrigerators are available for switching off when demand is greater than available RE supply.

Table 27 Assumptions for DSM Analysis

Average load of refrigerator - kW	0.148
Voltage - V	230
Load factor	45%
Annual consumption - kWh	583
Maximum load delay - h	0.25

4.6.2 Water Sector Demand Side Management

An evaluation using the available WASCO storage reservoir water, to offset water pumping demand, was undertaken. It is assumed that demand can be satisfied either by pumping from the water purification plant or by gravity discharge from the water storage reservoirs. The analysis applies only to the volume of water in reservoirs and the pumps associated with those reservoirs (or that service the same areas as the reservoirs). The data in Table 28 was obtained from WASCO and used in the analysis. Pumps are switched on when the available RE exceeds demand. Reservoirs are discharged as required to meet water demand.

Table 28 Reservoir Capacities (Source: WASCO)

Reservoir Location	Capacity in Imperial Gallons	Elevation in ft
Morne In-Ground	30,000	700
Morne Fortune	50,000	850
Bocage	500,000	500
Morne Dudon	50,000	700
Entrepot High Level	10,000	372
Rock Hall	100,000	365
Ti Rocher	30,000	800
Grace	300,000	608
Augier	200,000	527
LaTourney - 1	100,000	262
LaTourney - 2	100,000	398
LaTourney - 3	100,000	408
Laborie	100,000	365
Total	1,670,000	
Total in litres	7,591,970	

The maximum energy needed for pumping was also estimated using data obtained from WASCO. Using the rating of a typical water pump used by WASCO of 100 imperial gallons per minute (27.28 m^3/h), an average elevation of 160.7 m (527.3 ft) based on installed storage tanks and an assumed pumping efficiency of 60%, 3,065 kWh is required to fill all the reservoirs over a required time of 11.5 hours. This represents a pumping efficiency of 2477 l/kWh with a baseline maximum required pump power of 265.6 kW. Growth in peak load for the water sector was estimated using water production data (Government, 2022). Cumulative water production was charted for the period 1982 to 2016. The curve obtained was defined by a third order polynomial with R^2 exceeding 0.99. A mean historic growth rate of 0.58% per annum was calculated and used to project the growth in water production over the period of this research as illustrated in Figure 20.

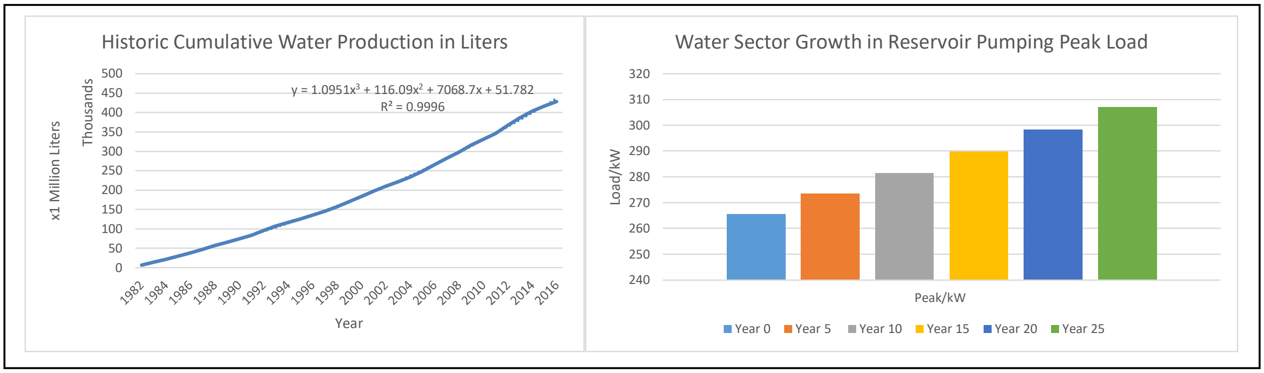


Figure 20 Water sector cumulative production curve and growth in reservoir pumping peak load

The assumed demand profile, for the water sector, follows the electricity system load profile for a day in January 2015 and is illustrated in Figure 21. The overall electricity system load profile is generally driven by air conditioning, lighting and pumping loads derived from a specific dataset (Energy Dynamics Ltd, 2016). Most of the demand is human-driven as there are very few automated industrial processes. Human activity is generally associated with water demand, particularly during the evening peak. The nighttime lower demand is associated with lower human activity, and therefore, lower water consumption. Consequently, the assumed demand curve is considered reasonable in the absence of water sector demand profile data.

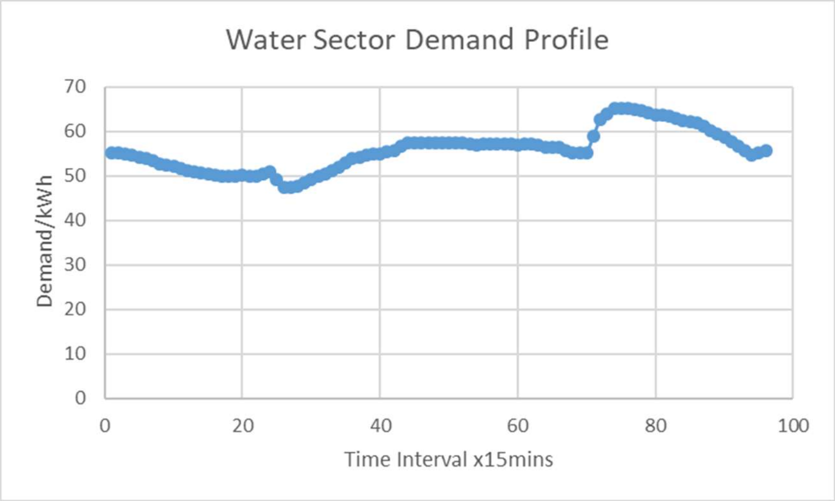


Figure 21 Assumed water sector demand profile

4.6.3 Commercial and Hotel Sector Ice Storage

The ice storage potential of the commercial and hotel sectors is based on the cooling demand. Based on data provided by (Energy Dynamics Ltd, 2016), on average, 48% of demand in buildings is used for cooling. The number of storage tanks required for each substation is estimated by assuming the maximum cooling demand must be provided for one (1) hour.

In year 25, the number of commercial customers is projected at 12,433 and the number of hotel customers at 62. A unit ice storage tank of capacity of 288 kWh thermal is used in both the commercial and hotel sectors with a total capacity of 3,598.56 MWh thermal. This is the second smallest size tank available from the commercial catalogue of one reputable supplier (CALMAC, 2019). The minimum coefficient of performance, i.e., the cooling capacity output in kW thermal to the electric power input in kW, is assumed to be 3.0 assuming air cooled chillers (Yu et al., 2014). This translates into an electrical storage capacity of 96 kWh electrical per storage tank and total storage capacity of 1,199.52 MW electrical. The tanks can be distributed at customer sites with the largest cooling loads. The ice storage capacity for each sector, in kWh electrical, is provided in Table 29.

Table 29 Total ice storage capacity

Sub station	Number of Hotels	Hotel ice storage capacity in kWh_{el}	Number of Commercial Centers	Commercial ice storage capacity in kWh_{el}
Vieux Fort	4	384	1,218	116,928
Soufriere	8	768	452	43,392
Praslin	1	96	243	23,328
Cul de Sac	3	288	1,490	143,040
Castries	3	288	1,085	104,160
Union	2	192	1,057	101,472
Reduit	41	3,936	1,455	139,680
Total	62	5,952	7,000	672,000

As no studies have been done for district cooling in Saint Lucia, this study assumes the use of on-site ice storage tanks only. There are no centralized sources of generation close to verified dense cooling load centers. Additionally, the island is mountainous so issues with topography will increase the challenge in designing and building a district cooling system that will economically service distributed cooling loads.

5 Section 5 Analytical Tools and Model

5.1 Selection of an Energy Model

Several energy models were evaluated in the literature review. Many of the models were built to evaluate large interconnected or small hybrid systems and analyses were done in hourly timesteps. It was not clear at the beginning of the research what elements would need to be modelled in terms of stakeholder inputs or how the inputs would need to be manipulated. Also, to get an insight into the operation of the island system on a sub hourly timeframe, the decision was made to build a model in Microsoft Excel with calculations done in 15-minute time steps. Additionally, a purpose-built model allowed the capability to adapt the model architecture as needed and full flexibility in altering calculation algorithms to suit the SIDS energy system. A Microsoft Excel model was, therefore, built for adaptability and ease of use without restriction of software code in existing models. The modelling calculation steps look fifteen (15) minutes ahead to dispatch energy for supplying demand.

5.1.1 Analysis of stakeholder requirements

The purpose-built energy model was used directly to generate scenarios to analyse the impact of the inputs obtained from the stakeholder survey. The model also provided results that can be compared to the outputs that the stakeholders required in the Delphi survey responses. This allowed a multi-criteria approach to be used for defining stakeholder scenarios and for comparison of the generated scenarios. No additional tools were used to evaluate the impact of the stakeholder feedback.

5.2 Framework and architecture of the custom energy model

The energy model has been developed in two (2) parts. A substation (SS) model was developed to simulate energy flows through each substation. All seven (7) substations are analysed using the same model. The specific parameters for each substation are read by the model when that substation is selected for analysis. This method was chosen to enable solar radiation data to be processed based on geographical location, particularly for distributed solar PV systems. The approach also allows variations in the demand curve, by location, and makes it possible to adjust other inputs to be area-specific, e.g., number of EVs available for charging and providing energy to the electricity network. Each substation contains its own demand curve and other specific inputs such as the number of customers in each sector. Fossil fuel consumption in all sectors, including the transport sector, is also converted into electricity demand for each substation through the SS Model. EV electricity demand is generated and energy efficiency savings, for all sectors, are all calculated in the SS Model. Calculations for each sector are performed on individual tabs called modules.

Demand and DG solar PV generation for all sectors are calculated for each substation in turn. The substations are processed in sequence with distributed solar PV energy that is generated on a particular substation also consumed on that substation and the residual demand and excess energy production from each SS exported and aggregated into the transmission system (TS) model, which is the second part of the energy model. The impact of V2G and localised ice storage are also calculated at the SS model.

In addition to aggregating residual demand from each substation, the TS model is used to introduce transmission level energy storage and generation from wind, hydro, geothermal and biogas sources. The order of energy dispatch can be configured in the TS model. The TS model provides RE generation, storage and DSM services to balance the residual demand aggregated from all the substations with energy supply. Diesel generation is provided in the TS model as this is a centralised source of energy. Though wind energy is supplied at the TS Model, it is generated from two (2) different sites, therefore, two (2) wind calculation modules are used. The outputs from the TS model are analysed using a Microsoft Excel Results model and a Microsoft Excel Financial model. The analysis results are checked against the stakeholder requirements at the end of the modelling process.

Stakeholder inputs are applied at both the SS model and the TS model. The TS model contains individual tabs, called modules, in which calculations are performed for each source of energy supply and storage. All stakeholder inputs are entered in the TS model at the 'Stakeholder Inputs' module. From there, the inputs are copied to the locations where they are used as inputs to relevant calculations. The generation and storage sources are then dispatched on a separate module called 'SS Electricity Demand'. Table 30 provides a list of the modules in each of the models. The architecture of each of the models is described in the following sections.

A conceptual overview of the energy flows in the electricity system SS and TS models is provided in Figure 22. All seven (7) substation calculations are performed in turn and the residual demand after consumption of DG solar energy and any excess solar PV generation are exported to the TS Model. At the TS model, centralised RE, energy storage and diesel generation are used to balance the aggregated residual demand from all substations with energy supply.

Table 30 Summary of SS and TS Model modules

Substation Model		Transmission System Model	
Module	Purpose	Module	Purpose
Solar	Solar profile for each substation	Stakeholder Inputs	Modelling inputs based on stakeholder feedback from Delphi survey questions.
Sector Load Profiles	Load profile for each sector: domestic, commercial, hotel, industrial and street lighting	T.S Cockpit	Calculation parameters for other modules such as wind, biogas, geothermal, DSM, et cetera; sensitivity inputs for RE source and peak load.
Cockpit	Used for selecting the SS to be analysed; contains baseline SS data, PV potential data for each SS, minimum State of Charge (SOC) for EV fleet batteries, average charge power per fleet for each SS.	EE	Energy efficiency inputs for domestic, hotel, commercial and industrial sectors
SS Electricity Inputs	Contains peak load data, HDV and LDV calculation parameters, EV charge connection profiles, ice storage parameters, domestic, industrial and street lighting parameters.	Wind-Anse Canot	Wind farm parameters and energy calculations for Anse Canot wind site.
Ind FF Demand	Calculates industrial sector demand based on demand curve; applies EE savings to	Wind-SM	Wind farm parameters and energy calculations for Sugar Mill wind site.

	industrial sector demand; converts industrial fossil fuel demand to electricity demand and calculates GHG emissions savings.		
Commercial FF	Calculates commercial sector demand based on demand curve; applies EE savings to commercial sector demand; converts commercial fossil fuel demand to electricity demand and calculates GHG emissions savings.	Solar	Aggregation of excess DG solar generation from all substations and calculation of utility solar PV output.
Comm Ice DEM	Calculates ice storage and discharge energy; calculates DG solar PV generation and consumption in the commercial sector.	Biogas	Calculation of biogas production and electricity generation from two (2) landfill sites.
Hotel FF	Calculates hotel sector demand based on demand curve; applies EE savings to hotel sector demand; converts hotel fossil fuel demand to electricity demand and calculates GHG emissions savings.	Geothermal	Calculation of geothermal energy generation.
Hotel Ice DEM	Calculates ice storage and discharge energy; calculates DG solar PV generation and consumption in the hotel sector.	Hydro	Calculation of run-of-river hydro power generation.
FF Dem Dom	Calculates domestic sector demand based on demand curve; applies EE savings to domestic sector demand; converts domestic fossil fuel demand to electricity demand and calculates GHG emissions savings.	Diesel Generation	Calculation of central diesel power generation.
DG Dom Dem	Calculates domestic sector solar PV generation (and energy storage) and calculates residual demand after consumption of DG solar PV.	DSM	Calculation parameters for and of DSM energy shifting.
SL Dem	Calculates street lighting energy demand and applies energy efficiency savings to demand.	V2G	Aggregation of EV charging demand and discharging energy supply from all substations and calculation of residual demand after V2G energy supply.
SS Trans FF Inputs	Calculates transport sector fossil fuel demand and converts fossil fuel demand to electricity demand.	Battery Chemical	Calculation of chemical battery energy storage and discharge.
DG Storage HDV EVs Dem	Calculates EV electricity demand, battery average state of charge, V2G discharge energy; and DG solar PV generation for HDV fleet, residual demand after consumption of HDV DG solar PV energy.	Storage_Ice	Aggregation of ice storage demand and discharge supply from all substations.
DG Storage LDV EVs Dem	Calculates EV electricity demand, battery average state of charge, V2G discharge energy; and DG solar PV generation for LDV, residual demand after consumption of LDV DG solar PV energy.	PHS	Calculation of PHS energy storage and discharge.

FF Dem Gen	Calculates projected diesel fuel consumption for electricity generation and associated GHG emissions.	SS Electricity Demand	Demand and supply balancing with dispatch of all sources of energy and storage. Used to set dispatch order.
Results	Calculates residual demand from all modules and aggregates excess DG solar PV generation.	Economic Outputs	Aggregation of fossil fuel consumed and displaced on all substations.
		Diesel Generation (Res Demand)	Calculation of residual demand generation from diesel and biodiesel in years 20 and 25.

The model framework is illustrated in Figure 23. The technical and financial constraints are entered as calculation parameters. Stakeholder inputs are used in calculations at both the TS and SS models. Residual demand, excess DG solar PV, V2G and ice energy are all exported to and aggregated in the TS Model. At the TS Model, demand is matched with supply and the energy balance is exported to the financial model for analysis. The results are also exported to the results model for data analysis. The analysed results are then compared to the stakeholder requirements. Note that the substation and transmission system models illustrated in Figure 22 are integrated into the overall framework at Figure 23. The stakeholder inputs, technical and financial constraints will guide inputs for modelling. Analysis of the modelling outputs from the SS and TS models is done by two (2) other Microsoft Excel workbooks (models), viz., the financial and results models.

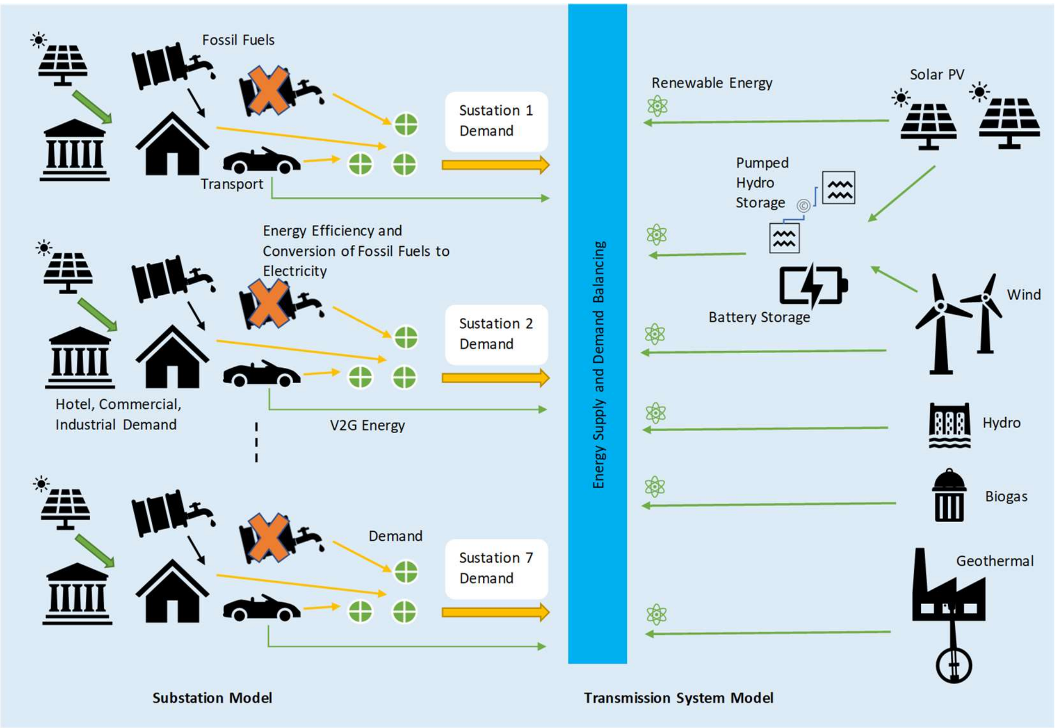


Figure 22 Conceptual overview of electricity system energy flow

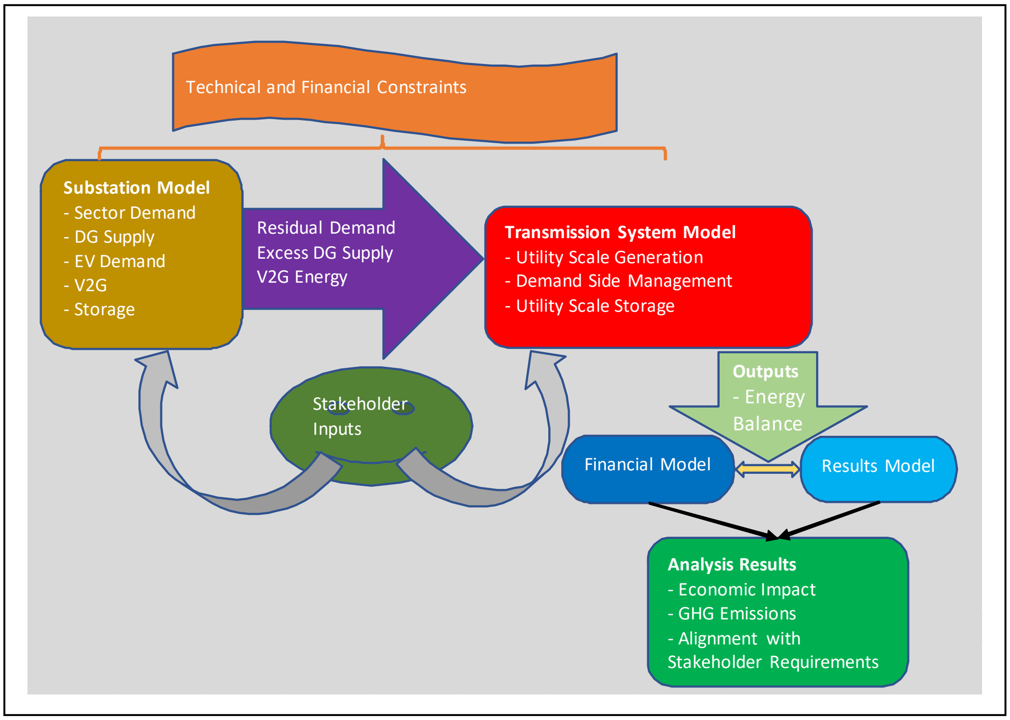


Figure 23 Framework of the Energy Model

5.3 Substation Model

In this research, the substation nodes of the single line system drawing, shown in Figure 6, are modelled to provide information on what happens at the distribution system, assumed to be associated with each substation. The substation is, therefore, assumed to be synonymous with the connected distributed system.

Each of the models is composed of several modules. Each module is dedicated to a specific set of calculations focused on a single calculation subject area. The inputs and analyses are guided by the financial and technical capacity constraints as well as the stakeholder inputs. A flowchart of the calculation methodology of the substation model is provided in Figure 24.

The energy demand for each sector is first calculated using the demand curve and the peak load assumed at the substation. The energy efficiency savings are applied to the calculated demand. Fossil fuel demand is converted to electricity demand based on the target RE penetration for the year under analysis. The total sector demand is then calculated. DG solar PV energy supply by sector on the substation is calculated. This energy is applied to the substation demand then the residual demand and excess energy are calculated. Energy demand for the EV fleet and DG solar PV energy supply associated with the EV fleet are calculated. The EV fleet solar PV supply is applied to the EV fleet energy demand. Residual EV fleet demand and excess solar PV generation are calculated. The total residual demand and total excess PV generation are then calculated. This information is exported to the TS Model to be aggregated.

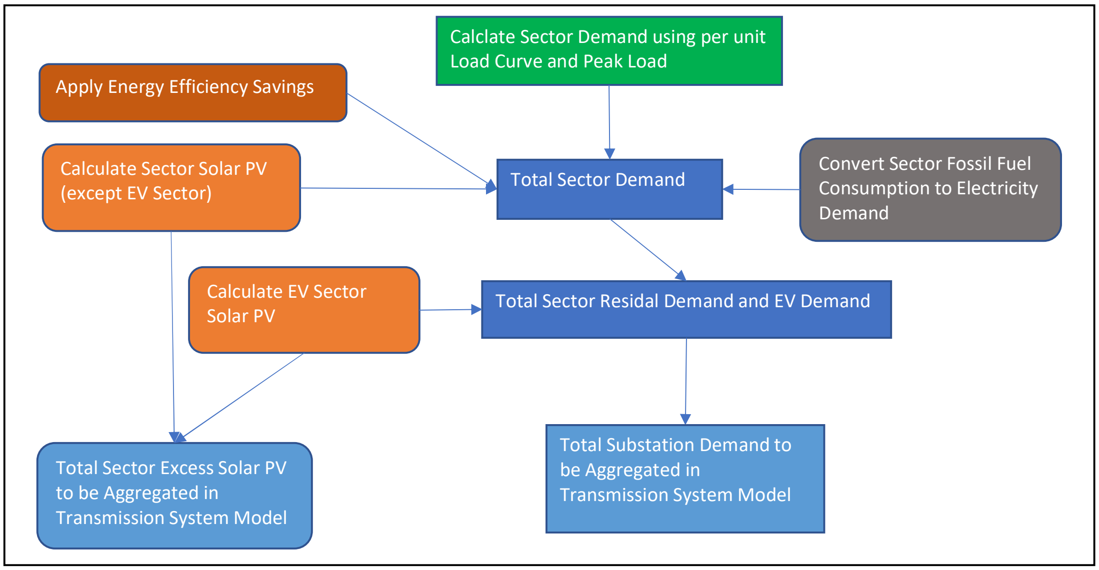


Figure 24 Flow chart of calculations in the Substation Model

5.3.1 Tables in the Excel Model and Key Algorithms

The modules presented in Table 30 are further described in the following sections.

5.3.1.1 Solar

This module contains solar global horizontal irradiation (GHI) for each substation location generated using Meteonorm® software. The data is provided in 15-minute intervals and the module selects data for calculation depending on the substation selected for analysis. GHI is converted to solar energy power and electricity output using the assumptions in Table 31.

Table 31 Assumptions used for calculation of solar PV output

Module efficiency	16%
System efficiency	87%
Module Peak Capacity Wp	315
Module Peak Capacity kWp	0.315
Area Requirement m^2/kWp	5.563
Module Area m^2	1.75
Average module degradation over 25 yrs	7.5%

Equation 9 Calculation of available power per installed kWp of solar PV

$$P = \left(GHI * A * \eta_m * \frac{\eta_{pv}}{m_p} \right) * (1 + SI)$$

$$PVO = P * P_{ins}$$

$$EO = PVO * \left(\frac{15}{60} \right) * M$$

P – Power per installed kWp in kW/kWp

GHI – Global horizontal irradiation in kW/m^2

A – Module area in m^2

η_m – Module efficiency

η_{pv} – PV System efficiency

m_p – Module peak capacity in kWp

SI – Sensitivity Input in %

PVO – PV output power in kW

P_{ins} – Installed PV power in kWp

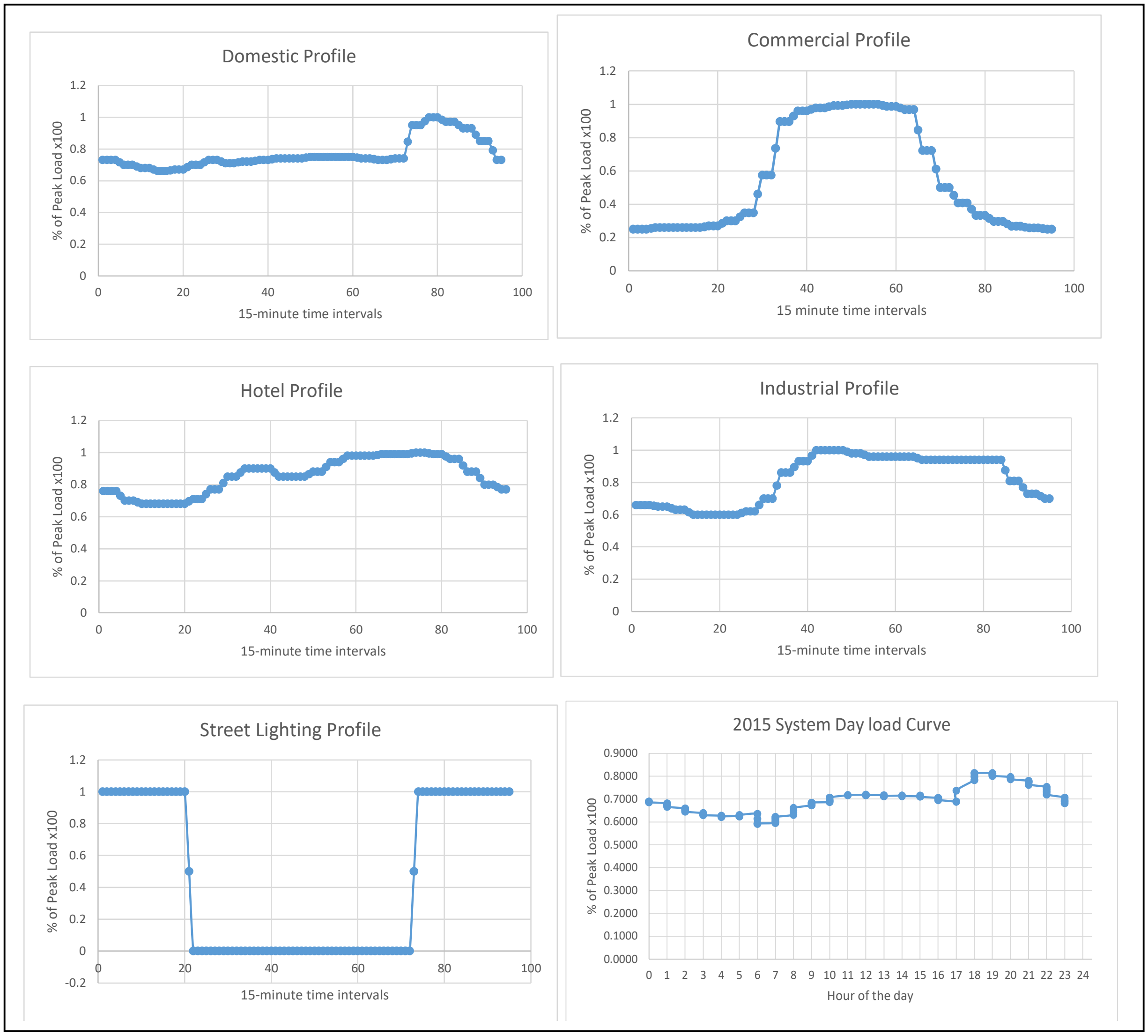
EO – Energy output over a 15-minute interval in kWh

M – Average module output after degradation over 25 years in %

Using the assumptions in the table, a specific output of 1400 - 1500 kWh/kWp is calculated depending on the substation location analysed. The equations used to calculate energy from solar PV are provided in Equation 9. The sensitivity input is used only during the sensitivity analysis. All baseline calculations were set to a zero (0) value.

5.3.1.2 Sector Load Profiles

This module contains 15-minute sector load profiles for each of the consumer sectors, viz., domestic, commercial, hotel, industrial and street lighting. The sector per unit (p.u. or percent of peak load) load profiles and system overall p.u. load profiles are provided in Figure 25. The p.u. values are calculated for each 15-minute interval by dividing the load by the maximum load over the total period. This is a 24-hour profile which is repeated 365 times to get the profile for an entire year for each sector.



Domestic Profile

Commercial Profile

Hotel Profile

Industrial Profile

Street Lighting Profile

2015 System Day load Curve

Figure 25 Sector and system load profiles

The limitation of this method is that the seasonal variations in total system demand are lost. In addition, the weekend load is a fraction of the weekday load. This variation is not captured. To account for this, the model uses an input to manually adjust the peak load, during calibration, to match the historic data from 2015. This setting is kept constant for calculations of projected load.

Using 2016 peak load per substation data, the ratio of substation peak load to total system peak load was established. Projected system peak load calculated using Equation 5 was distributed in proportion to historic (2016) substation loading to estimate projected peak load on each substation. Since a 24-hour load profile was available for each sector, in half hour intervals, the data was interpolated into 15-minute intervals. The 24-hour profile was repeated for 365 days of the year for each sector. The estimated substation peak was then used to scale the year-long sector load profiles for each substation. The scaled sector load profiles were then multiplied by 15/60 hours for each 15-minute interval and aggregated to build the projected overall demand profile for each substation.

5.3.1.3 Cockpit

This module contains inputs used in the calculations of other modules. Table 32 presents the peak load at each substation as a fraction of the system peak load. Substation peak loads do not occur at the same time, so a scaling factor is determined during the model calibration process to ensure that demand calculations are closely aligned with baseline values.

Table 32 SS peak load as percentage of system peak load

Sub stations	SS Peak Load/System Peak Load as %
Vieux Fort	17.4%
Soufriere	6.45%
Praslin	3.46%
Cul de Sac	21.3%
Castries	15.5%
Union	15.1%
Reduit	20.8%

The solar PV potential data at Table 18 is used in the model such that the data for the substation under analysis is referenced in performing calculations.

For calculations of EV energy charging, an initial state of charge is assumed for all EVs being connected to the electricity network. Table 33 provides the initial state of charge which is kept constant for all analyses.

Table 33 Initial state of charge of EVs when connected to the charging network

Initial SOC			
HDV	LDV	LDV	HDV
Solar Following	Solar Following	5.0%	10.0%

For each charging connection profile, the average charge power in kW can be adjusted to match the EV energy demand to the projected fossil fuel energy demand in the transport fleet for a calculation period. An example of charge power for the HDV solar following charge connection profile is provided in Table 34.

Table 34 Charge power in kW for the HDV Solar Following charge profile

Substations	Year 0	Year 5	Year 10	Year 15	Year 20	Year 25
Vieux Fort	0	3.1	2.65	12	2.1	1.85
Soufriere	0	3.1	2.65	12	2.1	1.85
Praslin	0	3.1	2.65	12	2.1	1.85
Cul de Sac	0	3.1	2.65	12	2.1	1.85
Castries	0	3.1	2.65	12	2.1	1.85

Union	0	3.1	2.65	12	2.1	1.85
Reduit	0	3.1	2.65	12	2.1	1.85

5.3.1.4 SS Electricity Inputs

This module contains inputs for calculations to be done on substation supply and demand. It contains tables with the system peak load projections, the fraction of total demand from each sector and the projected demand for each sector in 5-year intervals. Tables of inputs used in calculations on other modules are also included. Several charge connection profiles for EV charging are provided. These will be discussed in the EV module. Table 35 provides the projected demand growth for each sector adapted from the NETS.

Table 35 Projected demand growth from NETS

Projected Demand Growth Rate – NETS						
kWh	Domestic	Commercial	Hotel	Industrial	Street Lighting	Total
2020	124,106,324	138,678,810	86,230,798	19,361,592	11,909,841	380,287,365
2025	134,271,900	150,406,506	95,486,224	20,444,119	13,014,103	413,622,852
2030	145,270,141	163,159,658	108,814,554	21,588,612	14,220,750	453,053,715
2035	157,169,250	177,027,924	112,429,078	22,798,618	15,539,276	484,964,145
2040	167,751,158	189,268,347	123,720,956	23,912,128	16,694,730	521,347,320
2045	178,769,860	202,048,397	132,913,274	25,057,685	17,904,225	556,693,440

The projected growth in peak load from the NETS is provided in Figure 26.

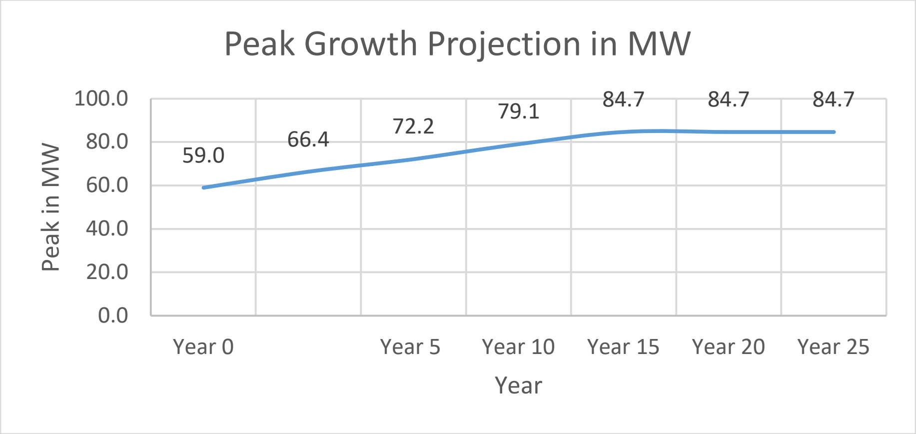


Figure 26 NETS projected load growth

The inputs used for calculations in the HDV and LDV EV are provided in Table 36 and Table 37 below. The minimum SOC for discharge of the HDV was determined by estimating the maximum distance a vehicle may be required to travel in between charge stations. This is assumed to be the distance of approximately 60 km between the seaports, one in the north and the other in the south of the island. The seaports are located in the two (2) major commercial centers, Castries and Vieux-Fort, located on opposite ends of the island. Items delivered at one (1) port sometimes have to be transported, by land, to the commercial center on the other end of the island, so the assumption is reasonable. Assuming an energy consumption of 1.336 kWh/km (2.15 kWh/mile) (Jeffers et al., 2021), the minimum amount of energy required for the journey is 80 kWh. The minimum SOC for V2G energy transfer is therefore set to 60% for the HDV, assuming a 160 kWh battery pack. The SOC on connection or reconnection to the charging network is therefore assumed at 10%.

For the LDV, the maximum distance expected to be travelled between charging is between an EV owner's home and the office. As the highest population density is in the north of the island, a typical route between the capital city of Castries and the suburban town of Gros Islet is considered. The roundtrip distance to be travelled is 30 km. Assuming an EV fuel economy of 0.160 kWh/km (GRENLEC, 2016), the minimum charge required is 5 kWh and the EV battery pack size is set to 62 kWh. A 15% minimum SOC is used in the calculations for the LDV. For V2G, discharge is assumed to be at the same rate as charging. The SOC on connection or reconnection to the charging network is, therefore, assumed at 5%.

Table 36 LDV calculation inputs for Reduit SS scenario C

No. of EVs on Sub Station System	12597	
Average Charge Power (to match demand FF Inputs)	1.6	kW
Initial SOC (to match demand FF Inputs)	5.0%	
Fraction of Fleet participating in V2G	100%	
Discharge rate multiple of charge rate	100%	
EV battery pack size	62	kWh
Min SOC for discharge	15%	
Min SOC for discharge - energy available	9.3	kWh
Electric Vehicle		
Storage Charge Roundtrip Efficiency	80%	
Discharge efficiency	75%	
System Losses	7.52%	
Maximum PV Potential	45	kWp
PV Size - DG Charge Stations	45	kWp
V2G (1=ON; 0=OFF)	0	
Select Charge Profile	LDV Solar	
Sunday load fraction of weekday	70%	
Initial SOC Energy	3.1	kWh
Charge energy	0.32	kWh
Discharge energy	0.32	kWh
Charge limit	99%	

Saturday load fraction of weekday	60%

Table 37 provides inputs for ice storage calculations in the commercial sector.

Table 37 Commercial ice storage calculation inputs Reduit SS scenario C

No. of Ice Tanks on Substation System	32.0	
Stored ice energy (kWh thermal, kWh electrical)	288	96
Charge hours	10	
Charge Power	9.6	kW
Initial SOC	0%	
Min stock fraction connected to network	100%	
Comm Customers Peak Load	6385	kW
Discharge rate multiple of charge rate	100%	
Min SOC for discharge	70%	
Available cooling storage	9216	kWhth
Ice Tanks		
Roundtrip Charge/Discharge efficiency	97%	
SS and sector fraction	12.6%	
Fraction of demand for cooling	48%	
Max cooling load	3065	kW
SS Demand Fraction	21%	
Penetration of Ice Storage	100%	
Maximum PV Potential	1250	kWp
Discharge energy per storage tank	2.4	kWh
Charge energy per storage tank	2.4	kWh
Max SOC for additional charging	99%	
Maximum unit charge energy	76.8	kWh
Fraction of total network ice demand	0.61	
Maximum unit discharge energy	76.8	kWh
Applied energy efficiency	19.86%	
System Losses	7.52%	
COP - Minimum	3	

Table 38 provides inputs for ice storage calculation inputs in the hotel sector.

Table 38 Hotel sector ice storage calculation inputs Reduit SS scenario C

No. of Ice Tanks on Sub Station System	21.0	
Stored ice energy (kWh thermal, kWhelec)	288	96
Charge hours	8	
Charge Power	12.0	kW

Initial SOC	0%	
Min stock fraction connected to network	100%	
Hotel Customers Peak Load	4118	kW
Discharge rate multiple of charge rate	100%	
Min SOC for discharge	70%	
Available cooling storage	6048	kWhth
Ice Tanks		
Roundtrip Charge/Discharge efficiency	97%	
SS and sector fraction	8.1%	
Fraction of demand for cooling	48%	
Max cooling load	1977	kW
SS Demand Fraction	21%	
Penetration of Ice Storage	100%	
Maximum PV Potential	7294	kWp
Discharge energy per storage tank	3	kWh
Charge energy per storage tank	3	kWh
Max SOC for additional charging	99%	
Maximum unit charge energy	63	kWh
Fraction of total network ice demand	0.39	
Maximum unit discharge energy	63.0	kWh
Applied energy efficiency	23.09%	
System Losses	7.52%	
COP - Minimum	3	

Table 39 provides inputs used for calculations in the domestic sector.

Table 39 Domestic sector calculation inputs Reduit SS scenario C

No. of Domestic PV Systems	1552	
Charge Power	0.0	kW
Initial SOC	1%	
Min stock fraction connected to network	100%	
Domestic Peak Load	5680	kW
Discharge rate multiple of charge rate	75%	
Domestic battery storage size	0	kWh
Min SOC for discharge	80%	
Charge Energy	0	kWh
Battery storage systems		
Roundtrip Charge Discharge efficiency	80%	
Discharge efficiency	97%	
Discharge energy	0	kWh
Unit Domestic PV Size	1.5	kWp
PV Size - Dom Charge Stations	2328	kWp

SS Demand Fraction	21%	
Penetration Domestic PV Systems	100%	
Max SOC for additional charging	0.0	kWh
Applied energy efficiency	22.66%	

In the LDV, HDV EV, hotel and commercial ice storage and domestic sector input tables, the parameters are varied depending on the substation and year under analysis. An energy efficiency savings of 55% is applied to the street lighting sector.

Equation 10 Formula for sector demand calculation

$$D = PL * p.u. * t - EES + Fe$$

D - Demand in kWh

PL – Peak load in kW

p.u. – per unit load (fraction of peak load in kW/kW)

t – time in hours

EES – Energy efficiency savings in kWh

Fe – sector fossil fuel demand converted to electrical demand in kWh

5.3.1.5 Industrial FF, Commercial FF, Hotel FF, FF Dem Dom

In these modules, the demand is first calculated using the peak load of the sector and the load profile. The fraction of demand from fossil fuels converted to electrical energy demand for the sector is calculated and the energy efficiency savings are applied for the year being analysed. The formula for demand calculation is provided in Equation 10.

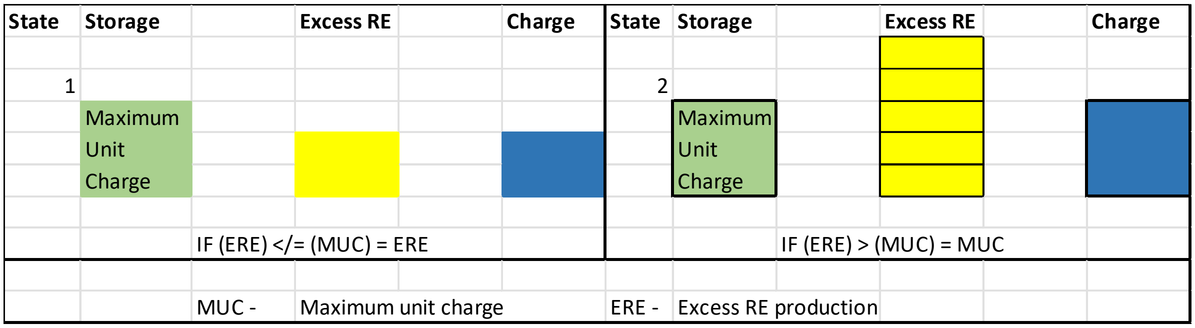
To convert fossil fuel to electrical energy demand, the fossil fuel demand for each substation and sector is first projected. The fraction of the fossil fuel demand that is to be converted to electrical energy is then calculated. Using the lower heating value (LHV) and the density, the fossil fuel volume to be converted to electricity is converted to an energy equivalent in kilo Joules. This is then converted to energy in kilowatt hour thermal. The thermal energy is converted to electric energy in kilowatt hours at a 100% conversion rate from thermal to electrical energy.

5.3.1.6 Commercial Ice Demand, Hotel Ice Demand

The demand from the commercial and hotel sectors is offset using the solar PV generation available for each sector. The modules calculate the conversion of excess RE into ice storage in tanks located at the commercial centres and hotels. The ice is used to service air conditioning load when there is residual demand on the transmission system after dispatch of cheaper sources of supply and storage. The roundtrip efficiency for ice storage and discharge was set at 97%. The primary charge and discharge algorithms used in these modules are provided in Algorithm 1.

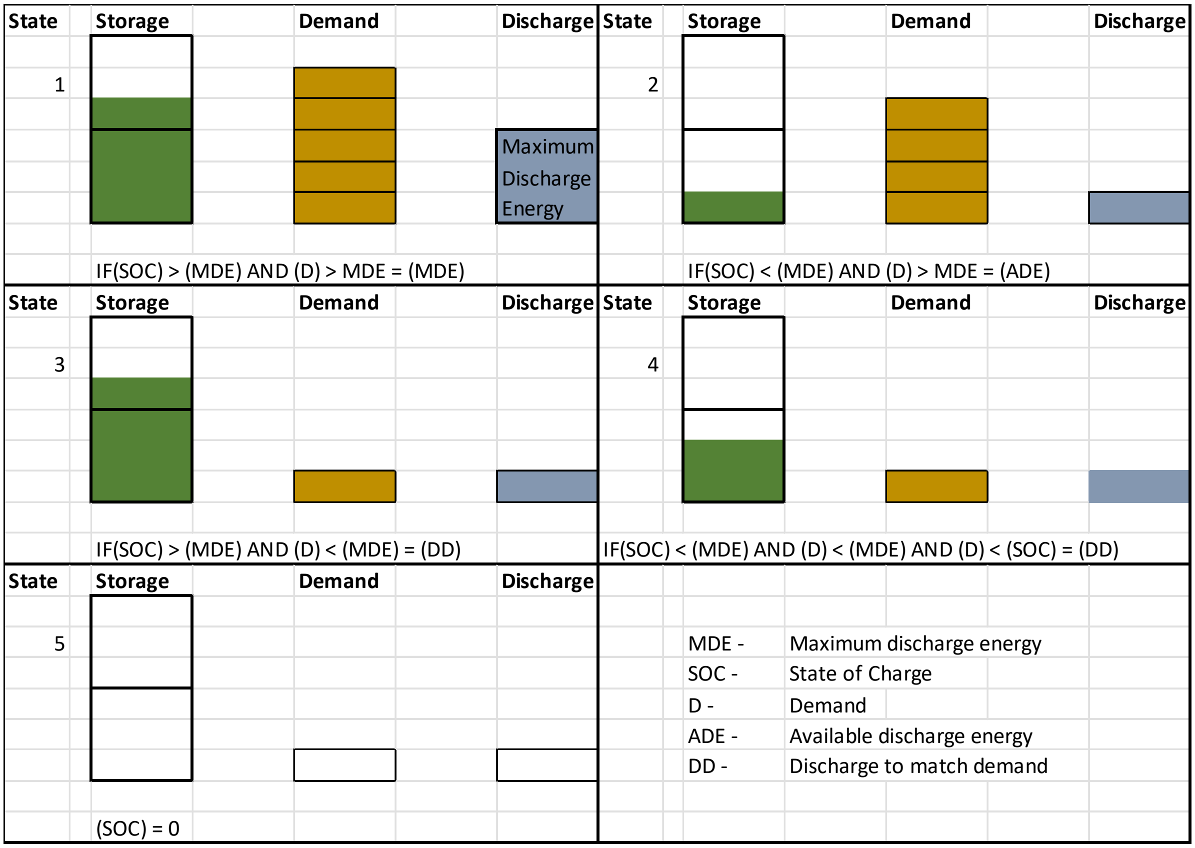
Charging

The algorithm accounts for two potential states that allow charging of the ice storage.



Discharging

The algorithm accounts for five potential states for discharging of the ice storage system.



Algorithm 1 Ice storage charge and discharge algorithm

5.3.1.7 DG Domestic Demand

In this module, demand from the domestic sector is offset by solar PV generation available in that sector. The residual demand after consumption of domestic sector solar PV is calculated then aggregated with residual demand from other sectors for export to the TS Model. Though the model can calculate domestic energy storage, this feature was not used.

5.3.1.8 SL Demand

This module calculates projected demand from the street lighting sector and applies savings from energy-efficient lighting. An energy efficiency savings of 55% over the baseline projected demand is assumed. Streetlights are assumed to be on between 0600 hrs. and 1800 hrs. every day.

5.3.1.9 SS Transport FF Inputs

This module is used to convert fossil fuel use in the transport sector to electricity consumption based on the fraction of the fleet that has been converted to EVs for the period under analysis. In the calculations, the fuel economy for a Nissan Leaf in the neighboring island of Grenada was used to convert fuel to electricity consumption in the LDV. Data from Grenada was selected as the terrain is similar to Saint Lucia and published information was available. The Grenada Electricity Services Ltd. (GRENLEC) performed a study of 2 Nissan Leaf vehicles and published a real world energy efficiency of 100 MPGe (miles per gallon equivalent) or 3.88 miles per kWh which converts to 0.160 kWh/km (GRENLEC, 2016). Similarly, published data for the Proterra electric bus was used to make conversions in the HDV. The published fuel economy in real world conditions was 1.34 kWh/km (Prohaska et al., 2016). Table 40 summarise the fuel economy numbers assumed for the existing vehicle fleet.

Table 40 Assumed average LDV and HDV fuel economy

Average LDV fuel economy	
mpg	25
l/100 km	9.41
Average HDV fuel economy	
mpg	4
l/100 km	58.80

The fuel consumption for the transport sector was first projected. The amount of fuel used by the fraction of the fleet being converted to EVs was then estimated. This information was used along with the fleet fuel economy to estimate the distance driven by the fleet for the year under analysis. The distance estimate was then used along with the assumed e-vehicle fuel economy for the EV fleet to estimate the electrical energy that would be consumed by the EV fleet. This projected consumption estimate was compared with the EV fleet demand calculated in the ‘DG Storage HDV EVs Dem’ and ‘DG Storage LDV EVs Dem’ modules to ensure the estimated demand was within +/- 10% of the projected demand for the HDV and LDV.

5.3.1.10 DG Storage HDV EVs Demand and DG Storage LDV EVs Demand

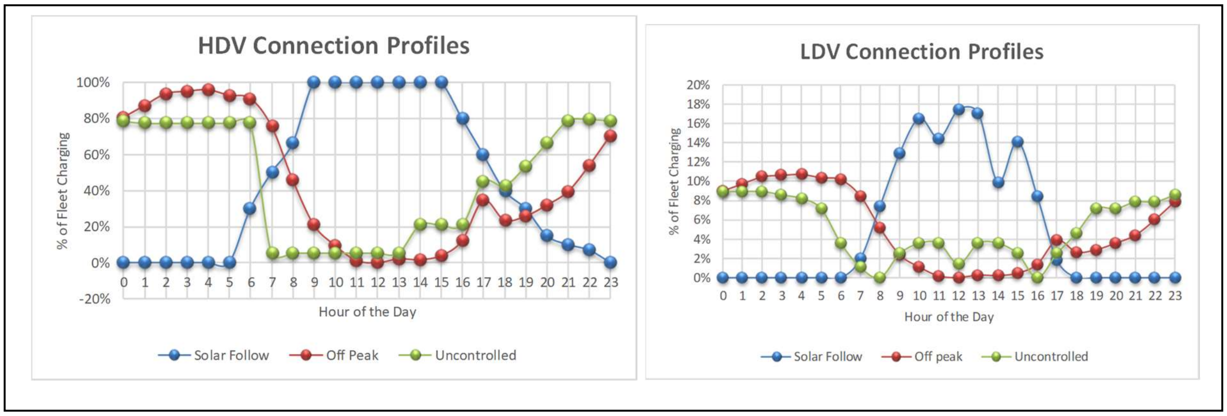


Figure 27 HDV and LDV EV charging connection profiles

These modules are used to calculate demand from EVs and energy supply from available EV batteries to the grid via V2G. Several EV charging connection profiles (CCPs) are available to select from at the 'SS Electricity Inputs' module. The profiles are provided as a percentage of the total fleet connected to the charging network at every hour of the day. All CCPs represent the same amount of charge energy over a 24-hour period. The CCPs are provided in Figure 27 and an explanation of how each was derived follows.

The solar CCP attempts to match the availability of solar radiation during daylight hours. The off-peak CCP concentrates charging during the night periods between the hours of 22:00 hrs. and 08:00 hrs. when demand is normally lowest.

The uncontrolled profile tries to match connection of the fleet to charge points at the bus terminals or at the bus and car owner's home station when the buses and cars are parked. The uncontrolled charge profile follows the trend that would be expected for connection of the fleets if there are no restrictions placed on charging. Since the LDV is expected to be parked for most of the day, charging is expected to take place during daytime hours. The HDV is expected to be in operation during daytime hours, so most charging is expected to take place at nights. All CCPs were manually generated.

For both the HDV and LDV, the product of charge hours by the percentage of vehicles connected for charging was kept the same for all CCPs ensuring that all profiles result in the same amount of charge energy consumed over a 24-hour period. This product is multiplied by the fleet size assigned to the substation being evaluated and the average fleet charge power to determine the amount of energy used for charging. The annual total EV charge energy demand was matched with the projected annual total fleet fossil fuel demand by adjusting the average fleet charge power to ensure that they were reasonably equivalent, i.e., that the two (2) amounts agreed to +/- 10% of each other.

The CCPs are repeated in 5-day cycles to cover the weekdays. On Saturdays, the profiles and, consequently, amount of energy needed for transport are scaled down by 25%. Similarly, the profiles are scaled down by 40% on Sundays to represent the lowest expected consumption for the week. The weekday and weekend profiles are repeated every week throughout the year to calculate the projected electrified transport electricity demand.

```
Calculation of charge energy
IF: SOC < MSOC, AND
IF: NC = 1, THEN
MCE, ELSE,
Set to 0.
Calculation of battery state of charge after charging
IF: SOC < MSOC, AND
IF: NC = 1, AND
IF: CSOC >= 0, AND
IF: CSOC < MSOC - MCE, AND,
IF: NEVPH >= NEVCH, THEN
SUM: CSOC + MCE, ELSE
IF: NEVPH < NEVCH, THEN
SUM: (APSOC + NCSOC) + MCE
```

Where: SOC – State of charge

MSOC – Maximum state of charge

NC = 1 – Connected to the network and available to charge

MCE – Maximum charge energy

CSOC – Current state of charge

NEVPH – Number of EVs in previous quarter hour

NEVCH – Number of EVs in current quarter hour

APSOC – Proportion of EVs from previous quarter hour multiplied by average previous quarter hour state of charge

NCSOC – Proportion of newly connected EVs multiplied by the assumed average state of charge of EVs on connection to the network

Algorithm 2 Charging of EVs as an aggregated fleet

The algorithm used for determining when to charge EVs as an aggregated fleet is provided in Algorithm 2. Storage charge efficiency was set at 80% (Brooks & IEEE, 2021). The amount of energy entering the battery packs at charging depends on the average charging power.

The algorithm for V2G discharging of the aggregated fleet connected to the network is provided in Algorithm 3. Discharging is permitted only if the average state of charge of the fleet batteries is greater than 60% for the HDV and 15% for the LDV and there is residual demand in the transmission system model. Consequently, V2G is not allowed if the battery state of charge falls below these values.

```
IF: SOC > mDSOC
IF: SSD < UDE, THEN
DISCHARGE: SSDpEV, ELSE,
IF: SSD > UDE, THEN
DISCHARGE: UDE, ELSE
SET to 0
```

Where: SOC – Current state of charge
mDSOC – Minimum state of charge to allow discharging
SSD – Substation demand per EV
UDE – Maximum unit EV discharge energy
SSDpEV – Substation demand per EV

Algorithm 3 Discharging of EVs as an aggregated fleet

This ensures there is always sufficient battery capacity to undertake a typical vehicle journey.

The discharge rate from the aggregated batteries is set to 25% of the charge rate for the HDV and 50% of the charge rate for the LDV. (Shirazi & Sachs, 2018) provided a V2G roundtrip efficiency range of 53% to 62%. Assuming a roundtrip efficiency of 60%, discharge efficiency was set at 75% (see Table 36 and Table 36).

Solar PV generation associated with the EV fleets is utilised to offset charging demand. The residual demand is aggregated with the other substation sectors residual demand and exported to the TS model.

In running the modelled scenarios, care was taken to ensure that the EV energy demand matched to +/-10% the projected fossil fuel demand for each year and substation with and without V2G. Each substation was run in sequence to ensure that residuals were calculated for aggregation into the 'TS Model Master'. Once all substations were calculated, the energy balancing was done in the 'TS Model Master'. The average fleet charge power was adjusted to ensure that total EV demand was equivalent to the sum of

V2G energy and transport sector demand keeping the amount of energy left unutilised in the EV fleet batteries to a minimum.

5.3.1.11 FF Demand Generation

This module calculates BAU electricity and fossil fuel consumption for the selected substation. An average diesel generator fuel efficiency of 4.28 litres per kWh, based on data available from LUCELEC's annual reports, was used to convert the projected electricity demand to fuel consumption. From this information, the amount of fossil fuel savings and GHG emissions avoided was calculated for each year analysed.

5.3.1.12 Results

In the results module, residual demand and excess solar PV supply from all sectors are aggregated for export to the transmission system model. Each substation must be calculated so that the residual values are aggregated for entry into the transmission system model. The substation selection for calculation is done at module 'Cockpit' cell 'E2'. Microsoft Excel is set to ten (10) 'iterative calculations' with maximum change of '100'.

5.4 Transmission System Model

In this model, generation sources connected at the transmission level are dispatched to serve residual demand aggregated from the substations. Any excess solar PV from distributed generation on the substations is also dispatched at the transmission system level. A flowchart of the calculation methodology of the TS model is provided in Figure 28.

Stakeholder inputs and calculation parameters are entered into the model. These inputs and parameters are used to set the constraints for calculation of RE output from the various sources such as geothermal, biogas and wind. The sources of energy are used to satisfy the aggregated residual demand from the various sectors in all the substations. Excess generation at different points in time is stored in different storage forms. DSM is applied to shift demand as possible from times when demand is greater than supply to the following 15-minute interval if sufficient supply is available. Pumped storage for the water sector is also dispatched when sufficient RE is available.

Demand for EV charging is supplied with the remaining available energy generation. The residual demand after EV charging and from all sectors is then supplied from the various sources of storage. A dispatch order is set in the model for the purpose of calculations. In practice, the order will depend on the marginal cost of supply for the various sources. This information has been provided with the scenario outputs.

V2G is supplied only after the energy needs for terrestrial transport are provided. Biodiesel is then used to satisfy all remaining demand. The model is run iteratively for ten (10) iterations as this has been found to generally result in a stable output. An explanation of the modules is provided in the following sections.

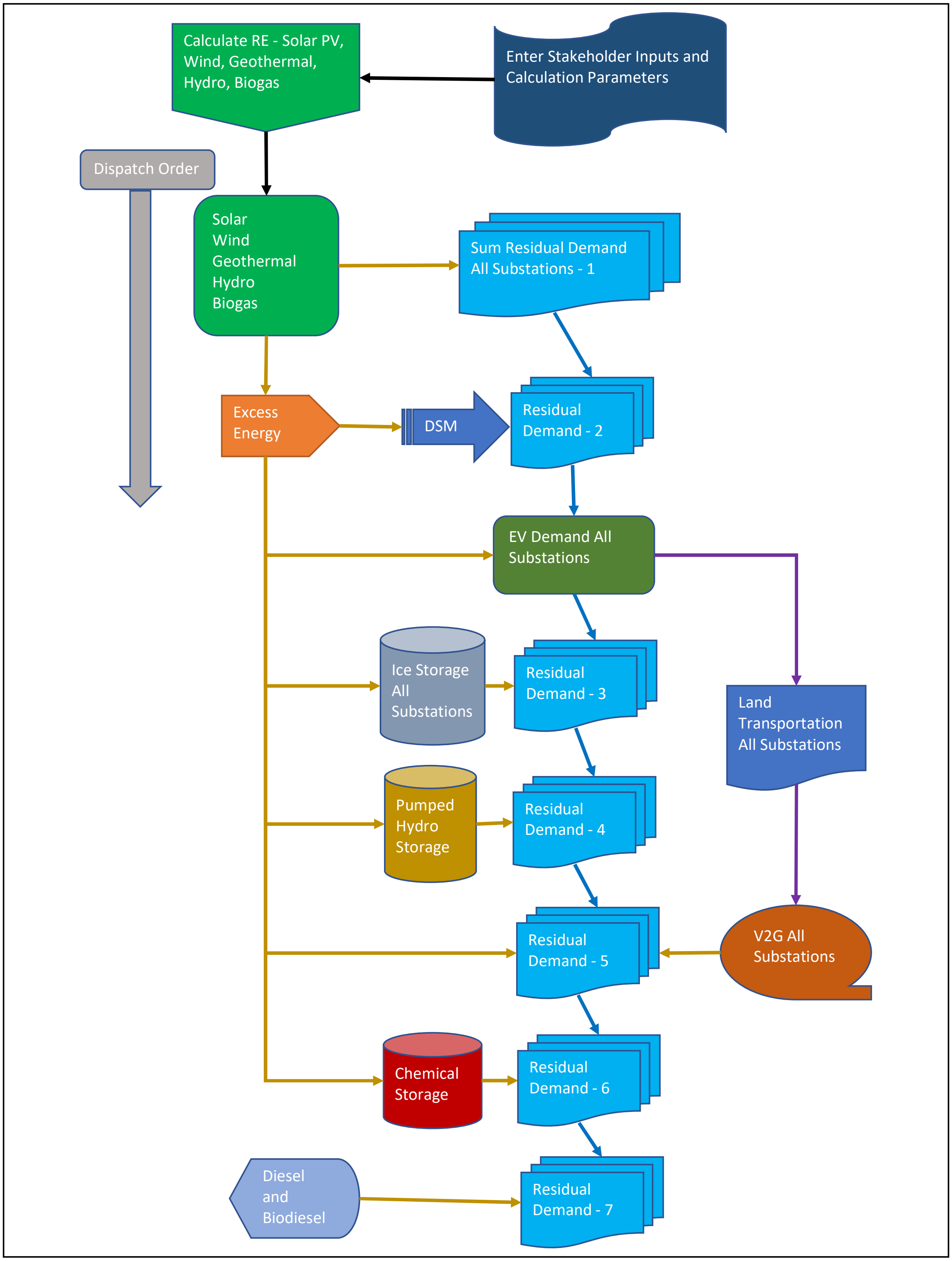


Figure 28 Flow chart of calculations in the transmission system model

Table 41 Table of stakeholder inputs

		Scenario A	Scenario B	Scenario C	Baseline
	Stakeholder Requirements				
S1	Level of domestic energy/import dependence	1 Government target	2 Lower target	3 Higher target	4 NETS
S2	Priority for penetration level RE type	1 Grid connected Distributed Solar with Battery Backup	2 Utility Wind	2 Utility Wind	4 Diesel
S3	Transport Energy Cost	2 Based on RE costs for EVs	2 Based on RE costs for EVs	2 Based on RE costs for EVs	2 Based on RE costs for EVs
S4	Profit Sharing	2 Part of profits kept in the local economy	3 All profits kept in the local economy	2 Part of profits kept in the local economy	2 Part of profits kept in the local economy
S5	Energy Pricing Instruments	1 Ice storage for cooling	1 Ice storage for cooling	2 EV fleet	4 BAU
S6	Energy cost to Consumer	2 Lifecycle cost plus profit margin	2 Lifecycle cost plus profit margin	2 Lifecycle cost plus profit margin	2 Lifecycle cost plus profit margin
S8	EV instruments	1 Immediate ban on ICE imports	1 Immediate ban on ICE imports	1 Immediate ban on ICE imports	4 BAU
S9	RE sources to be excluded	4 All In	2 No geothermal	4 All In	BAU
S10	Democratisation of Energy	5. Government	5. Government	3 Local Investor	5. Government
S11	Selection Options for Conversion Fossil Fuel Demand to Electricity	3 Mandated	3 Mandated	3 Mandated	4 None
S12	Energy Efficiency Policy	1 Target	3 Less	2 More/Maximum	4 NETS
S13	Source of Debt Financing	1 Commercial	2 Development Bank	1 Commercial	2. Development Bank

5.4.1 Tables in the Excel Model and Key Algorithms

Following is a description of the Excel model data and calculations performed.

5.4.1.1 Stakeholder Inputs

This module contains the inputs for the stakeholder generated scenarios. The inputs are aligned with the questions presented in the Delphi survey. The details for each scenario and the baseline BAU scenario will be discussed in the relevant sections of this report. An overview of the stakeholder feedback input table is provided in Table 41. The 5-year interval and scenario for analysis are also selected from the module.

Inputs S7 and S1-2 are not used. Descriptions of the input parameters are provided in Section 6 and Table 66. The baseline scenario inputs are described in Section 6.1.

5.4.1.2 TS Cockpit

In this module, inputs to technical variables used in calculations at other modules are entered. Some of the information provided here include the power capacity and maintenance periods for the geothermal plant, the maximum available capacity for wind and solar energy for the period being analysed and initial fill level for the PHS reservoirs, among others.

The parameters used for calculation of energy from the wind farms for year 25 Scenario C are provided in Table 42. The wind farm size can be set at this interface or it can be set from scenario input S2 in the 'Stakeholder Inputs' module.

Table 42 Wind farm parameters for year 25 scenario C

Wind Power Potential in MW	266.8
No of turbines per farm	49
Total Power on Grid in kW	225,400
Wind farm availability	97%
Downtime days	11

The size of utility solar PV can be set at this module or at input S2 in the 'Stakeholder Inputs' module.

The parameters used for biogas calculations are provided in Table 43. The annual maintenance period for each biogas plant is specified. The fraction of total energy output from each biogas plant is also provided.

Table 43 Biogas parameters

Biogas	VF Landfill	Deglos Landfill	Deglos Fraction	Vieux Fort Fraction
Day of year for start of maintenance	200	80	0.74	0.26
Maintenance period in days	2	2		
Day of year for end of maintenance	202	82		
1-Include/0-Exclude	1			

Table 44 Geothermal plant parameters for year 25 scenario C

Geothermal		Unit 2	Unit 3	Unit 4
Day of year for start of maintenance	50	110	170	230
Maintenance period per unit/days	5			
Day of year for end of maintenance	55	115	175	235
Unit Capacity in MW	7			
Planned Number of Units	4			
Maximum Geothermal in MW	28			
1-Include/0-Exclude	1			
Days between servicing of units	60			

The parameters used for geothermal plant calculations are provided in Table 44. The annual maintenance period is set for five (5) days. The capacity of one (1) generation unit is set to 7 MW. The period between maintenance of the installed four (4) units is 60 days, to ensure that at least three (3) units are always running.

In addition, substations can be excluded from the analysis using an input at this module and the water sector demand curve is also supplied. Sensitivity input for RE resource and peak load are entered via this module.

5.4.1.3 EE (Energy Efficiency)

This module contains energy efficiency tables that are referenced for calculations at the various 5-year time intervals. The tables have been derived as explained at Section 4.4.2.

5.4.1.4 Wind-Anse Canot and Wind-SM

These modules contain the technical inputs and calculations of wind energy for the sites Anse Canot, located in the district of Dennery and Sugar Mill, located in the district of Micoud. The log law, stated at Equation 12, valid to heights up to 100 m, was used for the calculation of wind speeds at the hub height of the selected turbine. A surface roughness length of 0.04 m was selected (Danish Wind Industry Association, 2003).

Equation 12 Log law for calculation of wind speeds at hub height of a turbine

$$u(z)=u(z_r)[\ln(z/z_0)/\ln(z_r/z_0)] \quad \text{for } z>z_0$$

where $u(z)$ is the wind speed at height z,
z_r is a reference height,
z_0 is the surface roughness length

Equation 11 Equation for calculation of wind turbine power

$$P = 0.5\,\rho\,A\,v^3 C_P$$

Where P is Turbine power (watts)

ρ is density of air taken as 1.18 kgm^{-3} at 26°C and one atmosphere of pressure,

A is the rotor swept area, 3959m^2,

v is the wind speed (m/s), and

C_p is the coefficient of performance at the particular wind speed.

C_p and A are provided by the wind turbine manufacturer.

Power from a wind turbine was calculated using Equation 11. The coefficient of performance (Cp) can be defined as the ratio of the mechanical shaft power generated by the wind to the total power available from the kinetic energy of the wind flowing through the turbine swept area (Cui et al., 2014). For simplicity, the gearbox and generator were assumed to operate at efficiencies near 100% so were not factored into the calculations. The total generation from all turbines at a site was estimated by multiplying the power from one (1) turbine by the number of turbines at the site. This method does not account for the diversity in location of the turbines at the sites which may result in a smoother power output from the aggregated farms. For maintenance purposes, the model assumes the downtime days in Table 45 for the two (2) wind farm locations. The assumed downtime days satisfy the industry standard wind farm availability which is usually taken as 97% (Conroy et al., 2011). The estimated capacity factor for the Sugar Mill site is 35% and for the Anse Canot site, 31%. Wind turbine parameters were provided in Section 4.5.8.

Table 45 Downtime schedule for wind farms

AnseCanot		Sugar Mill	
Start Downtime	End Downtime	Start Downtime	End Downtime
80	83	20	23
140	143	60	63
210	213	90	93
310	312	315	317

5.4.1.5 Solar

This module is a clone of the solar module in the SS Model.

5.4.1.6 Biogas

This module estimates biogas production from the organic fraction of municipal solid waste from the two (2) landfill sites, Vieux Fort and Deglos. Waste characterisation information from 2008 was used as the baseline for the calculations. It has been assumed that the organic fraction of the waste stream has not changed and will not change as there are no programmes for recycling or treatment of organic waste streams. It is also assumed that waste sorting will be done at the landfill sites to separate out the organic fraction for anaerobic digestion. The baseline data is provided in Table 46.

Table 46 Organic fraction of MSW for the two landfill sites

	Vieux Fort Landfill	Deglos Landfill
Total Solid Waste/kg	20,131,342	59,057,744
% organic fraction	40%	50%
Amount of organics/kg	8,052,537	29,528,872
breakdown of organics		
Food waste	55%	69%
Agricultural crop residue	9%	7%
Yard waste	36%	24%
Breakdown quantities		
Food waste/kg	4,428,895	20,374,922
Agricultural crop residue/kg	724,728	2,067,021
Yard waste/kg	2,898,913	7,086,929

Table 47 provides methane potentials used to convert the available waste volumes to methane and then biogas volumes.

Table 47 Table for conversion of waste volumes to biogas. Source: (Spurk et al., 2016)

Waste Type	Vieux Fort Landfill Waste for Plant	Deglos Landfill Waste for Plant	% Fresh Material (%FM)	Dry Matter content %	Organic DM Content %DM	CH4 Content %	Methane Yield Nl/kg oDM	Specific Biogas Yield Nm^3/t FM
Seasonal Fruit Waste in kg	3,543,116	16,299,937	1%	15%	76%	60%	420	80
Bulk green waste in kg	579,783	1,653,617	5%	35%	90%	53%	318	189

Organic Household in kg	2,319,131	5,669,543	16%	37%	69%	56%	238.7	107.5

The generated biogas was converted to electricity using a thermal generator with an efficiency of 35%. Biogas storage with maximum capacity of 18,200m^3 is also used to provide a storage buffer when there is no demand.

It is assumed that the Deglos landfill biogas generation plant is offline on day 80 and the Vieux Fort generation plant is offline on day 200 for two (2) consecutive days every year for maintenance purposes. General scheduled maintenance is done every 2,000 to 20,000 operational hours for the CHP unit (Akbulut et al., 2021) and desludging once a year.

5.4.1.7 Geothermal

This module calculates geothermal energy production to follow demand within the range of 70% to 100% of nominal capacity of the geothermal plant. The unit size of a geothermal production module is 7 MW and up to 4 modules can be used. As the normal ramp rate for an Organic Rankine Cycle based geothermal plant can be assumed at 15% of nominal output per minute for dispatch (Matek, 2015; Millstein et al., 2021), the plant is fully ramped to capacity in seven (7) minutes and in flexible operating mode, the ramp rate is 30% of nominal power output per minute. The plant can, therefore, ramp to full capacity in one (1) minute while operating in flexible mode, as assumed in the model. The model runs in 15-minute time intervals so the actual ramping down of the geothermal plant after shutdown or up on startup is not captured in the modeling. Geothermal plants typically have an availability exceeding 98% (Barasa Kabeyi & Olanrewaju, 2022). For maintenance purposes, the model assumes one (1) seven (7) MW unit goes down for maintenance every 60 days for a period of five (5) consecutive days. Each module goes offline for maintenance once annually.

Table 48 provides assumptions used in the geothermal plant calculations. The expected well depth and temperature were obtained (World Bank, 2021). Parasitic load is estimated at 20% of gross power output (Chagnon-Lessard et al., 2020).

Table 48 Assumed operating parameters for Organic Rankine Cycle geothermal power plant

Type of Plant - Binary Organic Rankine Cycle	
Expected well depth/m	2000
Expected temperature/C	260
Nameplate unit installed capacity/MW	28
Parasitic load as % of gross power output	20%
Output to grid/MW	22.4
Max output as % of capacity	100%
Min output as % of capacity	70%
Availability	99.8%

5.4.1.8 Diesel Generation

This module calculates energy production from diesel generators operating between 30% to 94% of their nominal capacity. The peak generation capacity is adjusted based on the residual demand to be satisfied and the allowable fossil fuel generation penetration for the period being evaluated. The generator data obtained (Bodley, 2016) is provided in Table 49. Based on the data, the average maximum output as a percentage of nameplate capacity is 99%. The minimum output, as a percentage of capacity, is assumed to be 20% based on the datasheet for a typical Wärtsilä turbo charged diesel engine (WÄRTSILÄ FINLAND, 2016).

Table 49 LUCELEC generator set specifications

Unit	Year Installed	Nameplate Capacity (MW)	Max Operating Capacity (MW)
G1	1990	6.3	6
G2	1990	6.3	6
G3	1994	7	6.4
G4	1998	9.3	9.3
G5	1998	9.3	9.3
G6	1998	9.3	9.3
G7	2000	9.3	9.3
G8	2007	10.2	10.2
G9	2005	10.2	10.2
G10	2012	10.2	10.2

Generator sets G1 – G3 are assumed to be retired before the start of the transition period. G4 – G6 are retired and replaced in year 10, G7 is retired and replaced in year 15, G9 is retired and replaced in year 20 and G8 in year 20.

5.4.1.9 Demand Side Management (DSM)

In this module the amount of available demand from refrigerators is calculated and shifted from the current time interval to the following 15-minute interval if there is not enough energy available to satisfy demand in the current time interval. Additionally, there must be enough excess energy available in the next 15-minute time interval to cover the demand that is being shifted. The algorithm used is provided in Algorithm 4. The specifications used for evaluating the energy shift are provided in Table 27.

DSM in the water sector involves running the pumps feeding sixteen (16) reservoirs at various locations around the island when there is excess RE available and the reservoirs are not full.

Specifications for estimating energy to fill the reservoirs are provided in Table 50 and data was obtained from (Stantec, 2000).

```
IF: DR > 0, THEN -DR, ELSE
Set to 0, THEN ADD
IF: CD > CE, AND
IF: FE > FD, AND
IF: FE – FD ≤ CM, AND
IF: FE – FD ≤ CD – CE, THEN
FE – FD, ELSE
IF: CD > CE, AND
IF: FE > FD, AND
IF: CD – CE > CM, AND
IF: FE – FD > CM, AND
IF: FE – FD > CD – CE, THEN SET TO
CM, ELSE
Set to 0.
```

Where: DR – Demand reduction in previous quarter hour

CD – Demand in current quarter hour

CE – Energy in the current quarter hour

FE – Energy in the next quarter hour

FD – Demand in the next quarter hour

CM – Shiftable Demand

Algorithm 4 Calculation of shiftable demand from refrigerators in the Domestic sector

Table 50 Pumping energy specifications for DSM

Assumed total pumping capacity (m^3/h)	436
Total time to fill all reservoirs (hrs.)	9.4
Total reservoir volume (m^3)	7264
Average elevation	527.3
Average tank elevation and assumed head (m)	160.7
Assumed pump flow capacity (m^3/h)	27.3
Assumed pump efficiency	70%
Estimated shaft power (kW)	17.1
Max pumping power (kW)	273.1
Energy to fill all reservoirs (kWh)	2560
Pumping efficiency (l/kWh)	2966

```
IF: SL > WD, AND
IF: CD > WD, THEN
WD
IF: SL > WD, AND
IF: CD < WD, THEN
CD
IF: SL < WD, AND
IF: CD > WD, THEN
SL
IF: SL < WD, AND
IF: CD < WD, THEN
CD
```

Where:

SL – Storage level

WD – Water sector demand for the current quarter hour

CD – Current system demand

Algorithm 6 Algorithm for discharge of DSM reservoirs

The reservoirs are discharged when demand is greater than supply to reduce water pumping demand. The algorithm for initiating water pumping is provided in Algorithm 5.

The algorithm for discharging water from the reservoirs is provided in Algorithm 6. It is assumed that the water consumption demand profile is the same as the domestic sector demand profile. This assumption is made as no data is available to determine the water sector demand profile and because most customers are domestic.

5.4.1.10 Vehicle to Grid (V2G)

This module aggregates charge and discharge information for EVs from the various substations and calculates the residual demand and excess energy after V2G. Total EV residual demand is first aggregated from each substation and then available energy on the transmission system is used to supply the demand. The module also aggregates V2G from all substations and applies the available energy against residual demand at the selected position in the dispatch order. V2G discharge is triggered by demand and availability of battery energy as described in Algorithm 3.

5.4.1.11 Battery Chemical

```
IF: EE > CD, AND
IF: SE + EE – CD ≤ MS, THEN
EE – CD, ELSE
IF: EE > CD, AND
IF: SE + EE – CD > MS, THEN
MS - SE, ELSE
0

Where: EE – Excess energy
       CD – Current demand
       SE – Stored energy
       MS – Maximum storage
```

Algorithm 7 Calculation of energy for charging the chemical battery storage

This module calculates battery charging and discharging to shift energy from periods when energy supply exceeds demand to periods when demand exceeds supply. The algorithm that calculates the energy that goes into charging is provided in Algorithm 7.

```
IF: SE + EE – CD/RT ≤ MS, AND
IF: SE + EE – CD/RT > 0, THEN
SE + EE – CD/RT, ELSE
IF: SE + EE – CD/RT ≤ MS, AND
IF: SE + EE – CD/RT < 0, THEN
Set to 0, ELSE
IF: SE + EE – CD/RT > MS, THEN
MS, ELSE
IF: SE + EE – CD/RT ≤ 0, AND
IF: MS ≥ 0, THEN
0
```

Where: EE – Excess energy

CD – Current demand

SE – Stored energy

MS – Maximum storage

RT – Roundtrip efficiency

Algorithm 8 Calculation of energy in storage

The amount of energy in storage during the current quarter hour is calculated with Algorithm 8. In this calculation, the maximum storage potential is set by the user. Charge and discharge efficiencies are also accounted for in the calculations.

The amount of energy discharged from battery storage is calculated using Algorithm 9. The roundtrip efficiency for a lithium-ion battery used in all calculations was 90% (Steilen & Jörissen, 2015). The response time of lithium-ion batteries is in the sub-second time range (Development Bank, 2018) and, for modelling, it is assumed to be instantaneous as the smallest time step is 15-minutes.

5.4.1.12 Hydro

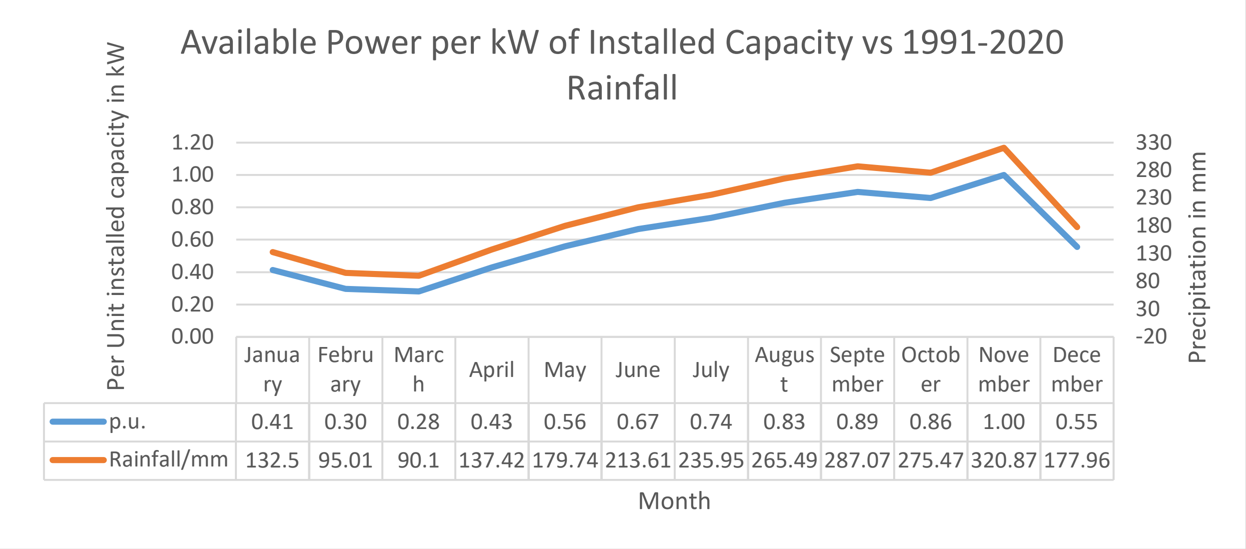
This module calculates energy available from installed run of river hydroelectric power plants. The available generation capacity, relative to installed capacity, is based on the available water flow rate of the rivers. This available capacity is modelled to reflect average annual rainfall variation for the country

for the period 1991-2020 (World Bank, 2022). The estimated capacity factor is 0.63. This is comparable to the capacity factor of 0.67 calculated using data for the installed hydropower plants in Saint Vincent (European Union, 2018), which is located 45 km to the south of Saint Lucia. The available power per installed kW modelled after the average monthly rainfall pattern is shown in

```
IF: PS > CS, AND
IF: PS > CD, THEN
CD, ELSE
IF: PS > CS, AND
IF: PS < CD, THEN
PS, ELSE
0
Where: PS – Previous quarter hour storage
       CS – Current quarter hour storage
       CD – Current demand
```

Algorithm 9 Calculation of energy discharged from battery storage

Figure 29.



Month	January	February	March	April	May	June	July	August	September	October	November	December
p.u.	0.41	0.30	0.28	0.43	0.56	0.67	0.74	0.83	0.89	0.86	1.00	0.55
Rainfall/mm	132.5	95.01	90.1	137.42	179.74	213.61	235.95	265.49	287.07	275.47	320.87	177.96

Figure 29 Available hydropower capacity per installed kW modelled against average rainfall pattern

5.4.1.13 Storage Ice

This module aggregates ice charging and discharging in the commercial and hotel sectors from all substations. The overall impact on the cooling demand is also calculated. The energy for making ice is provided from excess RE in the system based on the dispatch order and demand already served. The ice storage is used to offset air conditioning energy demand.

5.4.1.14 Pumped Hydro Storage (PHS)

This module calculates charge, discharge and storage energy in the PHS reservoirs. The roundtrip efficiency was set to 75% (Yekini Suberu et al., 2014) and the response time is less than a minute (IRENA, 2020), so it is not accounted for in the modeling as the smallest time step is 15-minutes. The algorithms used for filling the reservoirs (charging), calculating the amount of energy in storage and for discharge, are the same as for battery charging, storage and discharge as provided in Algorithm 7, Algorithm 8 and Algorithm 9. The number of pump and turbine starts are also calculated to estimate maintenance costs.

This is done by evaluating when the amount of storage in the reservoir changes. The algorithms used are provided in Algorithm 10.

```
Pump starts
IF: PCE = 0, AND
IF: CCE > 0, THEN
SET to 1 (Count for total)
Turbine starts
IF: PDE = 0, AND
IF: CDE > 0, THEN
SET to 1 (Count for total)
```

Where PCE – Previous quarter hour charge energy
CCE – Current quarter hour charge energy
PDE – Previous quarter hour discharge energy
CDE – Current quarter hour discharge energy

Algorithm 10 Count of turbine and pump starts

5.4.1.15 SS Electricity Demand

In this module, residual demand is aggregated from all substations. All generation sources, from the other modules, are dispatched and excess energy is moved to storage. Each of the storage sources from the other modules, viz., ice storage, V2G, PHS and battery are charged with excess energy and discharged to satisfy residual demand. The DSM module is also applied to reduce the residual demand. Finally, the biodiesel module is used to balance any residual demand remaining after dispatch of all other generation and storage sources. The dispatch order used for calculations is indicated in the module. This dispatch order is fixed for all scenarios.

5.4.1.16 Economic Outputs

This module is used to aggregate fossil fuel consumption and savings from all sectors. Economic calculations are performed in the financial model using data referenced from this and other modules.

5.5 Financial Model

This model calculates financial parameters for all investments in energy production and storage. Tariffs for the different energy and storage sources are calculated based on the stakeholder provided inputs and investment financial data. Details of the inputs modelled for each module in the model follow. Costs of transportation and taxes, for all infrastructure investments and grid connections, were included in the model. Costs have been adjusted for inflation during the transition period modelled. Calculations are done in 5-year intervals and values generally kept constant in the intervening 4-year period.

The cost of decommissioning or retooling of the energy assets is not considered in the analysis. This cost can be accounted for by setting aside a portion of annual profits for this purpose. 10-year linear depreciation is used in all calculations.

The corporate tax rate for all investments is 33% of profits. External debt interest payments are assumed to be made when debt is financed by international development banks. Profits are assumed to be repatriated as dividend payments to equity investors, even when they are local as re-investment in the country is not guaranteed. Value Added Tax (VAT) is collected on all RE sales at the point of generation. To keep tariffs as low as possible, and for research purposes, it is assumed that additional VAT is not collected on the energy component of the sale price of stored energy. VAT is paid on the operation and maintenance (O&M) cost components.

Table 51 Equity and debt rate assumptions

Source of Equity	Source of Debt	Interest rate/Required return	Term in years
Government		5%	
Local Investor		13%	
	Development Bank	4.5%	15
	Commercial Bank	8%	10
	Commercial Bank - EVs	5.5%	10

Table 51 provides assumptions on debt interest rates and required return on equity. The required return for Government equity was set to be marginally higher, at 5%, than the interest rate for lending from a Development Bank assumed at 4.5%. It is expected that Government would source equity funds through Development Bank loans. The required return on equity for local investors is set marginally higher, at 13%, than the average return on equity of 12.7% estimated for LUCELEC based on data available in their annual reports. The higher return is to attract investment in the RE sector over the fossil fuel sector. The bank interest rates are based on current prevailing rates available at local commercial banks and regional development banks.

5.5.1 Tables in the Excel Model and Key Algorithms

Following is a description of the Excel model data and calculations performed.

5.5.1.1 Utility Fixed Costs

It is assumed that all utility fossil fuel generation assets are paid off by the end of 2023. Consequently, the only LUCELEC fixed costs included in tariff estimates are for transmission, distribution and administration.

5.5.1.2 Source of Financing

The basic country-specific financial parameters are entered in this module. Table 52 provides the relevant summary.

Table 52 Basic financial inputs for calculations specific to Saint Lucia

Annual inflation rate (average 2010 to 2020)	1.1%
Customs and brokerage as % of CAPEX	6.0%
Import taxes for RE	0.0%
VAT	12.5%
Insurance rate as % of CAPEX	0.3%
Discount rate	12.7%
Import taxes for EVs	5.0%
Discount rate for EVs - bank loan rate	3.8%
Discount for DSM energy pricing policy option	10.0%
Profit on fossil fuel generation (Markup)	18.0%
Consumer price index - Energy commodities May 2022	4.5%

The assumed annual inflation rate is the average from 2010 to 2020 (International Monetary Fund, 2022). Customs and brokerage, import taxes and VAT are standard values for Saint Lucia. The insurance rate is assumed as a percentage of CAPEX.

The discount rate reflects the return on equity for LUCELEC in 2016. The discount rate for EVs is the prevailing interest rate for savings accounts at commercial banks in 2022. The discount for VAT, if DSM is selected by stakeholders for lowest cost energy pricing, is 10%. The average markup on fossil fuel tariffs is estimated at 18%. This is the average markup needed to match the calculated tariff to the historic average tariffs using the published fixed and variable O&M costs. The markup for profits on RE generation is assumed at 12%, which is the average profit estimated from LUCELEC annual operating reports. The U.S. consumer price index adjustment for May 2022 was also obtained (Statistics U.S., 2022).

External debt payments are assumed to be made to international development banks. Local commercial financing is assumed. Dividend payments for all investments are assumed as the percentage of profits exceeding the minimum retained earnings (assumed at 10% of profits).

5.5.1.3 Solar

The future costs of fixed-tilt solar PV are modelled based on research projections (Fürstenwerth et al., 2015). Linear interpolation is used between future projected cost periods. Estimates of shipping costs and local taxes are included in the calculations. The assumptions used are provided in Table 53.

Table 53 Assumptions for solar financial calculations

Item Cost	Year 5	Year 10	Year 15	Year 20	Year 25
CAPEX					
Panels (USD$ per Wp)	0.25	0.19	0.17	0.17	0.17
Inverter (USD$ per Wp)	0.093	0.065	0.055	0.053	0.053
Shipping and transport (USD$ per kWp)	44.62	47.93	51.48	55.29	59.39

Installation cost (USD$ per Wp)	0.13	0.14	0.15	0.16	0.17
Ground mount infrastructure (USD$ per Wp)	0.24	0.25	0.26	0.26	0.27
OPEX					
Insurance (USD$ per kWp)	4.01	4.30	4.62	4.97	5.33
Inspection and monitoring (USD$ per kWp)	2.15	2.31	2.48	2.66	2.86
Management (USD$ per kWp)	2.69	2.88	3.10	3.33	3.57

Projected costs for crystalline silicon solar panels were obtained (Smith et al., 2021). According to (IEA, 2022a), the global installed capacity of solar PV reached at least 760.4 GWdc in 2020. Using expert provided compound annual growth rates (Fürstenwerth et al., 2015) pg.21, cost of inverters, in 5-year intervals starting with the 2020 baseline value, were estimated using data from the report. Mounting, DC cabling, ground mount infrastructure and balance of systems were estimated in a similar manner using linear interpolation.

Assuming 290 solar panels with 72 cells configuration and 340W capacity can be fitted in a 20ft container with a shipping cost of USD$2,200 from the US to Saint Lucia, a unit shipping cost of USD$22.31 per kWp was estimated (Express, 2022; Trading, 2018). Assuming a full container is required for the other components, the shipping cost can be doubled and assumed at USD$44.62 per kWp. Costs are adjusted for inflation in the 25-year projection period.

To estimate installation cost, the labour for installation of a 1 MWp solar PV plant is considered. No data is available for Saint Lucia, so an indicative labour cost was obtained (Fu et al., 2018). This cost is adjusted for inflation over the 25-year analysis projection period.

A benchmark value of 0.25% of capital cost per year is assumed for insurance coverage (Feldman et al., 2021). This cost is adjusted for inflation over the 25-year projection period. The cost of technical inspection, monitoring and management are estimated (Fu et al., 2018) and adjusted for inflation over the 25-year analysis period.

The cost of property lease is based on the typical local market rate of XCD$12,000 per acre per year for leasing agricultural land. With a solar PV installed capacity of 0.0629 kWp/m^2 (see Table 10), this translates to the equivalent of USD$17.37 per kWp unit cost for leasing land.

A total cost premium of 10% was added for all utility solar PV and 51% to all distributed solar PV to account for the additional cost of hurricane resilience features.

5.5.1.4 Wind

The cost of the wind turbine with towers, foundation, 2020 balance of system and annual operating cost were obtained (Sens et al., 2022) (see Table 4) and converted to USD$ with a conversion rate of 1€:1.07USD$. The unit cost of the selected wind turbine with a tower was estimated at USD$2,618,504. All costs were escalated for inflation over the analysis period.

Assuming a potential installed capacity of 25.3 MW is possible in an area of 8 km^2 in the Grande Anse area in Dauphin district based on the wind assessment results and using the lease rate of XCD$12,000 per acre per year, the cost of land lease per kW is estimated at USD$345 per kW. This is adjusted for inflation over the 25-year analysis period.

Shipping and transportation costs vary depending on location. Assuming wind turbines are sourced from Europe, it takes up to 20 days (Arimo, 2022) for a cargo ship to cross the Atlantic Ocean to the Caribbean Sea. Assuming a single 8,500 twenty-foot equivalent units vessel is chartered for shipment of up to ten (10) full wind turbines at a cost of USD$54,000 per day (Lademan & Bambino, 2021), a shipping cost of about USD$108,000 per turbine is estimated. Inclusive of land transportation, a transportation cost of USD$150,000 per turbine is assumed (Baker, 2019) and adjusted for inflation over the 25-year analysis period.

5.5.1.5 Biogas

Costs for continuous stirred tank reactor biogas production and processing equipment were modelled using existing data (Spurk et al., 2016). O&M costs are inclusive of feedstock and desulphurization and adjusted for inflation. Feedstock cost is assumed at USD$0.92/tonne and this is adjusted for inflation annually. Insurance is assumed at 0.4% and maintenance at 3.3% of investment cost per annum. The costs in Table 54 were also obtained from the same source and adjusted annually for inflation.

Table 54 Cost assumptions for biogas plant

Cost Item	Cost per m^3 in USD$
Waste pretreatment equipment	167
Biogas production equipment	274
Engineering infrastructure and permitting	46
O&M per annum	
Operations personnel	10
Administrative	3
Desulphurization	0.55

The unit cost of biogas cogeneration equipment was obtained (Akbulut et al., 2021) for a 637 kW GE Jeanbacher unit JMS312 GS-BL and estimated at USD$586 per kW electrical and adjusted annually for inflation. The O&M cost for the CHP unit is estimated at USD$0.03 per kWh and adjusted annually for inflation. Assuming a shipping cost of a 33 m^3 20 ft container at USD$2,200, a unit shipping cost of USD$67 per m^3 is estimated and adjusted annually for inflation.

5.5.1.6 Geothermal

Investment costs for geothermal energy in Table 55 and O&M cost of USD$25 per MWh were obtained (International Energy Agency, 2010) and published information on the geothermal development project in Saint Vincent and the Grenadines, a SIDS island located 45 km south of Saint Lucia in the Windward Islands chain of volcanic islands. The costs are inclusive of resource exploration and drilling. The average cost per well for drilling three (3) wells was USD$6.97mn and the exploration and resource confirmation costs can be estimated at USD$14.1mn (Richter, 2020b, 2020a).

Table 55 Capital cost breakdown for geothermal power plant as % of total

Exploration and resource confirmation	12.5%

Drilling	27.5%
Surface Facilities	15.0%
Power Plant	45.0%

It is assumed that all shipping, transportation and taxation costs are rolled up into the known drilling, exploration and resource confirmation costs. It is also assumed that one (1) well will be required to provide the steam needed for each of the seven (7) MW ORC generation units. The cost of grid connection is assumed to be the same as for solar PV per MW. Costs, except for grid connection, projected by (Fürstenwerth et al., 2015), are adjusted annually for inflation. Variable costs for operating the power plant at USD$0.01 per kWh and steam field operations at USD$0.006 per kWh were obtained from (Gerardi & Hinchliffe, 2015) and adjusted for inflation.

5.5.1.7 Hydro

Investment, operations and maintenance costs for hydropower potential were obtained from the Saint Lucia Hydropower Potential Analysis Report (Fay & Grett, 2013) and presented in Table 56. The required penstock length is estimated based on data from the Report at 20.5m per kW of installed capacity.

Table 56 Hydropower capital costs in USD$

Project preparation ($ per kW)	614.4
Electromechanical equipment installed cost ($ per kW)	3,333
Penstock material for 2.5 m/s flow ($ per m)	281.36
Penstock construction ($ per m)	83

Fixed O&M is assumed at 5% of total investment cost per annum. Variable O&M cost is assumed at USD$0.002 per kWh (IRENA, 2012).

Based on the data available from (Lotus Pipes, 2017), assuming 165 mm diameter pipes are used, approximately 126 pipes of 3 m length can fit into a 20 ft container at USD$2,200 shipping cost with space for power generation components. This results in an assumed shipping cost of USD$5.82 per meter which is adjusted annually for inflation.

5.5.1.8 Diesel

Investment cost information is based on 2012 pricing of a 12 MW power plant in Saint Lucia. Investments are assumed to be made in replacement generation as current assets are retired and as additional generation capacity is required. No allowance is made for a reserve generation capacity.

Specifications for currently installed diesel generators was obtained from (Bodley, 2016) and provided in Table 49. Total installed cost of a 10.2 MW diesel generator with all associated ancillary equipment was provided by (LUCELEC, 2013) at a cost of XCD$71mn. This was used to provide a capital cost of diesel generators which was adjusted annually for inflation.

Fixed costs were obtained from LUCELEC's annual reports for the period 2012 to 2020 (LUCELEC, 2022) and projected linearly in Microsoft Excel as shown in Figure 30.

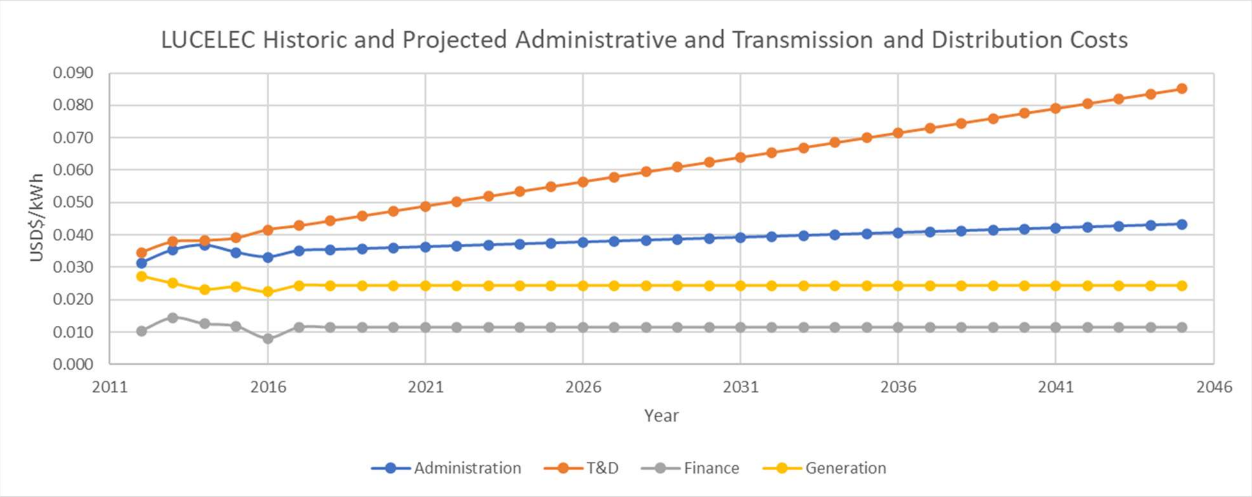


Figure 30 Fixed costs for LUCELEC

Fuel cost and diesel generator fuel efficiency for LUCELEC were obtained from the company's annual reports for the period 2012 to 2016. The international cost of diesel fuel per litre was obtained from (US EIA, 2022) for the same period and the difference in price between the two (2) sources were calculated as a percentage discount to LUCELEC. From this information an average LUCELEC diesel fuel pricing discount of 16% was estimated and used to project fuel prices as shown in Table 57.

Table 57 Diesel fuel parameters

Year	2012	2013	2014	2015	2016
Fuel efficiency kWh per liter	4.30	4.31	4.30	4.28	4.32
Fuel cost USD$ per liter	0.84	0.81	0.79	0.71	0.47
Fuel cost USD$ per kWh	0.20	0.19	0.18	0.17	0.11
Historic US price diesel no. 2 per liter	1.04	1.03	0.98	0.70	0.61
LUCELEC price discount	19%	22%	19%	-1%	24%

Diesel fuel cost projections are provided in Figure 5.

5.5.1.9 Energy Efficiency

Investment costs for lighting and air conditioning are based on actual 2017 prices for equipment in Saint Lucia. It is assumed that the electric utility company invests in the energy efficiency hardware and is compensated through the energy billing system through an energy efficiency supply contract arrangement.

The cost of a 9,000 BTU air conditioning unit in Saint Lucia is on average USD$1,000 and a typical 8W LED light bulb costs about USD$5.20. These prices are adjusted for inflation over the 25-year evaluation period.

O&M costs are assumed to be negligible for the investments over their assumed lifetimes of fifteen (15) years for air conditioning and ten (10) years for lighting.

It is assumed that the electricity utility makes the investment and customers are charged bill payments covering the cost of debt and administration.

5.5.1.10 PHS

Investment costs for PHS were obtained (Akinyele & Rayudu, 2014; Hohmeyer, 2017) and adjusted annually for inflation. The future trend for prices was also obtained (Lazard & Partners, 2016). The O&M costs included turbine and pump start costs. It is assumed that materials for building of PHS containment walls are all available locally, therefore, cost of shipping is expected to be included in the investment cost of USD$1500 per kW installed as only the turbines and electrical components will require shipping.

5.5.1.11 Battery (Chemical)

Investment costs for lithium ion battery systems were obtained from (Akinyele & Rayudu, 2014) and future trends in pricing were obtained from (IEA, 2022b) from which the average annual decrease in price, over the years 2019 to 2021, was calculated at 10.7% per year. As the cost decrease curve appears to be levelling off over these years, this annual decrease was held constant annually over the 25-year analysis period. The projected cost for 2021 was USD$140 per kWh, which is very close to the actual reported average cost of USD$132 per kWh (Colthorpe, 2021).

To estimate the cost of shipping, a battery capacity of 1.8 MW was assumed as the current maximum potential capacity for a 20 ft shipping container (Saft, 2022). With a shipping cost of USD$2,200 per container, this equates to USD$1.22 per kW of battery. O&M costs were obtained (DNV GL, 2017) and assumed at USD$10.70 per kW-year. All costs were adjusted annually for inflation. The cost of energy loss due to roundtrip efficiency losses of 10% was included in the analysis.

5.5.1.12 Ice Storage

Installed cost of ice storage systems was obtained (Deru & Hayes, 2018) at USD$388 per kW and adjusted annually for inflation. The cost of shipping was estimated by determining the number of 288kWh ice storage units of 7.62 m^3 volume that can fit into a 20 ft container. Approximately four (4) units can fit into a 20 ft container and using a shipping cost of USD$2,200 per container, this translates to a cost of USD$550 per unit. Fixed operation and maintenance costs for the ice storage systems were obtained from (Manuel, 2014). Storage losses of 3% of total energy were accounted for as a variable cost.

5.5.1.13 DSM

Investment costs for DSM were obtained (IDAHO Power, 2022) (see Tables 5 and 6, and Appendix 3). Capital cost was estimated at USD$122.61 per kW, fixed O&M cost at USD$11.87 per kW and variable O&M cost at USD$0.23 per kWh. All costs were adjusted annually for inflation. As all equipment is likely to be available locally, no shipping and transportation costs were included in the analysis.

The cost of DSM shifted energy is estimated as the sum of variable and fixed O&M costs inclusive of debt servicing costs. The value of DSM energy is estimated as the difference between the cost of the most expensive form of energy storage, which would be used as an alternative to DSM, and the cost of delivering the DSM service by the utility company. This value is calculated annually.

5.5.1.14 EV

Costs of electric vehicles were based on 2017 manufacturer suggested retail prices for typical vehicles in each transport category. Based on current price information, a cost of USD$75,000 is assumed for a pickup truck (Duffer, 2022), USD$500,000 for a semi-tractor truck (Buysse, 2022) and USD$350,000 for an electric bus (Madden, 2021). Each vehicle class is assumed to carry a 130-kWh battery pack. Pricing for an electric car with a 62-kWh battery pack is assumed at USD$47,500 based on current pricing at Courtesy Garage Ltd® in Barbados. No car dealers currently supply electric vehicles in Saint Lucia. Vehicle base prices are held constant as car manufacturing utilises mature technologies and battery pack prices are projected to reduce over the 25-year analysis period.

Based on information available (The American Automobile Association Inc, 2022), the cost of maintenance of an electric vehicle is on average 26% lower than a comparable internal combustion engine vehicle provided maintenance is done according to manufacturer recommendations. This translates to an estimated average annual savings of USD$350 assuming four (4) fluid and two (2) brake changes per year as shown in Table 58. The remaining maintenance cost of USD$1,008 per vehicle is adjusted annually for inflation.

Table 58 Estimated EV maintenance savings

Vehicle class	Fluids in USD$	Brakes in USD$
Trucks	795	1104
Buses	530	736
Tractors	530	736
Cars	265	736
Average	530	828
Grand total	1358	
EV Savings	26%	
EV Savings dollars	350	

5.5.1.15 V2G

The following costs were obtained from (Steward, 2017): cost of V2G bidirectional energy flow infrastructure at USD$5,000 per 10 kW level 2 DC unit and adjusted annually for inflation; cost to the aggregator for operating expenses and profits is 45% of revenues of which 5% is assumed to be management cost. The O&M costs included routine maintenance assumed at 5% of Original Equipment Manufacturer (OEM) cost. A cost for local installation of each V2G system is assumed at USD$1,500 and adjusted for inflation. V2G network communications cost of USD$30 per vehicle is assumed annually using low-cost wireless technology based on the literature.

To estimate the maximum number of V2G supply stations required, it is assumed that one (1) charge station can service two (2) vehicles simultaneously. A fixed annual remuneration of USD$1300 is assumed for V2G customers. (Huang et al., 2021) found that remuneration in the range of €1,000 to €7,000 had a positive impact on willingness to participate in V2G for Dutch customers. A fixed annual payment is assumed in addition to fixed plug-in times consistent with the solar follow charging connection profile as this will reduce variability in available V2G capacity which is important especially as the total number of participating vehicles in an island case is very small. These are important considerations for V2G contracts along with a guaranteed minimum battery state of charge (to maintain vehicle range). Fast charging of EVs is also an important consideration for any V2G programme as it generates more participant interest. The use of fast-charging can be modelled through higher charging power rates. Increasing charge power results in higher demand peaks and increased electricity consumption for providing V2G services. A profit margin of 18% is added to the tariff consistent with estimated LUCELEC profit margins.

It is assumed that the aggregator of the V2G programme will manage discharge rates to maintain manufacturer battery life warranties, therefore, no cost is assumed for additional battery degradation. Some studies have shown that under certain conditions, V2G can extend life of EV batteries (Uddin et al., 2017). 25% energy losses at discharge are also accounted for as a cost of V2G services in the modelling.

5.5.1.16 Economics

This module quantifies the direct costs and savings by aggregating results from the other modules for an overall economic analysis of the impacts. A fiscal multiplier of 0.59 was used over the first six (6) years of an investment from both government and private sector in the economic analysis.

The overall economic impact is estimated by analysing new revenues from RE and storage, and lost revenues from fossil fuels under a proposed new taxation system as compared to the existing system. Revenues from taxes on BAU fossil fuel sales are calculated and aggregated.

$$PLC = GP * \%PD$$

Where PLC - Profits leaving the country =

GP - Gross profits

%PD - % of profits paid out as dividends

% PD =

```
    IF: AROE < MRE, 0, ELSE
    IF: AROE < WACC, THEN
    AROE – MRE, ELSE
    IF: AROE – WACC >= MRE, THEN
    WACC, ELSE
    AROE - MRE
```

Where: AROE – average return on equity

MRE - minimum retained earnings = 10% * Total profits

Algorithm 11 Calculation of profits staying in the local economy

Revenues from taxes on RE and energy storage are also calculated and aggregated then compared to the BAU case. The value of avoided electricity generation due to energy efficiency and reduced T&D losses due to DG sources are not evaluated. It is assumed that EE investments will persist over the entire analysis period. Benefits due to improvements in air quality are not evaluated. If these benefits are estimated, the overall economic values will be higher than calculated.

The algorithm used for estimating the amount of profit staying within the local economy is provided in Algorithm 11. Profits leaving the country is assumed to be dividend payouts regardless of whether investors are locally or internationally based. The dividend to be paid is calculated as a percentage of total profits.

5.5.2 Calculation of tariffs

Individual RE, energy storage source and weighted average RE tariffs for the mix of generation and storage sources are calculated using the formulae provided in Equation 13.

Energy Source	kWh supplied	Energy tariff USD$ per kWh	Weighted average tariff USD$ per kWh

Solar	519,558,926	0.263	0.139
Wind	90,345,873	0.402	0.037
Biogas	3,766,705	1.868	0.007
Geothermal	168,756,540	0.358	0.061
Diesel	-	0.428	0.000
Hydro	12,870,665	0.512	0.007
DSM	14,261	0.403	0.000
V2G	23,366,336	0.390	0.009
Ice Storage	3,085,083	0.000	0.000
Chemical Storage	-	0.265	0.000
PHS	67,624,003	0.436	0.030
Res Dem Diesel	95,893,453	0.491	0.048
Total	985,281,844		0.337
		Average Tariff	XCD$0.90
			USD 0.34

Equation 13 Formulae for calculating tariffs

AvgREt = (FRE1/TRE) x Ret1 + (FRE2/TRE) x REt2 +….+ (FREn/TRE) x REtn

$$REt = (FC + VC + LAC + LTDC) * (1 + MU) * (1 + VAT)$$

$$SEt = (FC + VC) * (1 + MU) * (1 + VAT) + WAREt$$

$$WAREt = REt_1 * \frac{fRE_1}{tRE} + \ REt_2 * \frac{fRE_2}{tRE} + \cdots + REt_n * \frac{fRE_n}{tRE}$$

Where REt - Renewable energy tariff from generation source

FC – Fixed cost

VC – Variable cost

LAC – LUCELEC administrative cost

LTDC – LUCELEC T&D cost

MU – Markup up (%)

VAT – Value added tax (%)

SEt - Tariff for energy from storage source

WAREt - Average renewable energy tariff

REt$_n$ – The nth renewable energy source

$FREt_n$ – Total renewable energy from source n for a year

tRE – Total renewable energy from all sources for a year

Figure 31 provides an example of the tariff for a generation source, in this case hydro power, showing how the components add up to result in the tariff. In this case, the largest cost component is variable O&M at USD$0.285 per kWh and the smallest component is fixed O&M at USD$0.003 per kWh. It is expected that LUCELEC will remain the sole distributor for electricity, due to the very small size of the electricity network, hence, the administrative cost for LUCELEC is included in the tariff.

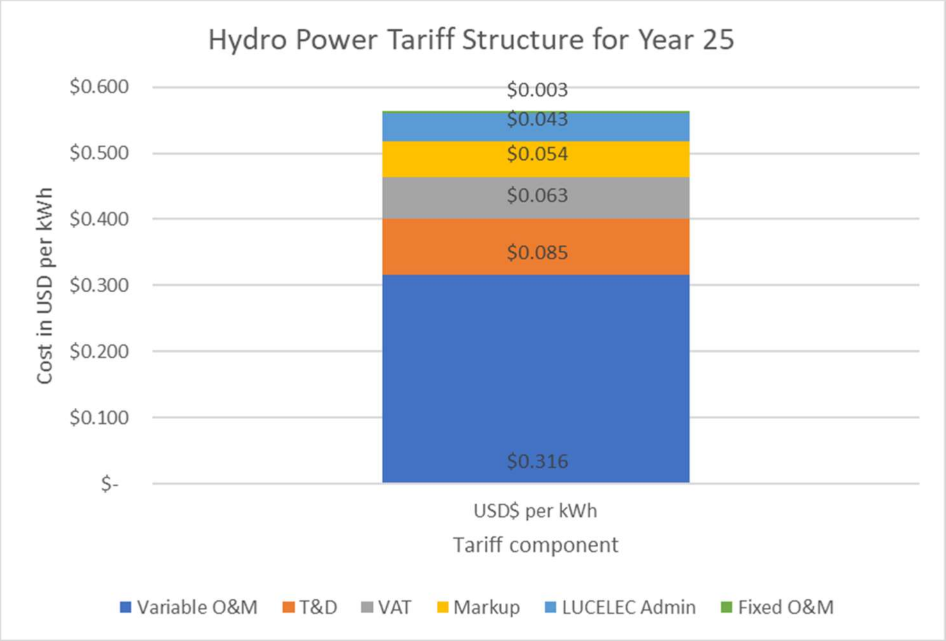


Figure 31 Example of Hydro tariff cost components

To calculate the overall tariff for each year, the weighted average tariff for all generation sources (WAREt) is calculated as shown in Table 59.

Table 59 Example of overall tariff calculation

Energy Source	kWh supplied	Energy tariff USD$ per kWh	Weighted average tariff USD$ per kWh
Solar	519,558,926	0.263	0.139
Wind	90,345,873	0.402	0.037
Biogas	3,766,705	1.868	0.007
Geothermal	168,756,540	0.358	0.061

Diesel	-	0.428	0.000
Hydro	12,870,665	0.512	0.007
DSM	14,261	0.403	0.000
V2G	23,366,336	0.390	0.009
Ice Storage	3,085,083	0.000	0.000
Chemical Storage	-	0.265	0.000
PHS	67,624,003	0.436	0.030
Res Dem Diesel	95,893,453	0.491	0.048
Total	985,281,844		0.337
		Average Tariff	XCD$0.90
			USD 0.34

5.5.3 Calculation of financial metrics

Free cash flow was calculated using the formula at Equation 14.

Equation 14 Free cash flow formula

FCF = EAIDT + DepExp + Dpmt – InvCst – Divi

Where FCF – Free cashflow

EAIDT – Earnings after interest depreciation and taxes

DepExp – Depreciation expense

Dpmt – Debt payment

InvCst – Investment cost

Divi – Dividend payment

The profits kept in the local economy is equivalent to the retained earnings, calculated as at Equation 15:

Equation 15 Equation for calculating profits kept in local economy

$$PK = EAIDT - RPD$$

Where PK – Profits kept in the economy

EAIDT - Earnings after interest depreciation and taxes

RPD - repatriated profits and dividend payments

IRR is calculated using the annual free cash flows and the ‘IRR’ function in Microsoft Excel with a guess of 9%. The net present values (NPV), Equation 16, was calculated using the ‘NPV’ function in Microsoft Excel and a discount rate of 12.7% (average ROE for LUCELEC).

Equation 16 Equation for calculation of net present value

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n}$$

Where: NPV – net present value

C_n – cash flow

N – total number of periods

n – period number (non-negative integer)

r – internal rate of return

The IRR is the discount rate (r) for a NPV equal to 0.

Return on equity was calculated by dividing the earnings after depreciation, interest and taxes by the cumulative equity invested for each year. The average (mean) return on equity over the 25-year analysis period was also calculated.

Commercial viability is defined as an ROE and IRR of 5% (as prevailing interest rates on savings accounts in commercial banks are generally lower than 5%) or higher and/or a positive NPV.

5.5.3.1 Calculation of Transition Tax Revenue

The transition tax revenue is calculated using Equation 17. VAT is the only source of transition tax revenues considered in the analysis.

Equation 17 Formula for calculating transition tax revenue

TTRE = VAT * Rv(RE + SE + EDCE)

Where: TTRE – Transition tax revenue

Rv – Revenue from sales of

VAT – Value added tax

RE – Renewable energy

SE – Storage energy

EDCE – EV Direct consumption energy

5.5.3.2 Calculation of difference EV tax revenue compared to BAU transport fossil fuels revenue

The equation used for calculating the difference between the business-as-usual transport fossil fuels tax revenues and the EV transition tax revenues is provided in Equation 18.

Equation 18 Formula for calculating difference in BAU transport and EV tax revenues

$$DifEB = VAT \times EVES - ProjDies \times PCd - ProjPet \times PCp$$

Where DifEB – Difference in EV compared to BAU transport fossil fuels tax revenue

EVES – EV Energy Sales

ProjDies – Projected diesel consumption in the transport sector

PCd – Projected unit cost of diesel fuel x %tax

ProjPet – Projected petrol consumption in the transport sector

PCp – Projected unit cost of petrol fuel x %tax

VAT – Value added tax

5.5.3.3 Calculation of required EV energy tariff for no revenue loss

The formula for determining the required EV energy tariff in any year to ensure no loss of tax revenues compared to BAU tax revenues is provided in Equation 19.

Equation 19 Formula to calculate required EV energy tariff for no revenue loss in transport sector

$$EVTNR = (1 + \%diff) \times EVET$$

Where EVTNR – Required EV energy tariff for no revenue loss

EVET – EV energy tariff

$\%diff = (DEvBAU / EVETR) \times VAT$

Where

EVETR – EV energy tax revenue

DEvBAU – Difference in EV tax revenue compared to BAU transport fossil fuels tax revenue

(DEvBAU = EVETR – BAU projected fossil fuel tax revenue)

5.6 Results Model

This model aggregates outputs from all other models for analysis. Energy delivered from all sources of generation and storage are analysed and tariff information from the financial model is summarised. Summaries and charts of the energy dispatched are also produced in this model. Results are summarised and analysed using graphs and tables which are provided in the results discussion.

5.7 Validation (Calibration) of the Model

To calibrate the model, firstly year 0 (2015) is selected. Available sample demand data for 2015 was compared with calculated demand data for the same year produced using the model sector load profiles. Substation peak loads for 2015 were estimated. This was used with the sector load profiles to calculate the total demand for the year for each substation. The total demand from all the substations was then aggregated. Total demand was adjusted by scaling the peak load value used in calculations.

Secondly, this calculated total demand was compared to the actual total demand data available from LUCELEC (LUCELEC, 2015). Generation, losses, peak load and customer demand estimated by the model were compared to actual data from LUCELEC's annual reports for 2015. For demand, generation and losses, the difference between the calculated and actual values was within the range +/- 2%. The model was, therefore, considered adequate for use. The difference in peak is higher, at 12%, as the model does not account for seasonal, instantaneous and unpredictable changes in demand. The results are presented in Table 60.

Table 60 Calibration data with 2015 reference data

Year	2015
Model Demand in kWh	358,180,960
Actual 2015 Demand in kWh	351,262,208
Model Peak in MW	52
Actual 2015 Peak in MW	59
Model Generation in kWh	385,061,089
Actual 2015 Generation in kWh	381,268,000
Model Supply in kWh	358,129,642
Model losses	6.99%
Actual 2015 losses	7.87%
Difference in Demand (Actual - Model)/Actual	-1.97%
Difference in Peak (Actual - Model)/Actual	12%
Difference in Generation (Actual - Model)/Actual	-0.99%
Difference in Losses	0.88%

A second calibration was done to test the model generated tariff against an estimate of the NETS 20-year suggested transition scenario. The model assumed parameters similar to or matching the NETS suggested 20-year energy scenario. Table 61 provides a comparison of the model tariff calculation parameters versus the NETS suggested parameters.

Table 61 Model calibration versus NETS for 20 Year Tariff

	Model	NETS
Solar/MWp	23	23
Wind/MW	13.8	12
Geothermal/MW	28	30
Storage (MWh)	19.2	19
Ownership	Utility	Utility
Energy Efficiency	NETS Assumptions	NETS Assumptions
Resulting Tariff XCD $	0.96	0.85

The NETS tariff for the shown scenario in year 20 was XCD$0.85/kWh. The model generated year 20 tariff was XCD$0.98/kWh. The model does not utilise the available storage as there is sufficient generation capacity to always satisfy demand. It is likely that the NETS model utilised the storage to provide ancillary services such as voltage and frequency regulation. These services are not simulated in the research model.

The results have a difference of approximately 15% which suggests that the assumptions made and calculation methodology used are quite similar. The installed capacity of the various generation and storage technologies are provided in Table 62 indicating the amount and year of installation for each technology type.

Table 62 NETS assumption for year 20 tariff estimation

Source	Year 5	Year 10	Year 15	Year 20
Solar – kWp	3000	8000	13000	23000
Wind - kW	0	13800	13800	13800
Geothermal - MW	0	0	14	28
Chemical Storage - kWh	0	5,164	11,880	19,008
Energy Efficiency Savings	3%	5%	8%	10%

5.8 Selection of V2G connection charge curve

The most effective charging connection profile was selected by comparing total amount of generation and storage needed to satisfy residual demand on application of the profiles and selecting the one that minimises both parameters. The total amount of ice, PHS and chemical storage required and the required biodiesel generation to satisfy the residual demand were allowed to change in a situation where all sources of generation and storage were utilised and all other parameters were held constant. V2G was enabled in all analyses. The charging connection profile was varied and the impact on the generation and storage needed to satisfy residual demand analysed. The results are provided in Figure 32. The impact on each parameter was scored from one (1) to three (3), with three (3) being assigned to the best performance. The scores were then summed as shown in Table 63.

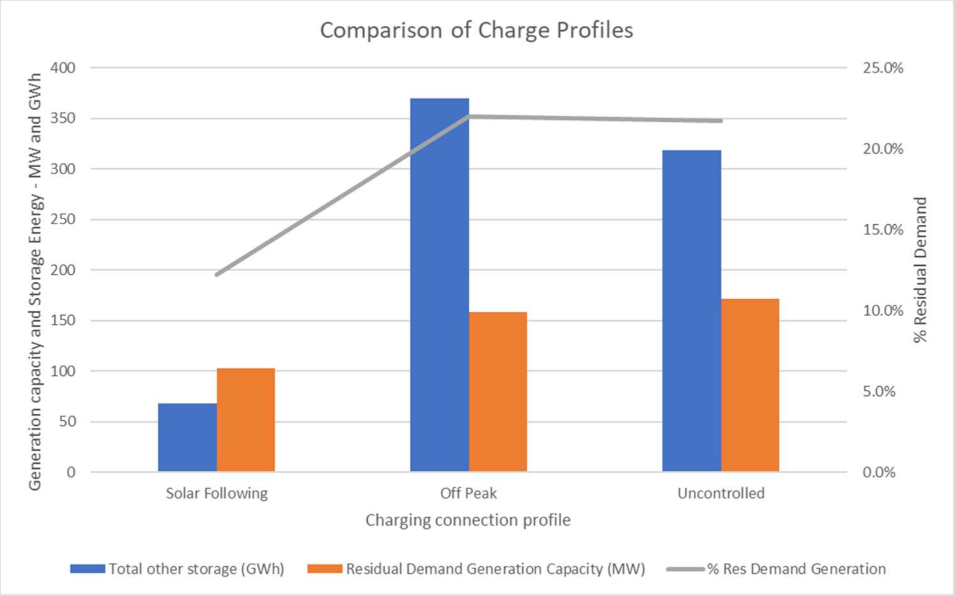


Figure 32 Comparison of parameters in selecting a charging connection profile

Table 63 Scoring of charge profiles

Charge Profile	% Residual Demand Generation - Score	Total other storage (GWh) - Score	Residual Demand Generation Capacity (MW) - Score	Total Score
Solar Following	3	3	3	9
Off Peak	1	1	2	4
Uncontrolled	2	2	1	5

The objective was to find the charging connection profile that minimised the amount of residual demand generation from biodiesel and the additional storage needed apart from V2G. Solar following had the highest total score and is, therefore, the charging connection profile that was used in all scenario analyses.

5.9 Methodology for sensitivity analysis

A sensitivity analysis was performed on the year 25 scenario results by varying input parameters by +/- 10%. The parameters listed in Table 64 were stress tested.

Table 64 Parameters for sensitivity testing

Parameter	Where sensitivity inputs applied

Renewable Energy	Installed capacity
Financials	CapEx and O&M Costs; Debt interest rates
Peak Load	Annual system peak load used to calculate total demand
Price of Fossil Fuels	Price of diesel, petrol and LPG

All sensitivity analyses except for peak load were run on the aggregated TS Model results for year 25. The peak load sensitivity is run on all substations to generate a new TS Model result for year 25.

5.10 Methodology for Evaluation of Key Performance Indicators

5.10.1 Indicator 1: RE Ratio

Stakeholder responses to the following questions presented in Section 6.2 support the use of RE ratio as a KPI: R1_7, 2nd priority; R1_9, all responses; R1_4,6, 1st and 3rd priority; R1_2, all responses; R2_RE, all responses; R2_GH, all responses; R3_11,14, 1st and 2nd priority; R4_6,14, 2nd priority; R4_1,10, 3rd priority. 69% of the Delphi questions had responses supporting this indicator.

RER is determined by dividing all energy from renewable sources, except biodiesel, by the total amount of energy consumed. Biodiesel is used to satisfy the residual demand after all other sources of RE generation and storage have been used. Biodiesel use to balance the remaining residual demand is therefore excluded as a RE resource for the purpose of calculating this ratio to enable comparisons since all stakeholder scenarios result in 100% RE systems.

5.10.2 Indicator 2: Overall Economic Impact

Stakeholder responses to the following questions presented in Section 6.2 support the use of overall economic impact as a KPI: R1_7, 3rd priority; R1_3,10,13, all responses; R1_4,6, 2nd priority; R2_5,8,12, all responses; R3_11,14, 3rd priority; R4_6,14, 1st priority. 46% of the Delphi questions had responses supporting this indicator.

Overall economic impact is defined as the PV of all investments, earnings, costs and savings over the 25-year period. The higher the value calculated, the more favourable the indicator.

Overall economic impact is evaluated as defined in Equation 20 where PV is the PV at year 0.

Equation 20 Calculation of overall economic impact

25-year Overall Economic Impact = PV [(S + CR + NR) – (RL + NC + CC)]

Where PV – present value

S – Savings = (Value of replaced diesel, petrol and LPG) x CFM

CR – Current Revenues = (Value of consumed diesel and petrol excise taxes + LPG subsidy) x GFM

NR – New Revenues = (VAT from RE sales x GFM) + (Retained earnings + Salaries + EE Savings + Energy Cost Savings) x CFM

RL – Revenues Lost = (Excise tax on replaced diesel, petrol, LPG) x GFM

NC – New Costs = Cost of finance RE, Storage, EV, DSM, V2G + Repatriated profits

CC – Current Costs = Diesel, petrol, LPG purchase cost

CFM – Consumer fiscal multiplier

GFM – Government fiscal multiplier

The savings are evaluated by calculating the total amount of diesel, petrol and LPG fuel displaced by electricity demand each year. This volume is multiplied by the projected unit cost for each of these fuels for each year in the 25-year analysis period. The total is multiplied by the consumer fiscal multiplier as it represents savings to consumers.

The current revenues are evaluated by calculating and summing the excise tax on fossil fuels each year over the 25-year period. This is reduced by the annual subsidy on LPG. The 2017 excise tax on petrol was USD$0.39 per litre (XCD$4.00 per gallon), USD$0.10 per litre (XCD$1.00 per gallon) for diesel used in the power generation sector and USD$0.39 per litre (XCD$4.00 per gallon) for diesel in other sectors (GOSL, 2022; IMF, 2018). The subsidy on LPG in the period between June 2021 to March 2022 was USD$0.27 per litre (Caribbeannewsglobal, 2022). All these values were held constant over the 25-year review period.

New revenues include the VAT on sale of RE at the source of generation and the VAT on fixed and variable O&M components in the tariff for stored energy that is resold into the grid. This is multiplied by the government fiscal multiplier and aggregated over the 25-year period. The retained earnings, value of salaries (administrative costs), customer energy efficiency savings and the savings from energy bills are all summed for each year and multiplied by the consumer fiscal multiplier. This is then aggregated over the 25-year period.

The revenues lost are evaluated by calculating the excise tax that could have been collected on diesel and petrol fuel volumes that were replaced by electricity. This is offset by the savings from the LPG subsidies that would have been paid for the volume of LPG replaced by electricity. The annual sums are multiplied by the government fiscal multiplier and summed over the 25-year period.

New costs cover the cost of finance which is the interest payments on the loan component of capital cost for RE, storage, EV, DSM and V2G investments. This cost is summed annually along with the repatriated profits from each investment area and the totals aggregated for the 25-year evaluation period.

Current costs refer to the purchase cost for fossil fuels using the annual projected costs as provided in Figure 5.

5.10.3 Indicator 3: Tariffs

Stakeholder responses to the following questions presented in Section 6.2 support the use of the 5-year interval tariffs as a KPI: R1_7, 3rd priority; R1_4,6, 2nd priority; R3_11,14, 2nd and 3rd priority; R4_6,14, 1st priority. 31% of the Delphi questions had responses supporting this indicator.

5-Year interval tariffs are calculated in the financial model and aggregated in the results model. The tariffs are estimated using energy delivered from each source of generation and energy storage, the associated investment costs, operational and maintenance costs and application of relevant taxes.

5.11 Steps in modelling a scenario

The following is a summary of calculations performed in the substation model and repeated in 5-year intervals for 25 years:

- Calculate demand in 15-minute intervals for a year using sector load profiles, EV demand and substation peak load;
- Calculate generation from solar PV using the solar PV generation profile for the particular substation;
- Calculate EV demand, V2G and ice storage;
- Convert fossil fuel demand to electricity demand;
- Utilise PV generation to offset demand in the sector where generation takes place; and
- Calculate the aggregated residual demand and excess solar PV energy.

The following calculations are performed in the transmission system model and repeated in 5-year intervals for twenty-five (25) years:

- aggregate residual demand and excess solar PV energy from all substations;
- Calculate generation from all sources connected at the transmission system level;
- Utilise generation to meet demand;
- Calculate system storage for all forms of storage;
- Supply residual demand using storage; and

- Balance the system using biodiesel generation.

The amount of each generation source is first set by the stakeholder input for the required penetration level of RE. The amount of wind, solar and geothermal energy are then manually adjusted to achieve the required target energy penetration level.

The following analyses are performed in the financial and results models for all 5-year time intervals for twenty-five (25) years:

- Calculate financial, sustainability and economic parameters from results; and
- Calculate KPIs.

5.12 Business case and economic evaluation

The business case evaluation is limited to the 25-year transition period for converting to 100% RE. In many cases, investments were made in each of the 5-year intervals analysed, including the 25th year. Consequently, the typical financial parameters such as discounted payback period and NPV are not very effective at providing decision-making information as the entire period over which the investments are providing returns is not captured in the scope of the research.

The group of financial indicators that have been selected to overcome this issue are the ROE which is calculated annually, the IRR and NPV which are both subject to the caveat of investments occurring at all 5-year intervals. In addition, a comparison of the overall economic impact for all scenarios was made. Together, the financial and economic evaluations provide sufficient information for both government and private sector decision-making for investments.

6 Section 6 Development of Scenarios

6.1 Baseline Scenario Inputs

In the baseline scenario or business as usual (BAU) scenario, demand growth is satisfied using only new diesel generation. As old generator sets are retired, described in Section 5.4.1.8, they are replaced by new diesel generators. Additional diesel generation capacity is brought online to meet all new demand. The electricity tariff is based on the cost of investments and the diesel fuel consumed. The tariff setting mechanism remains unchanged compared to the baseline described in Section 1.

Tariffs are calculated in 5-year intervals. Fixed costs are expected to generally follow historical trends. The cost of T&D is expected to increase faster than other costs as the infrastructure ages and becomes loaded beyond capacity and investments for upgrades become necessary and more frequent. The cost trend lines are provided in Figure 33.

The inputs for the baseline scenario are provided in Table 41 and repeated here for ease of reference in Table 65.

Table 65 Baseline scenario inputs

		Baseline
	Stakeholder Requirements	
S1	Level of domestic energy/import dependence	4 NETS
S2	Priority for penetration level per RE type	4 Diesel
S3	Impact of DG and financing on transport energy cost	2 Based on RE costs for EVs
S4	Ownership Structure Economics	2 Part of profits kept in the local economy
S5	Energy Pricing Policy Instruments	4 BAU
S6	Energy cost to Consumer	2 Lifecycle cost plus profit margin
S8	EV instruments	4 BAU
S9	Resilience to Natural Disasters	BAU
S10	Democratisation of Energy	5. Government
S11	Conversion Fossil Fuel Demand to Electricity	4 None
S12	Energy Efficiency Policy	4 NETS
S13	Source of Debt Financing	2. Development Bank

In this scenario, there are no targets for transition of fossil fuel consumption in the various sectors including transportation to RE. The input used at S1 is labelled ‘NETS’ and in calculations for all years this parameter is set to 0%.

For scenario input S2, the dominant source of generation is set to diesel as currently supplied by the utility company. Input S3 which looks at the cost of energy used in the transport sector is set to ‘2 Based on RE costs for EVs'. As there is no target for transitioning to EVs and for the use of RE in the transport sector, no RE generation for EVs is supplied under this scenario.

Input S4 is set to '2 Part of profits kept in the local economy'. Since no published plan for achieving the RE targets exists, there is no additional RE generation and no profits are generated. Input S5 is set to '4 BAU'. There is no preferential pricing policy option set and VAT remains unchanged on all energy investments.

Input S6 is set to '2 Lifecycle cost plus profit margin' for the tariff from RE investments. As there are no planned investments, no investment in RE is included in this scenario. Input S8 which looks at the policy for conversion of the transport fleet to EVs is set to '4 BAU'. The conversion rate of the transport fleet to EVs is set to 0% for every year in the 25-year transition period.

Input S9, which sets the forms of RE generation that should be excluded from development, is set to 'BAU'. With this input there is no exclusion for sources of RE that can be used, however, as no RE transition plan is published, there is no new RE generation over the transition period. Input S10 sets the equity ownership for RE investments. In this case the parameter set is '5. Government' which sets assumed government equity terms for RE investments. As no investments were made, the associated equity terms were not applied in this scenario.

Input S11 sets the targets for conversion of fossil fuel demand in all sectors (except transport and electricity generation) to electricity. Since no targets exist for this, the conversion rate was set to '0%' for every year. This is set by parameter '4 None'. Input S12 sets the energy efficiency targets for the scenario. The parameter is set to '4 NETS' which sets the target to '0%' for every year. Though government has set a target in policy, there is no action plan under implementation to achieve the target.

Input S13 was set to '2. Development Bank' as the preferred source of debt financing for RE investments in this scenario. Since no RE targets were set in the scenario, the debt terms associated with this parameter were not applied.

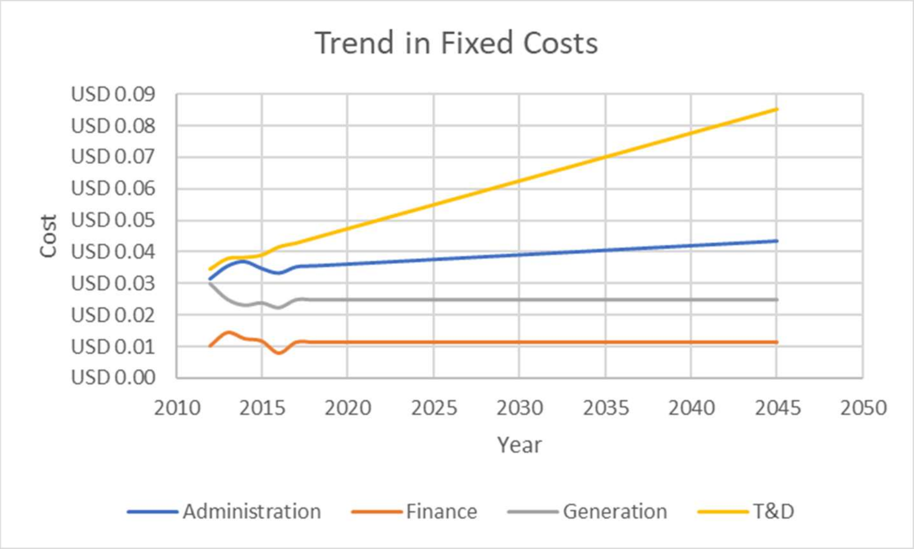


Figure 33 Trends in fixed cost components

6.2 Delphi Survey Results and Conversion of Stakeholder Responses to Scenario Inputs

The Delphi survey results are presented in the form of pareto charts with the most consistent responses at the top followed in order of priority by other responses. As previously explained in Section 4.1.5, the top three (3) responses are used to develop the three (3) stakeholder scenarios. The highest priority responses to each question are put together to form the inputs for Scenario A. The second priority responses are all used to form the inputs to Scenario B and, likewise, the third priority responses are used to form the inputs of Scenario C.

A summary of all responses and modelling inputs is provided in Table 66. In the first round, twenty-one (21) out of the twenty-seven (27) identified participants provided responses and in the second round nineteen (19) provided responses.

Table 66 Summary of Delphi survey outputs and modelling inputs

Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R1_7 (Priorities to improve energy security)	What should be the national priorities for improving energy security in the energy sector (electricity, transport, cooking, et cetera)?		
Feedback summary	Legislation and improved regulatory framework	Increased generation from RE options available to Saint Lucia	High costs, improving efficiency and reducing carbon footprint
Model Inputs	Mandated transition of FF to RE (S11 - 3 Mandated)	All RE sources/no geothermal (S9 -2 No geothermal)	EV pricing (S5 - 2 EV fleet)/Mandated transition of FF to RE (S11 - 3 Mandated)/Conversion to EV fleet (S8 - 1 Immediate ban on ICE imports)
Explanation	% of projected fossil fuel demand in domestic, industrial, hotel and commercial sectors converted to electricity demand	Solar PV, wind, biogas and hydro	Reduction in VAT on investments in EVs/projected fossil fuel demand in domestic, industrial, hotel and commercial sectors converted to electricity demand/% of transport fleet to be converted from fossil fuel to electric vehicles
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C

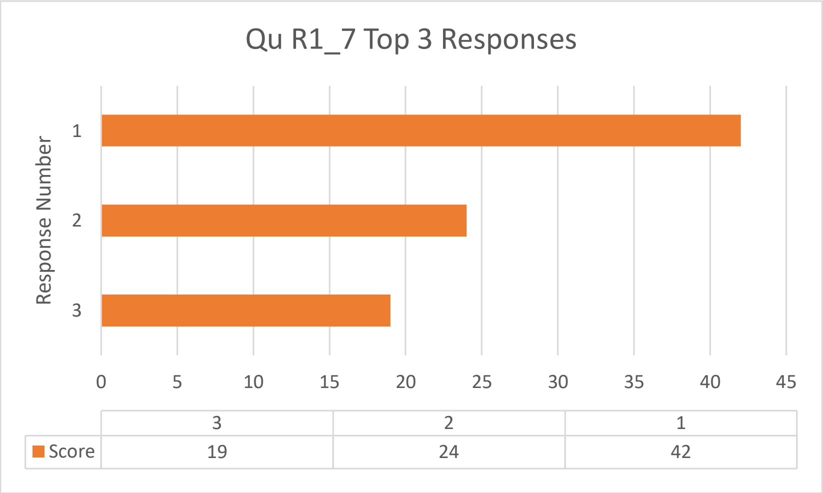
R1_8,11 (Environmental aspects)	What environmental aspects should be considered when making decisions on investments in the energy sector?		
Feedback summary	Pollution to land, air and water supplies should be minimised	Reduction of greenhouse gas emissions	Minimise land use conflicts and negative impacts
Model Inputs	Ban on ICE transport imports (S8 -1.Immediate ban on ICE imports)	All RE sources/no geothermal (S9 -2 No geothermal)	Maximise utility wind (S2 - 2 Utility wind)
Explanation	% of transport fleet to be converted from fossil fuel to electric vehicles	Solar PV, wind, biogas and hydro	Add the maximum amount of wind energy to achieve RE targets
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R1_3,10,13 (Government financial support)	Should government continue to provide financial support for investments in the energy sector or should all energy investments be financially viable on their own?		
Feedback summary	Mixed financing approach	Government provides financial support	Energy investments must be viable on their own
Model Inputs	Blended financing (S10 - 5 Government equity, S13 - 1 Commercial debt) & S4 - 2 Part of profits kept	Government financed (S10 - 5 Government, S13 - 2 Development bank) & S4 - 3 All profits kept in local economy	Commercial finance (S10 - 3 Local Investor, S13 - 1 Commercial) & S4 -2 Part of profits kept
Explanation	70% debt at 8% for 10 years and 30% equity return of 5%	70% debt at 4.5% for 15 years and 30% equity return of 5%	70% debt at 8% for 10 years and 30% equity return of 13%
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R1_9 (RE social acceptance)	Are there any sources of RE that may not be socially acceptable?		
Feedback summary	Exclusion of nuclear energy	Exclude geothermal energy	No RE sources should be excluded
Model Inputs	All RE sources (S9 - 4 All in)	No geothermal (S9 - 2 No geothermal)	All RE sources (S9 - 4 All in)
Explanation	Wind, solar PV, geothermal, biogas, hydro	Wind, solar PV, biogas, hydro	Wind, solar PV, geothermal, biogas, hydro
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R1_4,6 (Country benefits)	What benefits to the country would you like to see from sustainable energy investments?		
Feedback summary	Improved energy security, reliability and resiliency	Reduction in energy tariffs and fossil fuel-based energy production	More distributed generation to enable a system which is more resilient

Model Inputs	Long duration storage	Cost driven energy price (S6 - 2 Lifecycle cost plus profit margin; S3 - 2 Based on RE costs for EVs)	Long duration storage
Explanation	Use of pumped hydro and chemical storage	Energy pricing is based on investment and operations costs of RE plants	Use of pumped hydro and chemical storage
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R1_2 (Priority source of RE)	What sources of energy for electricity generation should receive priority for development in the electricity sector? Why?		
Feedback summary	Solar PV as a source of RE to be given priority	Use of solar PV and wind energy	Use of wind energy
Model Inputs	Maximise utility PV (S2 - 1 Grid connected solar PV with battery backup)	Maximise wind and distributed PV (S2 - 2 Utility wind)	Maximise utility wind (S2 - 2 Utility wind)
Explanation	Maximise utility solar PV use	Up to maximum wind potential plus distributed and utility solar PV (increase solar PV to 2.5 kWp per domestic customer)	Up to maximum wind potential
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R2_RE (RE target)	The GOSL has set a target of 35% by 2025 and 50% by 2030 for generation of electricity from renewable sources. Are you in agreement with this vision? If not, suggest an alternative.		
Feedback summary	Agree with the existing government target	Target for RE penetration should be lower	Targets should be higher
Model Inputs	Government targets agreed (S1 - 1 Government target)	Lower targets (S1 -2 Lower target)	Higher targets (S1 - 3 Higher target)
Explanation	Government targets of 35%/2025; 50%/2030 with addition of 75%/2035; 100%/2040)	Stakeholder targets of 20%/2025; 35%/2030 with addition of 50%/2035; 100%/2040)	Stakeholder targets of 35%/2025; 80%/2030 with addition of 95%/2035; 100%/2040)
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R2_GH (GHG emissions target)	The GOSL has set a target of 7% reduction in GHG emissions in the energy sector relative to 2010, by 2030. Are you in agreement with this vision? If not, suggest an alternative.		
Feedback summary	The target should be lower	The target is adequate	The target should be higher
Model Inputs	Output discussion	Output discussion	Output discussion
Explanation	GHG reductions due to RE calculated and discussed as an output.	GHG reductions due to RE calculated and discussed as an output.	GHG reductions due to RE calculated and discussed as an output.
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R2_EE (EE target)	The GOSL has set a target of 20% reduction in energy consumption in the public sector. Are you in agreement with this vision? If not, suggest an alternative.		

Feedback summary	Target is acceptable	Target should be lower	Target should be higher
Model Inputs	Government target (S12 - 1 Target)	Lower than target (S12 - 3 Less)	Higher than target (S12 - 2 More/maximum)
Explanation	20% EE target for domestic, hotel, industrial and commercial sectors	10% EE target for domestic, hotel, industrial and commercial sectors	23% EE target for domestic, hotel and industrial sectors; 20% EE target for commercial sector
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R2_5,8,12 (Sectors for improved EE)	What economic sectors should receive priority support for improving efficiency of energy consumption, i.e., achieving the same output with less energy?		
Feedback summary	The hotel sector should receive priority support	The commercial sector should receive priority support	The transport sector should receive priority support
Model Inputs	Ice storage pricing (S5 - 1 Ice storage for cooling in hotel sector)	Ice storage pricing (S5 - 1 Ice storage for cooling in commercial sector)	EV pricing (S5 - 2 EV fleet)
Explanation	Reduction in VAT on investments by 10%	Reduction in VAT on investments by 10%	Reduction in VAT on investments by 10%; DG solar EV pricing.
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R3_11,14 (Resilience objectives)	What should be the objectives of developing a resilient energy system in Saint Lucia?		
Feedback summary	A more reliable energy system which is resilient to climate change	Cleaner, sustainable and more affordable sources of energy with reduced carbon emissions	Lower cost and more affordable energy
Model Inputs	Long duration storage	Maximise wind and distributed PV (S2 - 2 Utility wind)	Cost driven energy price (S6 - 2 Lifecycle cost plus profit margin; S3 - 2 Based on RE costs for EVs)
Explanation	Use of pumped hydro and chemical storage	Up to maximum wind potential plus distributed and utility solar PV	Energy pricing is based on investment and operations costs of RE plants
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R4_6,14 (Stakeholder objectives for transition)	What are your objectives for transitioning the energy sector to sustainable energy (RE and energy efficiency)?		
Feedback summary	More control of and to reduce the cost of energy	More reliable energy system with higher energy security	Reduction in greenhouse gas emissions

Model Inputs	Cost driven energy price (S6 - 2 Lifecycle cost plus profit margin; S3 - 2 Based on RE costs for EVs)	Long duration storage	Output discussion
Explanation	Energy pricing is based on investment and operations costs of RE plants	Use of pumped hydro and chemical storage	GHG reductions due to RE calculated and discussed as an output.
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R4_1,10 (Public participation)	How should the general public participate in a transition to sustainable energy?		
Feedback summary	Public consultation, education and awareness building	Higher energy efficiency	Emphasis on distributed forms of energy generation
Model Inputs	Stakeholder engagement	Mandated transition of FF to RE (S11 - 3 Mandated)/Conversion to EV fleet (S8 - 1 Immediate ban on ICE imports)	Use of distributed solar PV
Explanation	Discussion of inputs/outputs	% of projected fossil fuel demand in domestic, industrial, hotel and commercial sectors converted to electricity demand/% of transport fleet to be converted from fossil fuel to electric vehicles	Domestic DG solar enabled

Cells shaded in 'green' are unique to the scenario and cells shaded in 'grey' show inputs that may be shared by at least two (2) scenarios. The following section provides detailed description of responses to each question and how the responses are integrated into the energy model.



1) We need to start with the legislation, currently we have restrictions on the size of the solar units one can place on their business and homes, this needs to change. Energy governance, enabling legislation, fiscal incentives for investments, energy policy and implementation plan that is responsive to energy landscape. Incentivise transition to renewable energy. Development of supportive regulatory frameworks.
2) We need to invest more in non-oil sources of energy generation, e.g., wind, solar, hydro, geo-thermal. There needs to be diversity driven by a national policy. Increased generation of electricity must continue with renewables and the market for generation and sale should not be a monopoly held by LUCELEC. Use of alternative energy sources: solar, wind and wave energy. Renewable clean energy. Other national priorities would be diversification (not relying on one source, but exploring geothermal, solar, wind, hydro, biomass energy in areas where these sources are plentiful on the island), and decentralization of energy systems. In other words, in the context of St Lucia can we adopt a hybrid energy system? Increased access to renewable energy. Electricity is a widely used form of energy in Saint Lucia and access and cost of electricity has a major impact on quality of life, productivity and growth. As such electricity for service delivery and economic activity should be prioritised. Expansion of renewable forms of energy for electricity generation – focus on solar, wind and geothermal. Develop a more diverse energy mix by investing significantly in the development of renewable energies in particular geothermal, wind, solar and biogas. This would reduce the dependence and intake on fossil fuels and energy imports. Once sustainable electricity is provided it can be used for both Cooking and Transportation. Electricity (household green energy). Using renewable energy for heating and drying applications.
3) Access to financing, for homes, small-medium size businesses, this will allow persons to be able to implement renewable energy projects which can improve efficiency and reduce our carbon footprint at the same time. Addressing the issue of high costs and lack of suitable financing for RE technologies.

Figure 34 Responses to survey question 1 (R1_7)

6.2.1 Question 1 (Survey R1_7)

What should be the national priorities for improving energy security in the energy sector (electricity, transport, cooking, et cetera)? Responses are summarised in Figure 34.

6.2.1.1 Modelling Inputs Question 1

6.2.1.1.1 First Rank

In option 1, the first ranked response, the key points expressed by the stakeholders are the need for improved energy governance through a revised energy policy, implementation plan, legislation and improved regulatory framework. It can be argued that the implementation plan will be agreed by all stakeholders resulting in firm and achievable targets for transitioning all fossil fuel demand to RE.

There are no existing targets for conversion of all fossil fuel demand to electrical energy demand. Consequently, the same targets, for average RE penetration relative to total energy generation, are assumed. In the model, the target inputs for fossil fuel conversion to RE in all sectors, by year, are provided in Table 67.

Table 67 Target for conversion of fossil fuel demand to electricity demand

Year 5	Year 10	Year 15	Year 20	Year 25
35%	50%	75%	100%	100%

The input is used in the 'SS Model Master' workbook to modify the conversion of fossil fuel demand to electricity in the sectors industrial, commercial, hotel and domestic. In the 'TS System Model Master' the input is stakeholder requirement 'S11', selection option '3 Mandated'. This option selects the values provided in Table 67 based on the year under analysis.

6.2.1.1.2 Second Rank

In option 2, the second ranked response, the stakeholders are requesting increased generation from RE options available to Saint Lucia including geothermal, solar, wind, biogas, biomass and hydro options. Biomass is not analysed as there is no existing forestry or similar activity that would generate biomass resources for energy generation in Saint Lucia. In their response to question R1_9, stakeholders have also excluded geothermal in their second ranked response.

The input used in the 'TS Model Master' workbook enables the analysis of the various forms of RE with the stakeholder requirement 'S9', selection option '2 No geothermal' which excludes geothermal. This option enables solar, biogas and hydro options. Wind and solar PV are automatically included in all calculations.

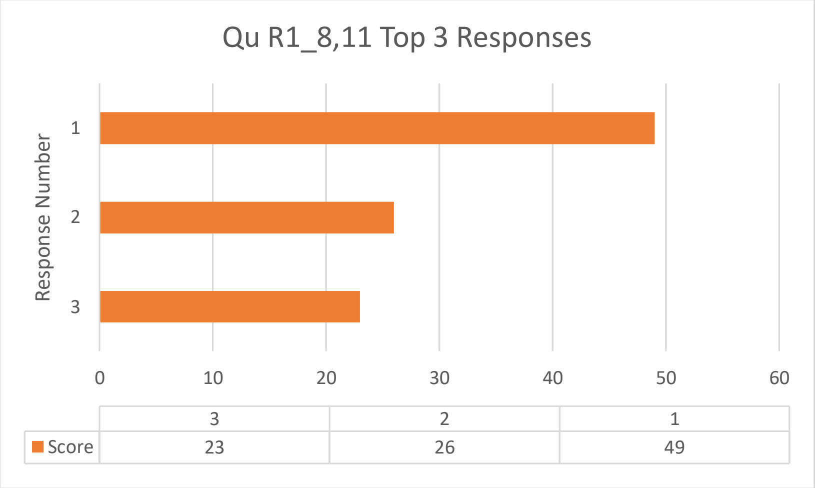
6.2.1.1.3 Third Rank

In option 3, stakeholders cite the issues of high costs, improving efficiency and reducing carbon footprint which are investigated by supporting the transition of the transport fleet to electric vehicles. The first input used in the 'TS Model Master' is 'S5' selection option '2. EV Fleet'. This option reduces the VAT on EV fleet investments by 10% for all classes of EVs.

The second input is used in the 'SS Model Master' workbook to modify the conversion of fossil fuel demand to electricity in the industrial, commercial, hotel and domestic sectors. In the 'TS System Model Master' the input is stakeholder requirement 'S11', selection option '3 Mandated'. Input values are provided in Table 67.

The third input used is a ban on import of internal combustion engine (ICE) vehicles and is assessed with all retired transport also being replaced with electric vehicles. All new vehicles imported must be electrified. The input used in the 'TS Model Master' is 'S8' selection option '1 Immediate ban on ICE imports' which is used in the 'SS Model Master' tab 'SS Transport FF Inputs' to set the rate of conversion of ICE vehicles to EVs. To accomplish a 100% fleet transition in twenty (20) years, the existing fleet must be retired at a rate of 5% per annum. Consequently, the fleet conversion rate in Table 68 has been used for the calculations.

6.2.2 Question 2 (Survey R1_8,11)



1) There must be very little or no impact to surface or ground water supplies and quality of air. Therefore, these two (2) must be at the forefront of any decision to alter the sector. Impact on water quality and consumption where water is used for cooling as in the case for geothermal energy. Impact on air quality, water resources, MEA compliance. Climate change, emissions, pollution in whatever form air, water, land, noise. No negative impact on environment. I firmly believe that the environment as a whole must be considered. That being said energy production must consider land, air and water pollution and their adverse effects. Increasingly, it can be noted that issues such as greenhouse emissions, climate change (change in weather and climate patterns), contaminated water and ground; and also reduced air quality.
2) Carbon emissions from particular investment. GHG emissions level is low but has shown a slight increase over the 2010 baseline. Therefore, selective investments should be significant enough to reduce level. GHG emissions, pollutants, other impacts on flora and fauna. Energy emission costs and applicable legislation in that regard. Impact on the environment in terms of CO2 or productive use e.g., agriculture, tourism et cetera. Reduced carbon footprint. Contributions to carbon sequestration. Availability of the renewable resource. Energy generation that produces no or little greenhouse gases.
3) Geographic constraints for equipment set up- landscaping and logistical impacts. Population density, space occupation for energy system and impact on community (social and economic impact, for example, whether agricultural land will be taken away, would public access to certain areas be restricted once the energy systems are installed?) The impact on existing and future land uses including potential conflicts, opportunities for co-existence and making optimal use of land resources. Monitoring of environmental impacts is also important, particularly impact on health. The amount of land required and opportunity cost. Compatibility of energy equipment with wildlife, building codes for the community et cetera. The impact on ecosystems such as mangroves and rivers should be factored in. Impact on wildlife and habitat. Land disturbance how would it affect farmers, land owners. Health impact on animal life, impact on the natural environment. Noise impact. Impact on the immediate ecosystem. Legislative constraints that may impede use of certain areas, such as protected

> Impact of investment on land and marine ecosystems. Would energy equipment and infrastructure affect other existing structures, such as communications infrastructure? Would these need to be modified to integrate in the drive towards the "green energy transformation?" Whether the manufacturing plant location will be viable in the long run – will the location be more conducive to other developmental innovations? The waste from the process (there is still some) how will it affect the environment? The level of consumption and the rate at which it can be renewed – does it harm the environment?

Figure 35 Responses to survey question 2 (R1_8,11)

What environmental aspects should be considered when making decisions on investments in the energy sector? Responses are summarised in Figure 35.

6.2.2.1 Modelling Inputs Question 2

6.2.2.1.1 First Rank

In option 1, the first ranked response, stakeholders require that pollution to land, air and water supplies be minimised or eliminated. Solar and wind energy projects result in minimal adverse environmental impacts. Anaerobic digestion for production of biogas is used to treat organic waste to reduce environmental pollution. As run of river hydro is the hydropower option considered, environmental impacts are anticipated to be minimal. A closed loop binary ORC geothermal plant is considered. All geothermal fluids are pumped back into the earth and emissions are kept to a minimum. Consequently, the highest impact for reducing potential of land, air and water pollution is to reduce the use of fossil fuels. As use of RE for electricity generation will ultimately achieve this objective, focus is placed on electric mobility in the transport sector to respond to this stakeholder requirement.

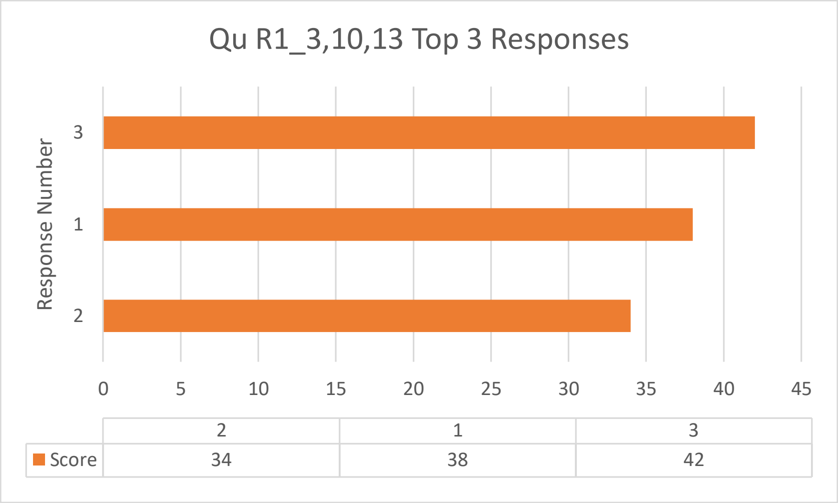
In modelling, a ban on the import of ICE vehicles are assessed with all retired transport also being replaced with electric vehicles. All new vehicles imported must be electrified. The input used in the 'TS Model Master' is 'S8' selection option '1-Immediate ban on ICE imports' which is used in the 'SS Model Master' tab 'SS Transport FF Inputs' to set the rate of conversion of ICE vehicles to EVs. To accomplish a 100% fleet transition in twenty (20) years, the existing fleet must be retired at a rate of 5% per annum. Consequently, the fleet conversion rate in Table 68 has been used for the calculations.

Table 68 Transport fleet conversion rate to EVs

Year 5	Year 10	Year 15	Year 20	Year 25
25%	50%	75%	100%	100%

6.2.2.1.2 Second Rank

In option 2, the second ranked response stakeholders require that new energy investments result in a reduction of greenhouse gas emissions. As all the sources of RE available for exploitation have much lower emissions than fossil fuel generation, all options could be used in the modeling, however, in their response to question R1_9, stakeholders have also excluded geothermal in their second ranked response.



3) There should be a mixed approach. In the case of fledgling local enterprises that may lack the financial wherewithal but have sustainable plans partnerships should take place. Incentives for renewable energy developments too can spurn the interests of private investors regionally and internationally. Government support is needed to ensure a proper functioning society as the energy sector can face market failures for which regulations are necessary. Support from the government is needed, however, it should be equitably available. Support should be provided at start up, with a specific set target to be attained by the business. At which point the government investment / support should stop. The business should then become viable, sustainable and ongoing without aid and or assistance. Government should create the fiscal space for private investors. Through concessions. These concessions will allow all energy investments to be financially viable on their own.
1) With the current rises in fuel, transportation, other raw materials, I believe that the government should continue to provide support. The absence of that may mean that persons who fall in the low-income bracket may not be able to afford electricity. Energy investment has always enjoyed government subsidies particularly when starting operations. I therefore believe that as we push to energy diversity particularly in renewable financial support from government must continue. …. Tax incentives among other support measures are surely needed for budding energy companies. I believe government should provide assistance to investments within the energy sector. Additionally, because of the high start-up costs, limited resources and the importance of moving towards a greener energy space globally I believe that government has as an obligation to provide support (both technical and financial) to viable investments within the sector. It can also be noted that the overall benefits of such projects to small island states can be invaluable and help us to significantly reduce our energy and import (fossil fuel) bill. Government must definitely continue to provide financial support as majority of persons with the ideas do not have the financial means in SIDS…Gov't may have to support financially to encourage the development of renewable energy projects that deliver long-term benefits.

Within the context of Saint Lucia and other SIDS, governments should continue to provide some financial support even if it is indirect support as these have proven to be a major catalyst for increased energy investments.

2) The energy company needs to diversify in other sources of energy that can be cheaper for consumers, good for the environment and profitable enough to be viable on their own. No direct financing from Govt. Ultimately the aim should be to have a financially viable energy sector especially as there is the thrust towards low-carbon economy. However, government should create the enabling environment towards this together with relevant players. Critically though, the role of government should be to create the necessary enabling environment to facilitate investments and innovation by the private sector. Government ought to create an enabling environment for investments including policy and legislative frameworks. Additionally, governments ought to incentivise investors and incrementally transition to private sector. In so doing the energy sector will become financially sustainable. Energy investments should be viable on their own.

Figure 36 Responses to survey question R1_3,10,13

The input used in the 'TS Model Master' workbook enables the analysis of the various RE forms with the stakeholder requirement 'S9', selection option '2 No geothermal' which excludes geothermal. This option enables solar, biogas and hydro options. Wind and solar PV are automatically included in all calculations.

6.2.2.1.3 Third Rank

In option 3, stakeholders require that conflicts with land use and negative impacts on other potential land uses for infrastructure and ecosystems be kept to a minimum. Since utility scale solar PV would have the largest land requirement for the same installed capacity, when compared to wind and geothermal energy, the amount of this resource will be minimised. The hydro and biogas resources are very small in comparison to the other sources and will not have a significant land use impact.

The 'TS Model Master' input 'S2' selection option '2 Utility wind' will be selected as the option to be maximised while keeping utility solar PV at the minimum required to achieve energy targets.

6.2.3 Question 3 (Survey R1_3,10,13)

Should government continue to provide financial support for investments in the energy sector or should all energy investments be financially viable on their own? Responses are summarised in Figure 36.

6.2.3.1 Modelling Inputs Question 3

6.2.3.1.1 First Rank

In option 3, the first ranked response, stakeholders are suggesting that a mixed financing approach be used to support investments in the RE sector. Government support should be provided to enable commercial financing to be accessed.

Three (3) modelling inputs are used. The first is for the source of equity financing entered as input to the 'TS Model Master' 'S10', selection option '5 Government'. This option sets the following financial parameters for calculations assuming a mix of 30% local government equity financing with required return of 5%. The second is commercial debt financing set with ‘S13’ selection option ‘1. Commercial’. This sets the debt term to 10 years at an interest rate of 8%.

The third modelling input to the ‘TS Model Master’ is ‘S4’ selection option ‘2 Part of profits kept in the local economy’. This option assumes some of the profits from operating the RE plants are re-invested in the local economy. It also assumes some level of local investor ownership financed with commercial terms. The mix of government facilitated equity and investor commercial financing satisfies the requirement of a mixed approach to project financing.

6.2.3.1.2 Second Rank

In option 1, the second ranked response, stakeholders require that government provides financial support for RE investments. This can be accommodated by enabling access to debt financing by the general public at the same concessional rates accessible by Government from international development banks.

Three (3) modelling inputs are used. The first is for the source of equity financing entered as input to the ‘TS Model Master’ ‘S10’, selection option ‘5 Government’. This option sets the financial parameters for calculations assuming a mix of 30% local government equity financing with required return of 5%. The second is development bank debt financing set with ‘S13’ selection option ‘2 Development bank’. This sets the debt term to 15 years at an interest rate of 4.5%.

The third modelling input to the ‘TS Model Master’ is ‘S4’ selection option ‘3 All profits kept in the local economy’. This option assumes all the profits from operating the RE plants are re-invested in the local economy. It also assumes local investor ownership financed with government facilitated debt and equity terms.

6.2.3.1.3 Third Rank

In option 2, the third ranked response, stakeholders require that energy investments be viable on their own without government financial support. For this option, it is assumed that commercial debt financing is used and equity is provided by foreign investors.

Three (3) modelling inputs are used. The first is for the source of equity financing entered as input to the ‘TS Model Master’ ‘S10’, selection option ‘3 Local Investor’. This option sets the financial parameters for calculations assuming a mix of 30% equity financing with required return of 13%. The second is commercial bank debt financing set with ‘S13’ selection option ‘1 Commercial’. This sets the debt term to 10 years at an interest rate of 8%.

The third modelling input to the ‘TS Model Master’ is ‘S4’ selection option ‘2 Part of profits kept in the local economy’. This option assumes some of the profits from operating the RE plants are re-invested in the local economy. It also assumes some level of local investor ownership financed with commercial terms. The financing parameters satisfy the requirement for energy investments to be commercially sourced.

6.2.4 Question 4 (Survey R1_9)

Are there any sources of RE that may not be socially acceptable? Responses are summarised in Figure 37.

6.2.4.1 Modelling Inputs Question 4

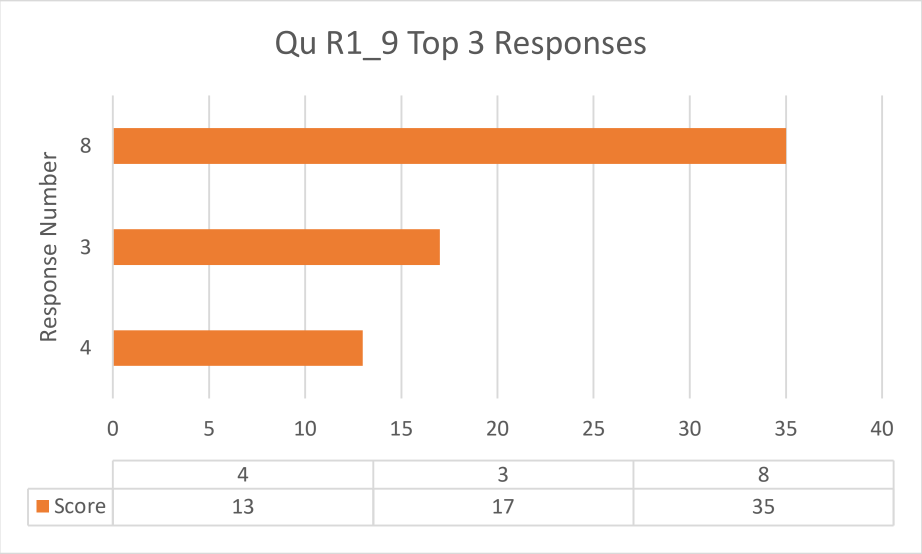
6.2.4.1.1 First Rank

In option 8, the first ranked response, stakeholders indicate exclusion of consideration of sources of nuclear energy. This does not affect the sources of RE available in Saint Lucia, viz., solar PV, wind, biogas, geothermal and hydro, so all will be considered.

The model option used is input ‘S9’ selection input ‘4 All in’ which includes all sources of RE in all analyses.

6.2.4.1.2 Second Rank

In option 3, the second ranked response, stakeholders exclude geothermal energy as an option to be considered. The model input to be used is input ‘S9’ selection input ‘2 No geothermal’ which excludes geothermal energy from all analyses.



8) Nuclear sources.

3) A source of energy which may not be socially acceptable is that of geothermal energy for fear of eruptions. In St Lucia Geothermal Energy might be the only source of renewable energy which will not be socially acceptable as the drive-in volcano, which is a tourist attraction, will have to be repurposed to harness the energy. I do not think that locals are in favour of interfering with the Sulphur Springs to generate electricity. I have sat in many town hall discussions on this. The majority of people in Soufriere who were invited to these forums spoke passionately against interfering with the volcano. They believe this will have more catastrophic consequences than the geothermal energy exploitation mission sought after. Geothermal in Belplaine Soufriere is not viewed favourably by the residents of the potential drilling area. Perhaps geothermal because of the association with earthquakes. There may be some misgivings about geothermal energy because of the perception that it can trigger volcanic activity.

4) To my knowledge there are none which have garnered any social discontent. No issues with any of the renewable sources being contemplated.

Figure 37 Responses to survey question R1_9

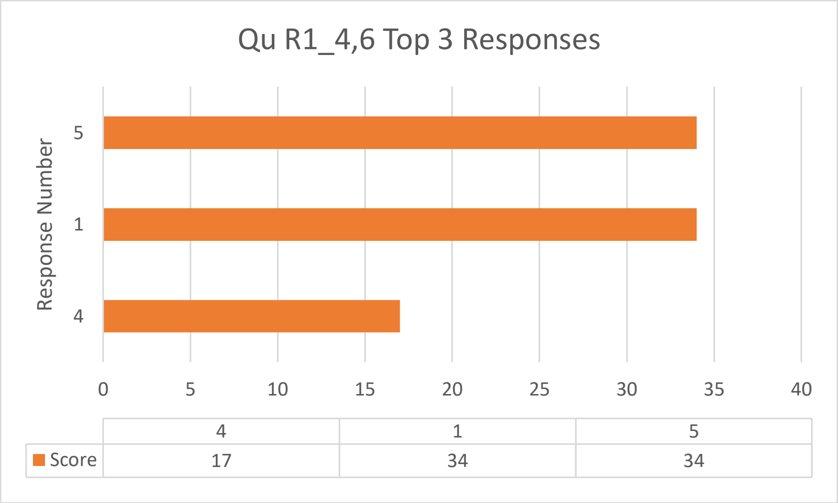
6.2.4.1.3 Third Rank

In option 4, the third ranked response, stakeholders express explicitly that no RE sources should be excluded.

The model option used is input ‘S9’ selection input ‘4 All in’ which includes all sources of RE in all analyses.

6.2.5 Question 5 (Survey R1_4,6)

What benefits to the country would you like to see from sustainable energy investments? Responses are summarised in Figure 38.



5) Energy security, economic growth, enhanced reliability and resiliency particularly from natural disasters. Increased resilience of the energy system to external shocks.

1) Reduced tariffs, reduced rates. Reduction in energy cost to consumers. Ultimately a lower cost of living and greater stability w.r.t. cost of input materials or sources (e.g., fossil fuels vs solar). Reduce energy cost to consumers. Reducing the cost of energy, productive use of sustainable energy investments in manufacturing and other sectors which directly impact the country. Reduced energy tariffs to allow improved economic growth. Reduction in oil-based energy production, savings from the reduction of importation of fuel. Reduction in energy costs, reduction in fuel importation bill. Stable and possible lower energy prices, environmental integrity and local ownership. Cost containment. Reduced currency outflows. Energy Security and financial protection from the volatility of fuel pricing. Being energy independent. Reduced reliance on foreign sources of energy. Less reliant on imported fuel / energy hence better able to mitigate the associated risks in regards to shortages and price. Sustainable futures, improve efficiencies, reduced production costs. Improved quality of life. Reduced volatility of electricity prices in response to oil price shocks.

4) More efficient power supply, with very few outages or fluctuations. Greater resilience in post hurricane recovery through more distributed generation. Modernization of outdated infrastructure to support Smart initiatives. Encouragement and support for innovation and development in new technologies in general. Better consumer choices / options. Attraction of grant funding.

Figure 38 Responses to survey question R1_4,6

6.2.5.1 Modelling Inputs Question 5

6.2.5.1.1 First Rank

In option 5, the first ranked response, stakeholders want improved energy security, reliability and resiliency from external shocks and natural disasters. Arguably, all these parameters can be met with indigenous RE to provide energy security coupled with long duration energy storage to add reliability and resilience to the electricity network. This input will place emphasis on the use of pumped hydro and chemical energy storage.

In the 'TS Model Master' the input used is the maximum estimated PHS capacity available as well as battery energy storage.

6.2.5.1.2 Second Rank

In option 1, the second ranked response, stakeholders would like to see a reduction in energy tariffs and fossil fuel-based energy production. This requirement will be analysed by looking at the impact on final energy cost to consumers from increasing the share of RE in the generation mix.

Two (2) inputs are used. 'TS Model Master' input used is 'S6' selection option '2 Lifecycle cost plus profit margin'. This option analyses final tariff to the end consumer based on investment, operation and maintenance costs and expected net profit of RE power plants.

The second 'TS Model Master' input used is 'S3' selection option '2 Based on RE costs for EVs'. This input sets the cost for charging EVs based on investment, operation and maintenance costs of RE power plants.

6.2.5.1.3 Third Rank

In option 4, the third ranked response, stakeholders would like more distributed generation to enable a system which is more resilient to natural disasters. To enable this, RE coupled with long duration energy storage will be utilised. This input will place emphasis on the use of pumped hydro and chemical energy storage.

In the 'TS Model Master' input used is the maximum estimated PHS capacity available as well as battery energy storage.

6.2.6 Question 6 (Survey R1_2)

What sources of energy for electricity generation should receive priority for development in the electricity sector? Why? Responses are summarised in Figure 39.

6.2.6.1 Modelling Inputs Question 6

6.2.6.1.1 First Rank

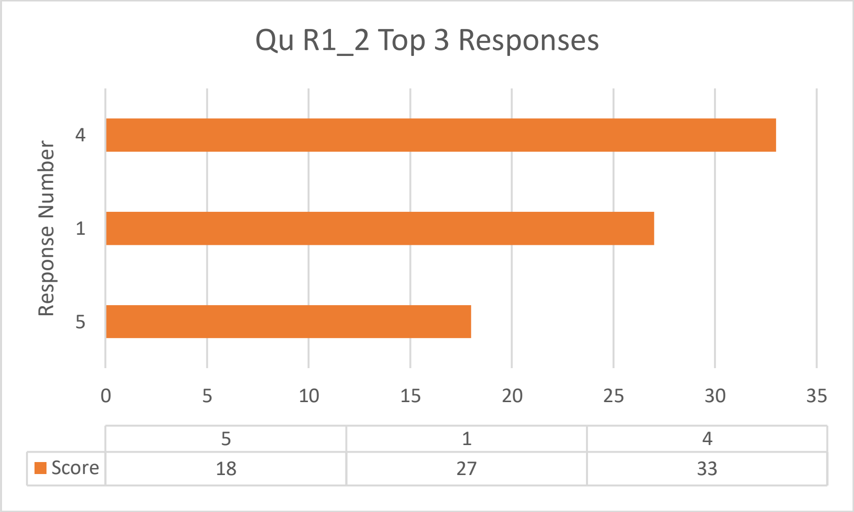
In option 4, the first ranked response, stakeholders chose solar PV as a source of RE to be given priority for development.

In the 'TS Model Master' the input used is 'S2' selection option '1 Grid connected solar PV with battery backup'. This will enable utilisation of up to the maximum available capacity of utility scale solar PV which is distributed in different locations.

6.2.6.1.2 Second Rank

In option 1, the second ranked response, stakeholders would like to emphasise the use of solar PV and wind energy.

In the 'TS Model Master' the input used is 'S2' selection option '2 Utility wind' to enable up to the maximum wind capacity to be utilised. Distributed solar PV is enabled in the 'SS System Model Master' with 2.5 kWp installed capacity per domestic customer and utility solar PV is also utilised.



4) Solar - We are in the tropical zone. There is an abundance of sun all year round, and in every part of the island. We have evidence from solar water heaters, solar powered businesses and homes that this can be yoked and is efficacious. Solar because of its simplicity, (ease of conversion, mature technology), Opportunity for quick rollout. I believe solar energy should be prioritised given that some inroads have already been made by electricity company LUCELEC, and entities such as Solar Dynamics with solar hot water systems. Expansion might be easier for this source given our prevailing climatic conditions as well. Low hanging fruit, assessment show potential for generating significant power and land space is available especially for crown lands. Country has rich solar resources which should be further exploited in respect of DG and utility scale projects…

1)	Solar and wind. The natural abundance of supply on island. The fact that they complement each other with solar peak production during the day and wind sustaining generation throughout the night. I believe they are easier to install and maintain. Also, I believe they are environmentally friendly, most persons have some knowledge of the two and it may be more socially acceptable in the short-term; because the technology involved are well established. Solar and Wind because of the potential that exists for these forms and also because they are becoming competitive with conventional generation particularly with falling battery prices that can help address the issue of intermittency and stability. These sources should receive priority for development because (i) of the island's favourable resource potential (ii) they are proven technologies that can be procured at reasonable cost (and costs are rapidly declining) (iii) they were identified in the most recent National Energy Transition Strategy.
5)	Wind due to its availability and consistency.

Figure 39 Responses to survey question R1_2

6.2.6.1.3 Third Rank

In option 5, the third ranked response, stakeholders would like emphasis to be placed on the use of wind energy.

In the 'TS Model Master' the input used is 'S2' selection option '2 Utility wind' to enable up to the maximum wind energy potential to be utilised.

6.2.7 Question 7 (Survey R2_RE)

The St. Lucia Government (GOSL) has set a target of 35% by 2025 and 50% by 2030 for the generation of electricity from renewable sources. Are you in agreement with this vision? If not, suggest an alternative.

All modelling inputs assume a 2040 target of 100%. Responses are summarised in Figure 40.

6.2.7.1 Modelling Inputs Question 7

6.2.7.1.1 First Rank

In option 1, the first ranked response, stakeholders agree with the existing government target generally indicating that it can be achieved but a lot of work is needed.

In the 'TS Model Master' the input used is 'S1' selection option '1 Government target'. This option uses the government set RE targets in Table 69 for 2025 and 2030 along with additional assumed targets for 2035 to 2045 which are used in the calculations.

Table 69 Government RE penetration targets plus assumed targets for 2035 to 2045

Year	2025	2030	2035	2040	2045
Target RE penetration	35%	50%	75%	100%	100%

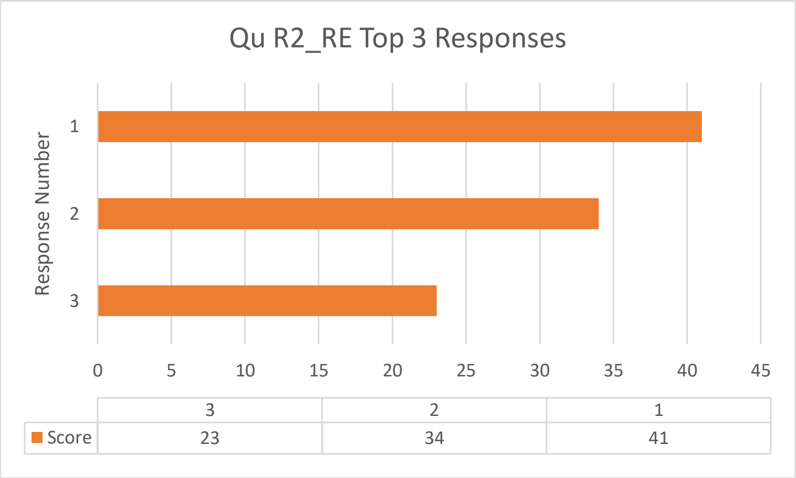
6.2.7.1.2 Second Rank

In option 2, the second ranked response, stakeholders think that the target for RE penetration should be lower. They have also suggested potential revised targets some of which have been assumed in the analysis.

In the ‘TS Model Master’ the input used is ‘S1’ selection option ‘2 Lower target’. This option sets the assumed targets suggested by the stakeholders and provided in Table 70.

Table 70 Lower RE penetration targets

Year	2025	2030	2035	2040	2045
Target RE penetration	20%	35%	50%	100%	100%



1) Yes, I am in agreement, we have already seen strides with implementation of LUCELEC’s 3MW the solar farm in La Tourney Vieux Fort. In agreement but should be noted that at the time targets were set, the landscape seemed more poised towards achieving through wind and solar. Much work is required through geothermal given the stage at which development process is at, so 2030 target may need adjustment or steady and significant investment in solar is needed together with supporting legislation especially on existing maximum cap allowed. Generally, “yes”, although higher benchmarks would always be better…
2) (Lower). I do not believe we have the political will to execute and realize this goal. I believe that the vision can manifest to an extent. I would therefore suggest 20% by 2025 and 40% by 2030. I find this timeline impossible to meet. We are presently experiencing the worst economic downturn and financial recession in the history of world economies catalysed by the Covid-19 pandemic. It may take us years to ricochet from this blow. Government will need to expedite their plans with the commensurate financial resources to enable progress in order to achieve this target.

	In the absence of these, it is surely a tall mandate. I would extend 35% to 2035 and 50% to 2040. The timelines are way too short and targets are too ambitious considering where we're currently at. The timelines should be over a thirty-year time frame. I think the targets may serve as motivation but given the current pace of development they do not seem achievable. I don't think these goals will be achieved given the political landscape in St Lucia. There needs to be an apolitical approach with a commitment by all political organisations jointly to prioritize these goals. Considering it's already 2022, these targets are unrealistic. Given our current status a more realistic target would be 35% by 2030 and 50% by 2035. I was unaware of this; perhaps better methods of communicating these aspects and its benefits to the country should be explored. I would want to know whether this is achievable by 2025, if not a more realistic goal should be put in place, say 25%.
3)	(Higher). 2030 should be revised to 80%. I think by the year 2030 we should be close to 100%. Our energy usage is very small compared to developed countries so it is very easy to implement renewable sources of energy.

Figure 40 Responses to survey question R2_RE

6.2.7.1.3 Third Rank

In option 3, the third ranked response, stakeholders expressed that the targets should be higher and provided suggestions.

In the 'TS Model Master' the input used is 'S1' selection option '3 Higher target'. This option sets the assumed targets suggested by the stakeholders and provided in Table 71.

Table 71 Higher RE penetration targets

Year	2025	2030	2035	2040	2045
Target RE penetration	35%	80%	95%	100%	100%

6.2.8 Question 8 (Survey R2_GH)

The Government of Saint Lucia (GOSL) has set a target of 7% reduction in GHG emissions in the energy sector relative to 2010, by 2030. Are you in agreement with this vision? If not, suggest an alternative. Responses are summarised in Figure 41.

6.2.8.1 Modelling Inputs Question 8

6.2.8.1.1 First Rank

In option 1, the first ranked response, stakeholders indicate that the target should be lower as they are skeptical of the government's ability to achieve the set target.

The impact on GHG emissions is an output of the analysis and will be reviewed in the results discussion.

6.2.8.1.2 Second Rank

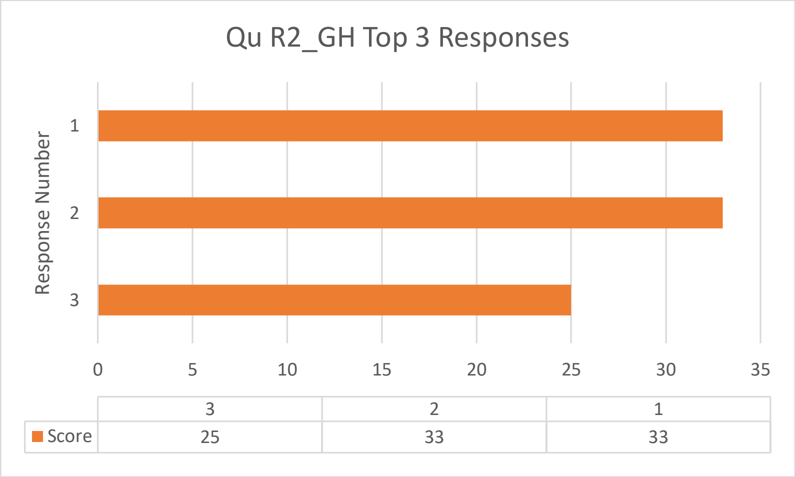
In option 2, the second ranked response, stakeholders think that the target is adequate and achievable.

The impact on GHG emissions is an output of the analysis and will be reviewed in the results discussion.

6.2.8.1.3 Third Rank

In option 3, the third ranked response, stakeholders think the target is not aggressive enough and should be higher.

The impact on GHG emissions is an output of the analysis and will be reviewed in the results discussion.



1) No - (Lower) historically we have not been able to achieve a 5% reduction, there has been not consistent decline, I would suggest a target of at least 3%. I agree with this vision, but in the current environment I believe 3.5% is more practical why? Opportunities for high impacts visible reductions are limited, hotels and the small manufacturing sector should be purposely targeted.

2) Yes - I believe that we can reduce our emissions by 7% considering that our emissions are already significantly low. This seems attainable if we adopt an aggressive approach to fulfilling the mandate of renewable energy cultivation. We can accomplish a lot in 8 years with adequate funding and intellectual power. Yes, attainable especially with thrust to increase EV use. 7% reduction is a bit low but is a fair target as majority of GHG are from vehicles in SIDS. It means that majority of vehicles will have to shift to electric for GHG to be reduced significantly…

3) No – (Higher); it should be close to 50%. Such a target seems very mediocre. Perhaps reduction should match that of renewable energy targets and at the very least 25%.

Figure 41 Responses to survey question R2_GH

6.2.9 Question 9 (Survey R2_EE)

The Government of Saint Lucia (GOSL) has set a target of 20% reduction in energy consumption in the public sector. Are you in agreement with this vision? If not, suggest an alternative. Responses are summarised in Figure 42.

6.2.9.1 Modelling Inputs Question 9

6.2.9.1.1 First Rank

In option 2, the first ranked response, stakeholders indicate that the government set target is acceptable and attainable.

The input used in ‘TS Model Master’ is ‘S12’ selection option ‘1 Target’. This sets the target for energy efficiency in the sectors domestic, hotel, commercial and industrial as provided in Table 5.

6.2.9.1.2 Second Rank

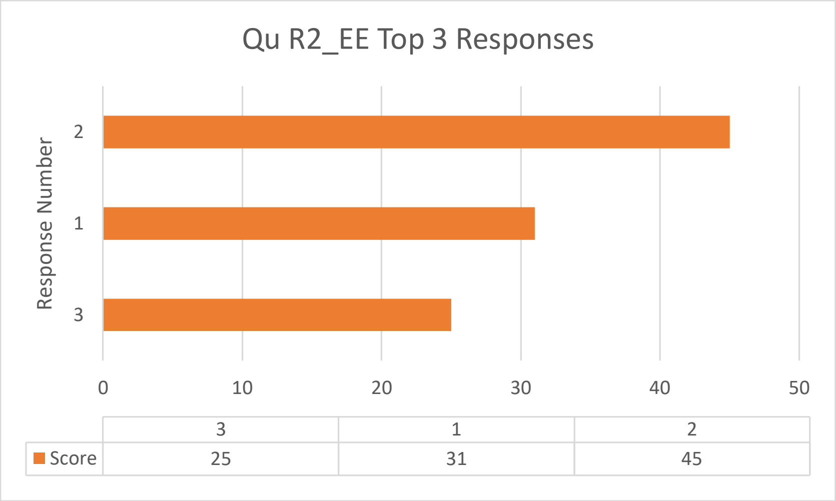
In option 1, the second ranked response, stakeholders indicate that the target should be lower as there is not enough public confidence that it can be achieved.

The input used in ‘TS Model Master’ is ‘S12’ selection option ‘3 Less’. This sets the target for energy efficiency in the sectors domestic, hotel, commercial and industrial as provided in Table 5.

6.2.9.1.3 Third Rank

In option 3, the third ranked response, stakeholders indicate that the target is not aggressive enough and should be set higher.

The input used in ‘TS Model Master’ is ‘S12’ selection option ‘2 More/Maximum’. This sets the target for energy efficiency in the sectors domestic, hotel, commercial and industrial as provided in Table 5.



2) Agree - Should more consideration be given to the use of resources within the public sector I am sure we can reduce consumption by 20% or even more. 20% reduction is fair. Generally, “yes”, although higher benchmarks would always be better. I am, but it depends on the time frame. I would like to know how this vision would be achieved. Yes, can be achieved through further retrofitting (and M&E) and good practices. There is a lot that the Government can do to meet this target in the public sector. It is very achievable. This is a reasonable target…

1) No (Lower) - I do not see that happening. The GOSL continues to rent property in various districts/constituencies around the island in other to achieve that target they would have to build their own facilities that will be built with the mind set of achieving that target. The target was set with no clear strategy for achieving it. It is past 2020 and while a few EE interventions have taken place there is need for more investments.

3) No (Higher), it can be closer to 50%. Should aim higher.

Figure 42 Responses to survey question R2_EE

6.2.10 Question 10 (Survey R2_5,8,12)

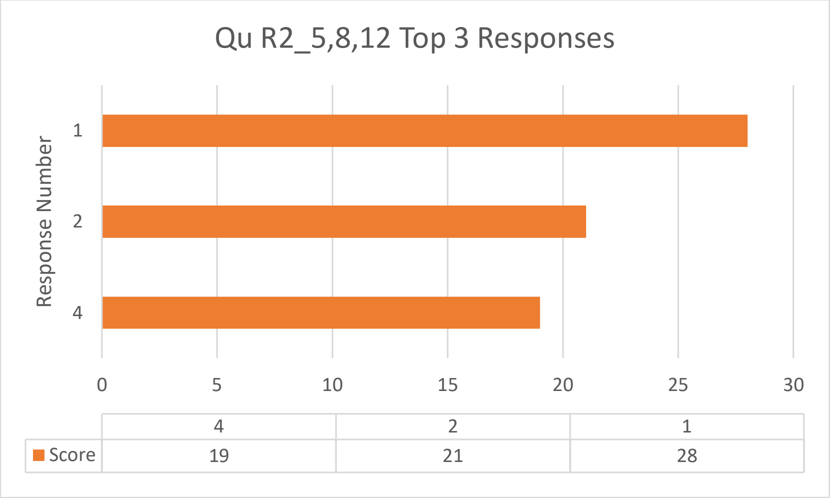
What economic sectors should receive priority support for improving efficiency of energy consumption, i.e., achieving the same output with less energy? Responses are summarised in Figure 43.

6.2.10.1Modelling Inputs Question 10

6.2.10.1.1 First Rank

In option 1, the first ranked response, stakeholders indicate that the hotel sector should receive priority support for improving efficiency of energy consumption. This is normally achieved using more efficient lighting and air conditioning which is modelled using ‘TS Model Master’ input ‘S12’.

It is proposed that network level transmission losses can also be reduced by reducing the electricity demand during peak daytime hours when air conditioning is most needed. One way to achieve this is by having ice storage that makes use of RE when available to make ice. The stored ice can be used to provide cooling when demand is high and cheaper sources of RE are not available. This reduces the demand on the electricity network.



1) Tourism because collectively, it’s the largest single commercial utiliser, impact of cost of energy receives greater attention hence there is a basis for collective strategies to be formulated. Tourism related services. Hotel sector.
2) The manufacturing sector, though there are not many, should receive priority. Private business (manufacturers), Commercial, Industrial, Construction.

4) The public transportation sector and the government fleet of vehicles. These all-use fossil fuels the foremost source of pollution and GHG. Transportation sector, public transport – minibuses can be mandated to be replaced with hybrids or vehicles with an agreed fuel economy. Suggested lower import duties and road tax on these. The transportation and commercial sectors should receive support. Especially bus, taxi and government transportation.

Figure 43 Response to survey question R2_5,8,12

The input used in the ‘TS Model Master’ is ‘S5’ selection option ‘1 Ice storage for cooling’. This option reduces the VAT on ice storage equipment investments by 10% for ice storage in the hotel sector.

6.2.10.1.2 Second Rank

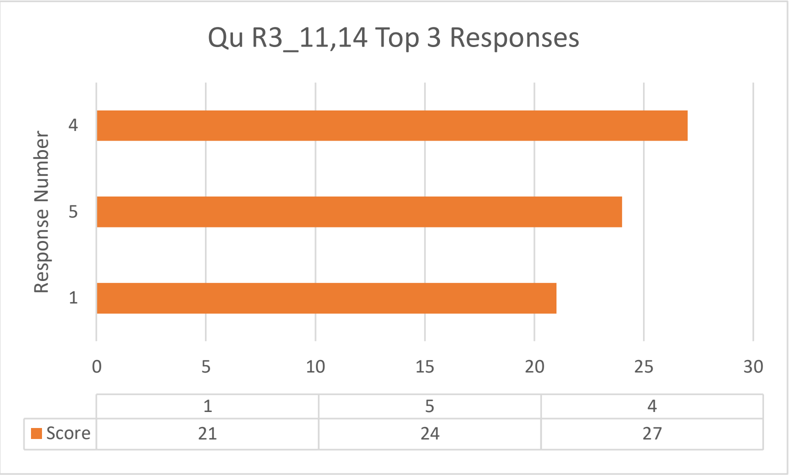
In option 2, the second ranked response, stakeholders indicate that the commercial sector should receive priority support for improving efficiency of energy consumption. As in the first ranked response, this will be achieved by investigating ice storage for cooling in the commercial sector.

The input used in the ‘TS Model Master’ is ‘S5’ selection option ‘1 Ice storage for cooling’. This option reduces the VAT on ice storage equipment investments by 10% for ice storage in the commercial sector.

6.2.10.1.3 Third Rank

In option 4, the third ranked response, stakeholders indicate that the transport sector should receive priority support for improving efficiency of energy consumption. This can be achieved by conversion of the transport fleet to EV which are much more energy efficient.

The input used in the ‘TS Model Master’ is ‘S5’ selection option ‘2 EV Fleet’. This option reduces the VAT on EV fleet investments by 10% for all classes of EVs. In addition, DG solar energy used in the transport fleet is priced for use at location by excluding the cost of transmission and distribution in the tariff.



4) Improve the reliability of the system to climate change and the yearly occurrences of adverse weather systems. Reliability and low environmental impact. Deliver reliable energy services, which is little affected by weather conditions (after a storm, heavy rains, lightning strikes). Limiting the impact of exogenous shocks in that sector, resilience to natural or manmade disasters. To limit the impact on the infrastructure from various events such as weather and cyber-attacks as well as having the means of restoring systems as quickly as possible. Micro grids will help in this regard, particularly if there is extensive damage to transmission and distribution networks. Establish an energy system that addresses the challenges and impact of climate change as well as Natural hazards, e.g., Hurricanes. Ensuring energy security, efficiency and reliability. Decrease vulnerability of the energy system. Developing a system that can speedily recover from shocks. Reducing vulnerability to natural hazards. Decreasing the length of disruption in services following natural hazards. Decreasing time of restoration of services to critical infrastructure and services.

5) Sustainable, affordable and environmentally friendly energy systems should be our objectives. Cleaner energy. Enactment of policies to ensure that energy infrastructure is maintained and developed to continue to support energy system resilience. Our aims should be to operate in the most environmentally (friendly) ways, to reduce waste and emissions and to bring in more affordable energy sources. Overcome key risks and vulnerabilities (climate and otherwise) of the island's energy systems by enhancing resilience of entire energy value chain (infrastructure and processes). Reduced carbon emissions, healthier country. Less reliance on foreign assistance – leads to reduced debts.

1) Cost reduction, cheaper energy. Reduce the financial cost of energy for businesses; Reduced cost of living (after the initial setup is factored). Opportunities to supply better services for the people since a major expense for the country is the importation of fuels. More stable cost of energy.

Figure 44 Response to survey question R3_11,14

6.2.11 Question 11 (Survey R3_11,14)

What should be the objectives of developing a resilient energy system in Saint Lucia? Responses are summarised in Figure 44.

6.2.11.1Modelling Inputs Question 11

6.2.11.1.1 First Rank

In option 4, the first ranked response, stakeholders would like to have a more reliable energy system which is resilient to climate change. This requirement can be met with RE coupled with long duration energy storage. This input will place emphasis on the use of pumped hydro and chemical energy storage.

In the 'TS Model Master' input used is the maximum estimated PHS capacity available as well as battery energy storage.

6.2.11.1.2 Second Rank

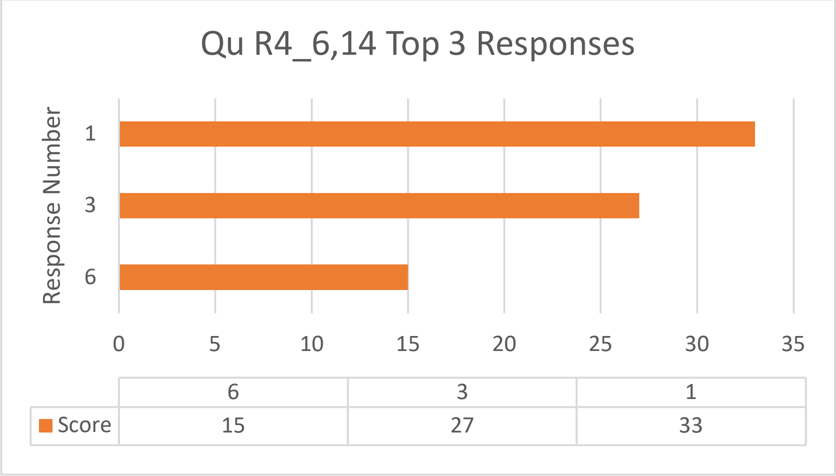
In option 5, the second ranked response, stakeholders indicate the need for cleaner, sustainable and more affordable sources of energy with reduced carbon emissions. To achieve this requirement, emphasis will be placed on the use of solar PV and wind energy.

In the 'TS Model Master' the input used is 'S2' selection option '2 Utility wind' to enable up to the maximum wind capacity to be utilised. Distributed solar PV is enabled in the 'SS System Model Master' and utility solar PV is also utilised.

6.2.11.1.3 Third Rank

In option 1, the third ranked response, stakeholders require lower cost and more affordable energy. This requirement will be analysed by looking at the impact on final energy cost to consumers from increasing the share of RE in the generation mix.

Two (2) inputs are used. ‘TS Model Master’ input used is ‘S6’ selection option ‘2 Lifecycle cost plus profit margin’. This option analyses final tariff to the end consumer based on investment, operation and maintenance costs and expected net profit of RE power plants.



1) Ability to produce and therefore determine cost of energy. Reduce price volatility. Price containment in terms of the tariff. Introduce dividend programmes, incentives and subsidies for renewable energy use, and carbon taxes, loss of subsidies for less desirable forms of energy. Cheaper energy. Reduced energy cost and associated economic benefits to be derived. Economic benefits at the personal level. More useable income in the wallet. Energy security, limiting the impact on climate change as well as lowering cost to increase the country’s competitiveness and standard of living. Reduce Energy costs. To benefit from the lower cost of energy generation from renewable energy. Achieve savings in fuel cost, redeployment of savings to other sectors, economic resilience building.

3) Reliability and low environmental impact. Achieving energy security, affordability while maintaining very reliable services.

6) Reduce greenhouse gas emissions by 50% and improve air pollution. As time goes by our quality of life is hindered by our use of fossil fuels for energy; more children are born annually with allergies and sensitivities with developmental issues. With a polluted environment, development and growth are stunted. With renewable energy and its efficient use, we will have less pollutants transmitted in the air we breathe, absorbed by the foods we eat, and carried in the water we drink. To reduce carbon dioxide emissions and attain Saint Lucia’s NDC targets. Environmentally friendly, cleaner energy. Cleaner environment. Environmental protection and emissions reductions. Institute a cap on carbon emission.

Figure 45 Response to survey question R4_6,14

The second ‘TS Model Master’ input used is ‘S3’ selection option ‘2 Based on RE costs for EVs’. This input sets the cost for charging EVs based on investment, operation and maintenance costs of RE power plants.

6.2.12 Question 12 (Survey R4_6,14)

What should be the objectives of developing a resilient energy system in Saint Lucia? Responses are summarised in Figure 45.

6.2.12.1Modelling Inputs Question 12

6.2.12.1.1 First Rank

In option 1, the first ranked response, stakeholders would like to have more control of and to reduce the cost of energy. This is achievable using RE.

Two (2) inputs are used. 'TS Model Master' input used is 'S6' selection option '2 Lifecycle cost plus profit margin'. This option analyses final tariff to the end consumer based on investment, operation and maintenance costs and expected net profit of RE power plants.

The second 'TS Model Master' input used is 'S3' selection option '2 Based on RE costs for EVs'. This input sets the cost for charging EVs based on investment, operation and maintenance costs of RE power plants.

6.2.12.1.2 Second Rank

In option 3, the second ranked response, stakeholders would like a more reliable energy system with higher energy security. This requirement can be met with RE coupled with long duration energy storage. This input will place emphasis on the use of pumped hydro and chemical energy storage.

In the 'TS Model Master' input used is the maximum estimated PHS capacity available as well as battery energy storage.

6.2.12.1.3 Third Rank

In option 1, the third ranked response, stakeholders would like to see a reduction in greenhouse gas emissions.

The impact on GHG emissions is an output of the analysis and will be reviewed in the results discussion.

6.2.13 Question 13 (Survey R4_1,10)

How should the general public participate in a transition to sustainable energy? Responses are summarised in Figure 47.

6.2.13.1Modelling Inputs Question 13

6.2.13.1.1 First Rank

In option 5, the first ranked response, stakeholders want a focus on public consultation, education and awareness building. This is a key requirement for the energy transition process to ensure that stakeholder requirements are understood and adequately addressed during the transition. The Delphi survey is an example of how a consultation process can be executed. The survey responses also indicate a need for public education and awareness of the characteristics of the different forms of RE.

6.2.13.1.2 Second Rank

In option 2, the second ranked response, stakeholders require higher energy efficiency in all energy sectors.

The first input is used in the ‘SS Model Master’ workbook to modify the conversion of fossil fuel demand to electricity in the sectors industrial, commercial, hotel and domestic. In the ‘TS System Model Master’ the input is stakeholder requirement ‘S11’, selection option ‘3 Mandated’. Input values are provided in Table 67.

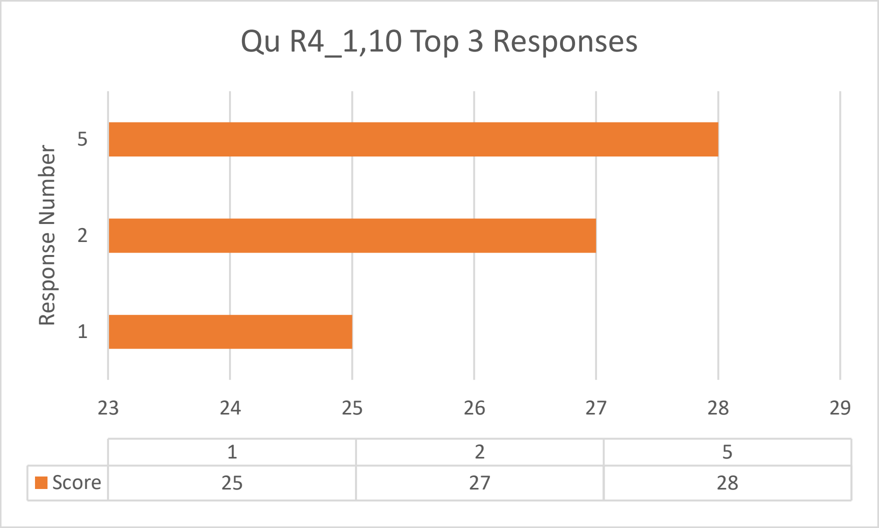
The second input used is a ban on import of internal combustion engine (ICE) vehicles and is assessed with all retired transport being replaced with electric vehicles. All new vehicles imported must be electrified. The input used in the ‘TS Model Master’ is ‘S8’ selection option ‘1 Immediate ban on ICE imports’ which is used in the ‘SS Model Master’ tab ‘SS Transport FF Inputs’ to set the rate of conversion of ICE vehicles to EVs. To accomplish a 100% fleet transition in twenty (20) years, the existing fleet must be retired at a rate of 5% per annum. Consequently, the fleet conversion rate in Table 68 has been used for the calculations.

6.2.13.1.3 Third Rank

In option 1, the third ranked response, stakeholders would like to see an emphasis on distributed forms of energy generation, particularly solar.

This requirement is evaluated with the use of domestic distributed solar PV enabled in all modelling through the ‘SS Model Master’. The standard PV system size set for a domestic customer is 1.5 kWp.

The results from the Delphi study will be used for both inputs and target outputs of the stakeholder scenarios analysed in the energy system modeling.



5) Greater awareness for buy-in to shift to use of RE as users and practitioners, accessibility to incentives. Town hall meetings, call in programmes, radio and television talk shows, Target schools and hold discussions with students. Target workplaces, particularly those in the industrial/manufacturing sector which are significant contributors to carbon emission. Actively engage in consultative processes to shape policy. Advocacy with a view to motivating the late adopters and laggards, Testimonials. Provide opportunities and information for feedback on national energy plans and activities. For any country the success of transitioning to sustainable energy is dependent on acceptance and participation of the General Public. The public must be engaged and be made aware of the benefits associated with sustainable energy so that they can participate….

2) Purchasing energy-efficient appliances. Implement RE, energy conservation and energy efficiency measures that are affordable and cost effective, et cetera. This should be done through investments in energy-efficient vehicles like electric cars and buses. Adopting best practices and measures in the conservation of energy at their homes and businesses.

1) Think Green and getting into the habit of building houses that run on solar. Allowing them to generate their own energy. Persons who can afford should move to solar energy to run their homes and small businesses. Promoting self-generation and alternatives to fossil energy use. Provide opportunities for green business based on sustainable energy. Provide opportunities for accessing sustainable energy products. The ability to convert waste, for example, wastewater for use in other purposes and reviewing their energy consumption patterns.

Figure 47 Responses to survey question R4_1,10

6.3 Potential impact of utility controlled solar follow charge profile

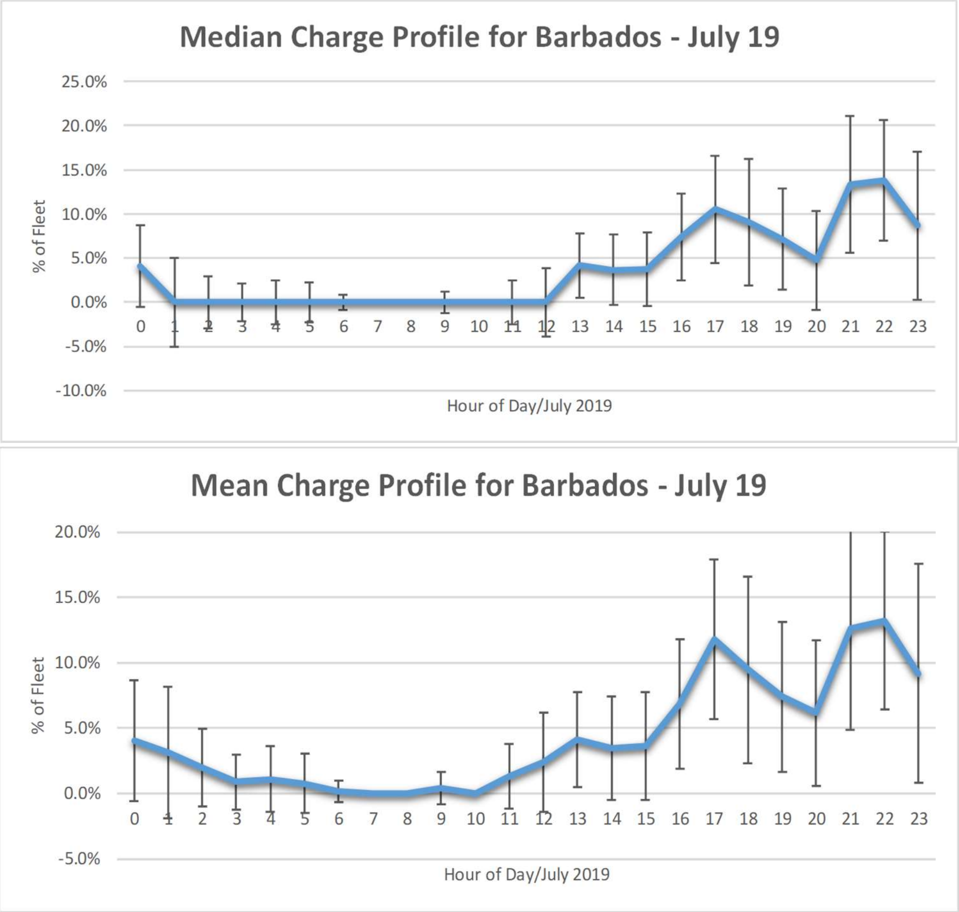


Figure 46 Uncontrolled charge profile from empirical data - Megapower, Barbados

In order to estimate the potential for utility control of or the impact on peak loads of the charging connection profile, an investigation is undertaken, using empirical data from Megapower, an EV company in Barbados, to determine the variability to be expected in EV connections for every hour in the day. 680 data points for the month of July 2019, were used to generate the curves (presented in Figure 46) for uncontrolled charging. From the data, the total individual users of the charging network and the percentage of the total fleet connected for charging at each hour of the day were calculated. The mean and median of the percentage of the fleet connected at each hour of the day were calculated using the daily data. The standard deviation was also calculated for the percentage of the fleet connected at each hour.

One (1) standard deviation error band is shown on the mean and median curves generated from the empirical data.

Equation 21 Formula for aggregating HDV and LDV charge profiles

AGP = PLDV x %FLC + PHDV x %FHC

Where AGP – Aggregated percentage of total fleet connected to the charging network

PLDV – Ratio of LDV

FLC – Total LDV connected to the charging network

PHDV – Ratio of HDV

FHC – Total HDV connected to the charging network

The manually generated HDV and LDV charging connection profile curves introduced in Section 5.3.1.10 were combined to form an aggregated charge connection curve for the entire fleet. This was done by adding the weighted average percentage of vehicles connected for each fleet every hour using the formula at Equation 21.

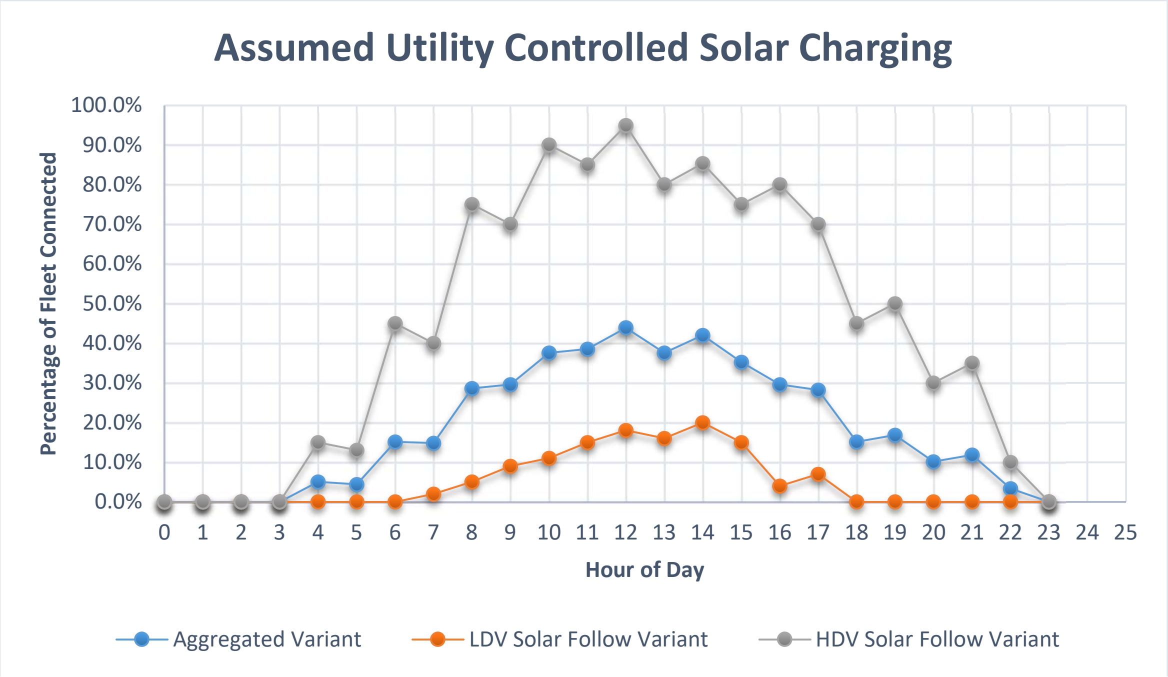


Figure 48 Assumed variant solar follow and aggregate charge connection curves

The one standard deviation error bands calculated using the empirical data were then applied to the aggregated curve at each hour of the day. This assumes that EV owners in Saint Lucia will have similar behaviour to those in Barbados in terms of variability in the percentage of the fleet that will be connected for charging at each hour of the day even though the Barbados data was for uncontrolled charging and the research connection profile assumes solar follow charging.

Variant HDV and LDV charge connection and variant aggregated curves were also generated and are shown in Figure 48 for comparison. The variant solar follow LDV and HDV charging connection curves were created so that the total charge % hours remained unchanged for each fleet and at least 65% of data points on the aggregated curve fell within the hourly standard deviation bars. This was done for the purpose of generating solar follow charge connection curves that result in smoothing of the peak demand profile as it is significantly affected by the EV charge connection profile. The variant curves are generated manually by selecting the % of fleet connected every hour to lie within the range of the one standard deviation error bands.

A second set of variant HDV, LDV and aggregated curves were also created. The variant solar following curves which resulted in the smoothest demand profile were used in the analysis. Figure 49 shows a comparison of the aggregated original solar follow and variant curves.

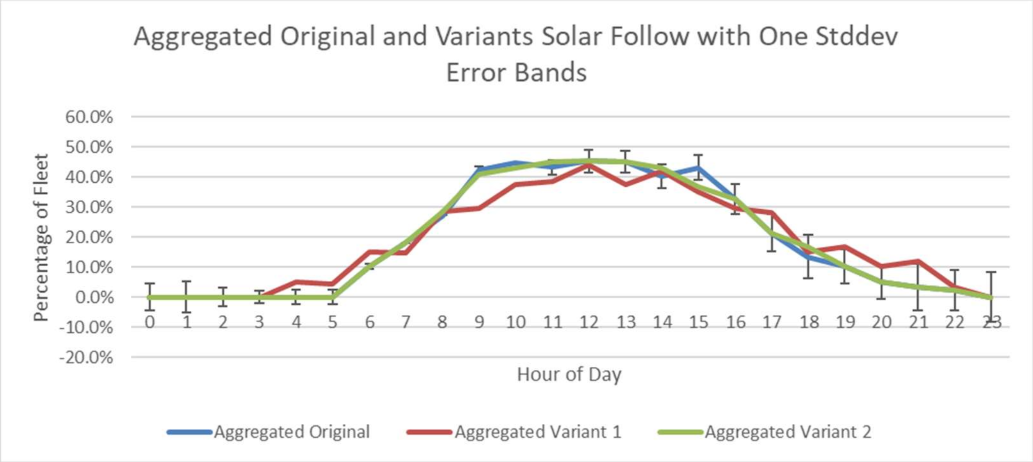


Figure 49 Comparison of original and variant solar follow charge profiles

If the same variability in behaviour is assumed for connecting customers, twenty-three (23) out of twenty-four (24) points on the variant 2 aggregate curve fall within the +/- 1 standard deviation error bands generated from the empirical data and applied to the original aggregate curve.

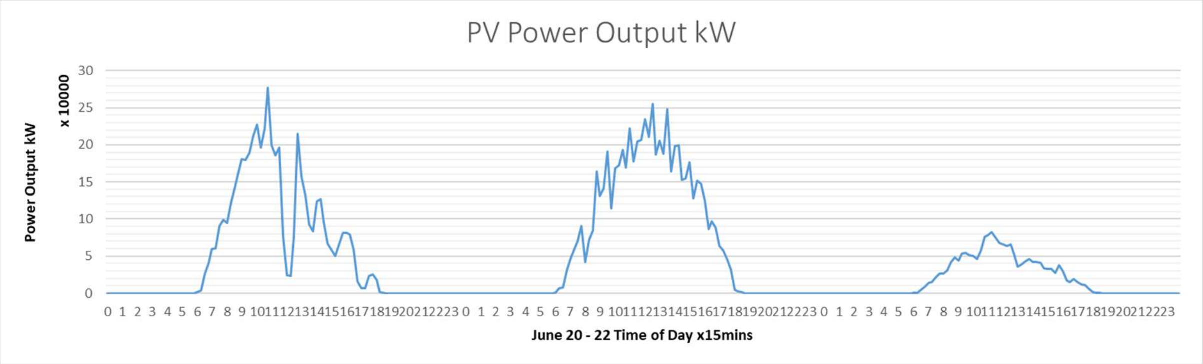


Figure 50 Solar PV power profile for 3 days in June

The charge connection curves are generated to match, as closely as possible, the expected solar generation profile. The solar profile for a period of three (3) days in June _for a year during the 25-year analysis period is provided in Figure 50.

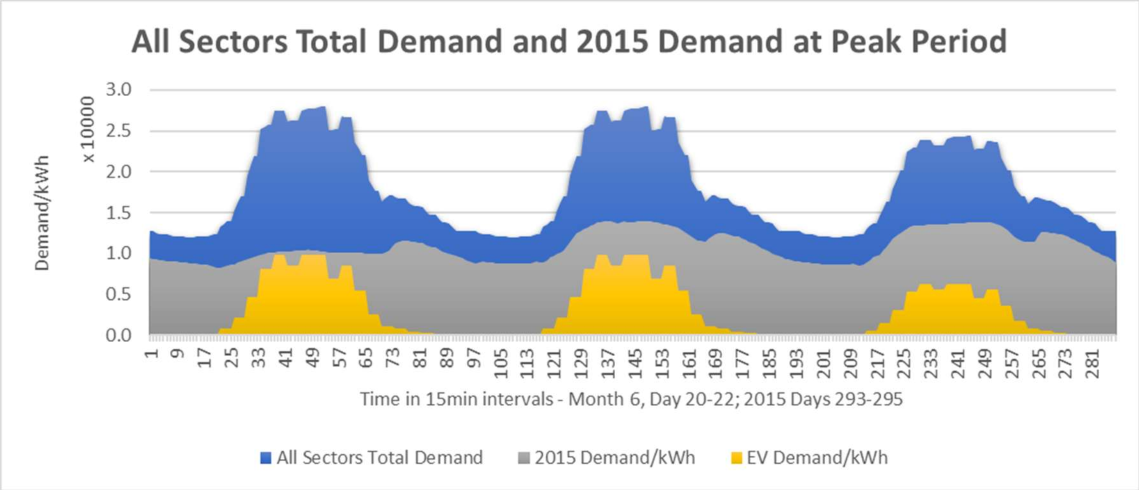


Figure 51 Impact of original charge connection curves on total demand profile

The impact of the original solar follow EV charge connection curves on the overall demand in year 25 is shown in Figure 51. This figure shows how the demand curve is shaped by EV charging demand and is compared to the 2015 demand curve. The daytime peak is not observable in the 2015 demand curve as there are very few EVs in Saint Lucia at that time. The impact of transitioning the entire terrestrial transport fleet to EVs on the demand curve is calculated and illustrated. Step changes in peak demand can be seen occurring each day while EVs are charging from available solar PV energy. This can cause issues with maintaining system stability.

A set of variants 1 solar follow charging connection curves were generated to reduce this variability as shown in Figure 52. This variant appears to have created more variability in the peak demand.

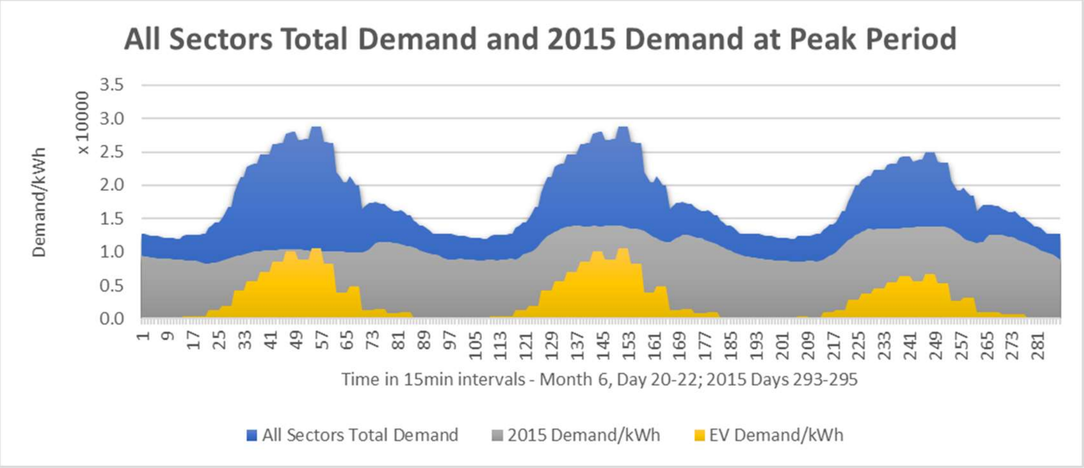


Figure 52 Impact of variant 1 charge connection curves on total demand profile

Variant 2 curves were generated and appear to have resulted in significant smoothing of the demand profile as show in Figure 53. This variant is used in all scenarios.

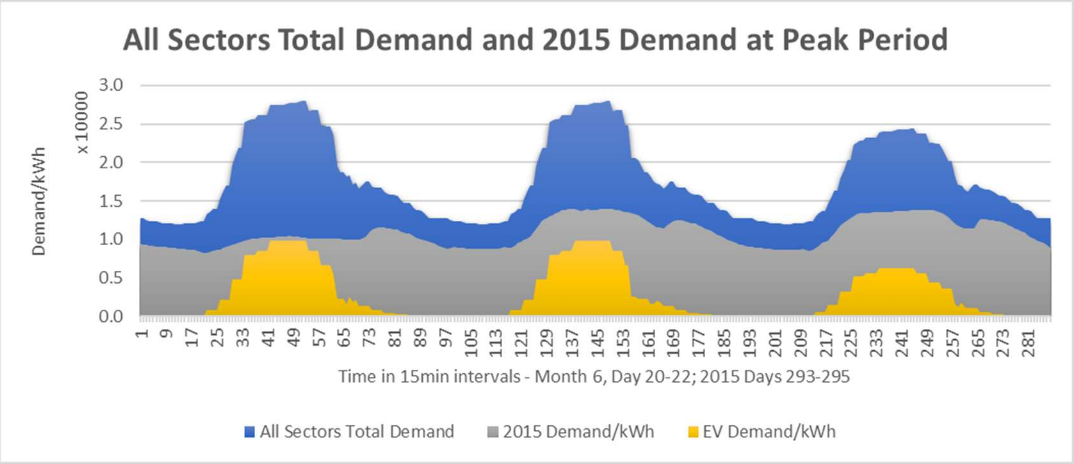


Figure 53 Impact of variant 2 charge connection curves on total demand profile

Control of the demand profile will have to be managed by the utility at a central location to ensure sufficient dispatchable capacity to meet demand and a smooth demand profile from EV charging.

In practice, significant variations in charging profiles can be expected on each substation. These variations can be minimised by offering the right incentives to charge during the day using available solar energy. One (1) of the incentives suggested in this research is charging at the point of generation for distributed solar PV used to service the transport sector. In this case, the energy is sold at a tariff reflective of the cost of onsite generation and overhead costs. This cost is significantly lower than the cost of grid electricity in comparison to the year 25 grid tariffs as will be seen later. This incentive can be assumed to minimise variations in the fraction of the fleet available at any point in time during daylight hours to charge or provide V2G services. This assumption requires that all consumers can charge their vehicles wherever they are during the day. It will be critical to invest in sufficient charging infrastructure at places of business as well as homes to ensure that this scenario is achievable. An analysis of charging infrastructure needs must be undertaken to ensure an optimal distribution of charging stations so that enough connections are always possible to enable smooth operation of the grid. This is an area for future research as it is not covered in the scope of this work.

7 Section 7 Results versus Hypothesis

7.1 Baseline Scenario Results

The baseline or business as usual (BAU) scenario assumes the use of diesel fuel to meet electricity demand for the next twenty-five (25) years. It does not include any additional RE or energy storage other than the currently installed 4.49 MW of solar PV. Despite the NETS, there is no published and government approved plan for the introduction of more RE into the electricity sector. There is, however, a continued effort to develop the geothermal energy resource. The inputs for the baseline scenario are provided in Table 72.

Table 72 Inputs to baseline scenario

Maximum Energy or Capacity by Source	Year 5	Year 10	Year 15	Year 20	Year 25
Solar – Utility (kWp)	4490	4490	4490	4490	4490
Solar - Distributed (kWp)	-	-	-	-	-
Wind (kW)	-	-	-	-	-
Biogas (kW)	-	-	-	-	-
Geothermal (MW)	-	-	-	-	-
Hydro (kW)	-	-	-	-	-
Diesel (MW)	*62*	*68*	*73*	*73*	*73*
DSM	OFF	OFF	OFF	OFF	OFF
DSM Energy (kWh)	-	-	-	-	-
V2G - HDV	OFF	OFF	OFF	OFF	OFF
HDV V2G Energy (kWh)	-	-	-	-	-
V2G - LDV	OFF	OFF	OFF	OFF	OFF
LDV V2G Energy (kWh)	-	-	-	-	-
Ice Storage - Commercial	OFF	OFF	OFF	OFF	OFF
Ice Storage - Commercial (kWh)	-	-	-	-	-
Ice Storage - Hotel	OFF	OFF	OFF	OFF	OFF
Ice Storage - Hotel (kWh)	-	-	-	-	-
Chemical Storage (kWh)	-	-	-	-	-
PHS (kWh)	-	-	-	-	-

Peak Residual Demand Diesel/MW	*5*	*7*	*7*	*6*	*6*

DSM, V2G and ice storage are designated as ‘OFF’ which means they are not included in the scenario. Wind, biogas, geothermal, hydro, chemical storage and PHS are all set to zero capacity. The required diesel generation capacity increases from 62 MW to 73 MW from year 5 to year 25 under the BAU demand growth scenario. This assumes that solar PV generation remains at 4.49 MWp. The residual demand is due to the model diesel calculation module which does not produce enough energy to cover the system losses. The losses are covered with the residual demand diesel generation.

Consequently, the ‘Res Dem Diesel’ value is simply added to the ‘Diesel’ capacity to find the total required capacity for meeting the demand. A chart of energy production, by source, for year 25 is provided in Figure 54 in GWh (millions of kWh).

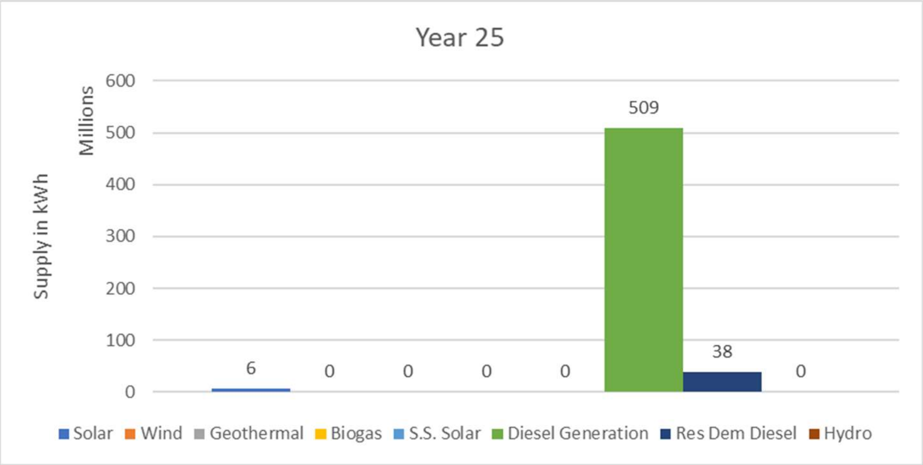


Figure 54 Baseline scenario generation by source

As shown in Table 73 most of the energy is provided by diesel generation with a small fraction, 1%, provided by the existing solar PV capacity. The peak load remains constant from year 15 based on the projection provided in Figure 8.

Table 73 Demand, load and energy details for baseline scenario

	Total RE Consumed - GWh	Total energy supplied - GWh	RER	Excess RE - GWh	% Res Dem Diesel	Total Demand - GWh	Peak Load - MW	Residual Demand - GWh	Peak Residual Load - MW	Total Peak - MW
Year 5	6.4	471.2	1%	0.0	7%	438.2	63	32.5	5	69

Year 10	6.4	516.3	1%	0.0	7%	480.1	69	35.7	6	75
Year 15	6.4	552.9	1%	0.0	7%	514.2	74	38.2	6	81
Year 20	6.4	553.1	1%	0.0	7%	514.4	74	38.2	6	81
Year 25	6.4	553.4	1%	0.0	7%	514.7	74	38.3	6	81

The result of continuing to supply 99% of electricity demand using imported diesel fuel is a continued upward trend in the tariff as illustrated in Figure 55. The tariff calculation assumes that diesel price discounts to LUCELEC remain in the same order of magnitude relative to historic diesel prices and diesel prices follow the World Bank predicted trend for the next twenty-five (25) years.

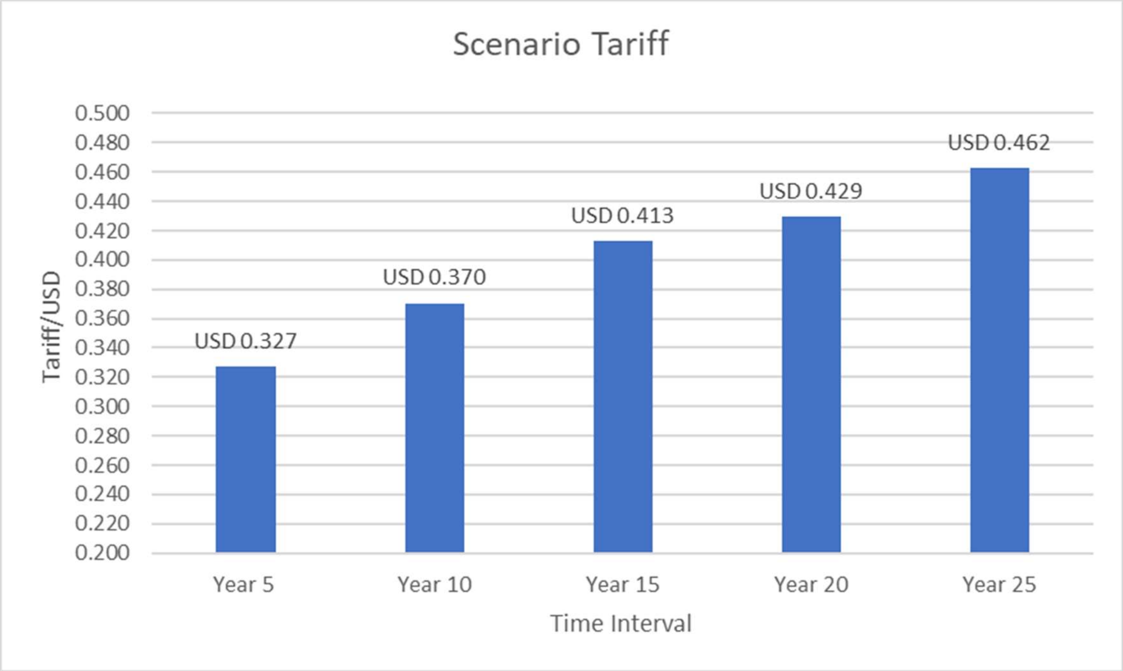


Figure 55 Expected trend in tariff for BAU scenario

The tariff is expected to grow from a year 5 value of USD$0.327/kWh to USD$0.462/kWh in year 25. Diesel generators are replaced as they go out of service. The total energy supplied from year 15 to year 25 is roughly the same at 553 GWh. The components of the tariff in year 25 are provided in Table 74.

Table 74 Components of tariff in year 25

Energy Source	Generated and Total Stored Energy - GWh	Energy tariff USD$/kWh	Weighted average tariff (USD$/kWh)
Solar	6.4	0.187	0.002
Diesel	508.8	0.461	0.424

Residual Demand Diesel	38.3	0.530	0.037
Total	553.4		0.462
		Average Tariff	XCD$1.24 USD$ 0.46

The estimated overall economic impact is estimated at -USD$1,252.9 million dollars, i.e., a significant loss to the economy. The estimated carbon emissions from fossil fuel use, for power generation, is expected to be around 312,420 tonnes of CO_2 in year 25 with 3,985 tonnes of CO_2 savings from solar PV generation.

The baseline scenario demand curve is provided in Figure 56 for the period year 25 June 18-20 in comparison to the 2015 demand curve for the same period. The three (3) days represented are Thursday, Friday and Saturday. The model does not distinguish the lower demand on the weekend, however, through calibration, the total annual production is demonstrated to adequately match the historic data for 2015.

Figure 57 shows the energy mix to satisfy demand under the BAU baseline scenario showing practically all demand being met with diesel fuel. The residual demand diesel generation generally covers the system losses as the diesel module calculation output is reduced by the system losses.

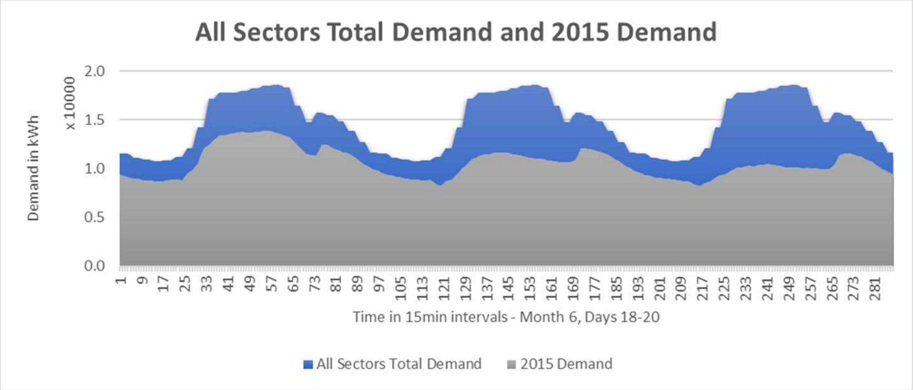


Figure 56 2015 and BAU demand curves

The year 25 peak load of 81 MW (including residual demand diesel generation) exceeds the 2015 peak of 59 MW by about 35%. Total generation exceeds demand by the residual demand diesel generation to cover system losses.

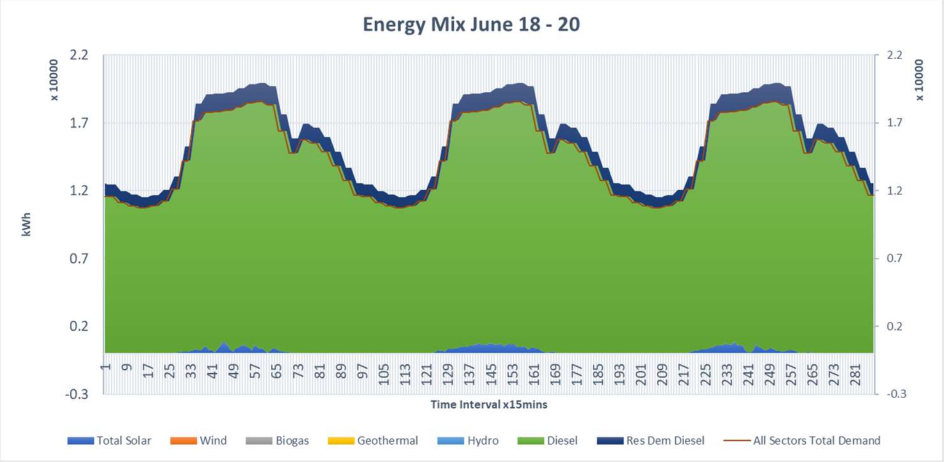


Figure 57 BAU energy mix to satisfy demand

7.2 Scenario responses to the stakeholder objectives

7.2.1 Scenario A - Transition Pathway

In this scenario, stakeholders have requested a focus on solar PV and energy storage. Consequently, the maximum possible amount of solar PV is used in each 5-year interval to achieve the RE average penetration targets. Overall results are provided in Table 75.

Table 75 Scenario A transition pathway

Maximum Energy or Capacity by Source	Year 5	Year 10	Year 15	Year 20	Year 25
Solar – Utility (MWp)	37.1	70.7	177.5	357.5	360.9
Solar - Distributed (MWp)	11.3	16.3	24.7	33.3	33.7
Wind (MW)	41.4	46.0	41.4	50.6	50.6
Biogas (MW)	-	-	-	0.8	0.8
Geothermal (MW)	-	7.0	21.0	28.0	28.0
Hydro (MW)	-	-	1.8	2.3	2.3
Diesel (MW)	38.2	29.4	12.9	-	-
DSM (MW)	-	-	-	5.0	5.2
DSM Energy (MWh)	-	-	-	1.2	1.2
V2G - HDV (MW)	-	-	-	-	-

HDV V2G Energy (kWh)	-	-	-	-	-
V2G - LDV (MW)	-	-	6.5	4.4	3.7
LDV V2G Energy (kWh)	-	-	1,631.6	1,097.3	928.8
Ice Storage - Commercial (MW)	-	-	1.1	1.5	1.5
Ice Storage - Commercial (kWh)	-	-	274.7	363.2	363.2
Ice Storage - Hotel (MW)	-	-	0.9	1.2	1.2
Ice Storage - Hotel (kWh)	-	-	224.1	299.7	299.7
Chemical Storage (MW)	7.4	25.0	47.6	63.6	63.7
Chemical Storage (MWh)	6.4	133.4	577.1	15,627.2	17,903.8
PHS (MW)	-	-	-	75.0	75.2
PHS (MWh)	-	-	-	1,884.7	1,884.7
Peak Residual Demand Diesel (MW)	32.8	47.5	64.7	74.8	75.0

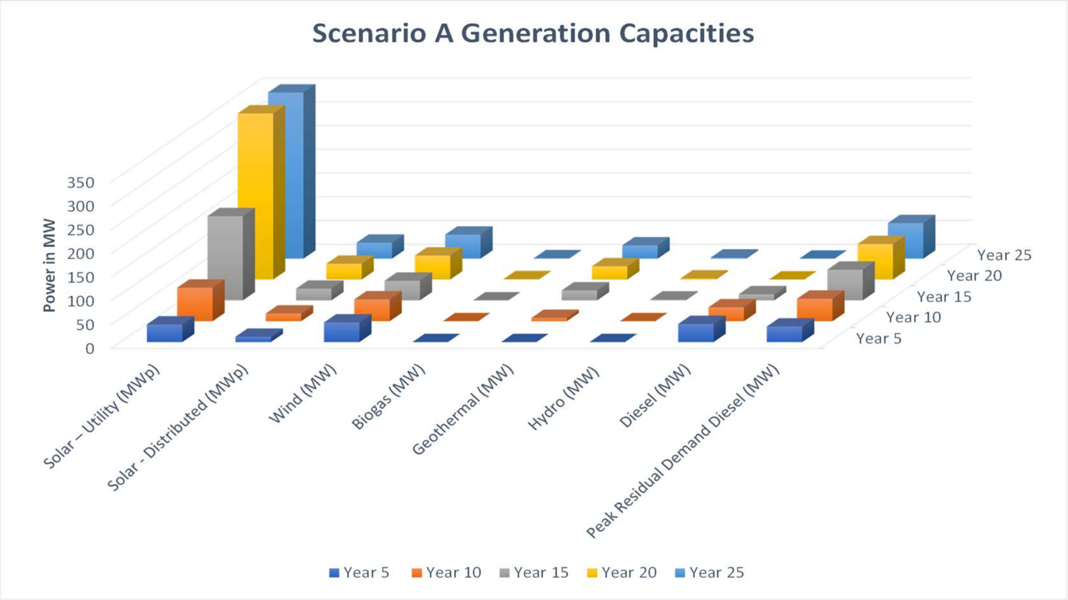


Figure 58 Scenario A generation capacities by year

The generation and storage capacities for the transition scenario are illustrated in Figure 58 and Figure 59.

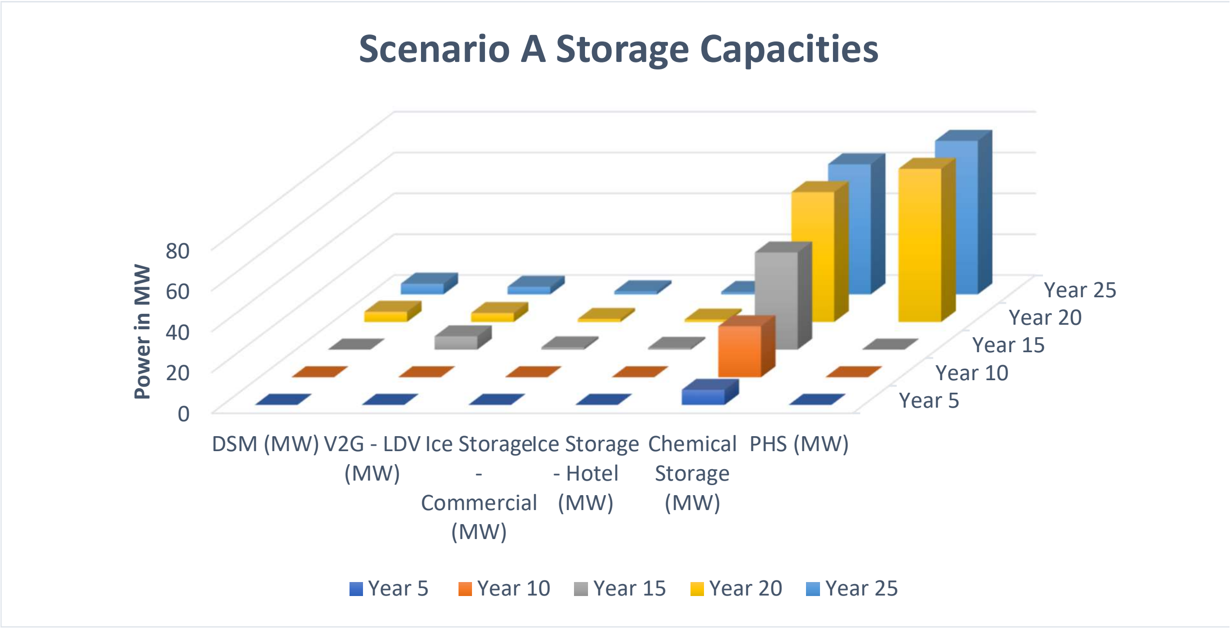


Figure 59 Scenario A storage capacities by year

The illustrations show solar energy as the dominant generation source as required by the stakeholders with capacity of all sources except diesel increasing over time. The peak residual demand diesel increases in capacity and is supplied by biodiesel in years 20 and 25. The storage capacities increase over time and are dominated by PHS and chemical storage.

In year 5, adjustments are made to the amount of solar PV and wind to achieve the target RE penetration. Chemical storage of approximately 7.4 MW|6.4 MWh power to energy capacity is required to avoid curtailment of RE. Biogas, geothermal, hydro, DSM, V2G and ice storage are all excluded since the low penetration level results in high costs per kWh. The amount of utilised resources is set initially to a fraction of total capacity equivalent to the target RE penetration, however, adjustments were made manually to

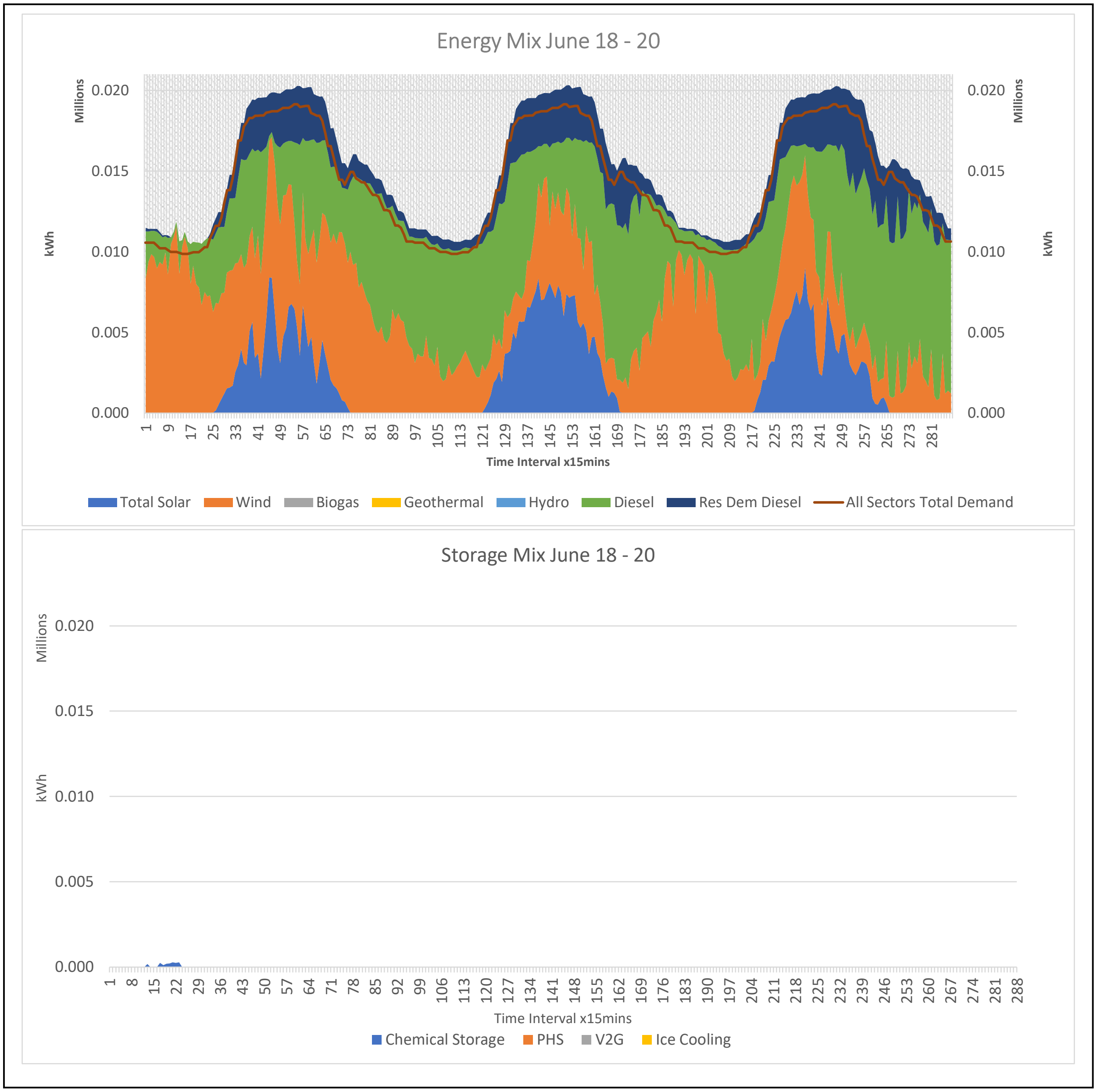


Figure 60 Energy mix at year 5

attain the required RE penetration target for the year. Conversion of the transport sector to electric mobility was included with unidirectional energy flow to EVs for charging. The average charge power was set to ensure that the fleet consumed within +/- 10% of the displaced fossil fuel that would have otherwise been used by ICE vehicles associated with each substation. The amount of solar PV and wind were adjusted to ensure there was no excess RE production with minimal use of chemical battery energy storage. For V2G, the charge power was adjusted manually for each 5-year period so that the fleet consumed the equivalent energy +/-10% for the projected fossil fuel demand while providing V2G services.

The energy mix at year 5 versus demand for an indicative period is illustrated in Figure 60. There is heavy dependence on diesel generation. Residual demand diesel is also supplied by regular diesel fuel and supplies energy needed to cover system losses. A minimal amount of chemical battery storage energy is delivered during the illustrated period.

Geothermal energy comes online in year 10 with 7 MW of installed capacity. The amount of chemical battery storage is increased to 25 MW|133.4 MWh and no additional form of storage or DSM are required to achieve the RE penetration target of 50%. Adjustments are made to the solar PV, wind energy and battery storage capacity to ensure the amount of excess RE production is 0. V2G is not active.

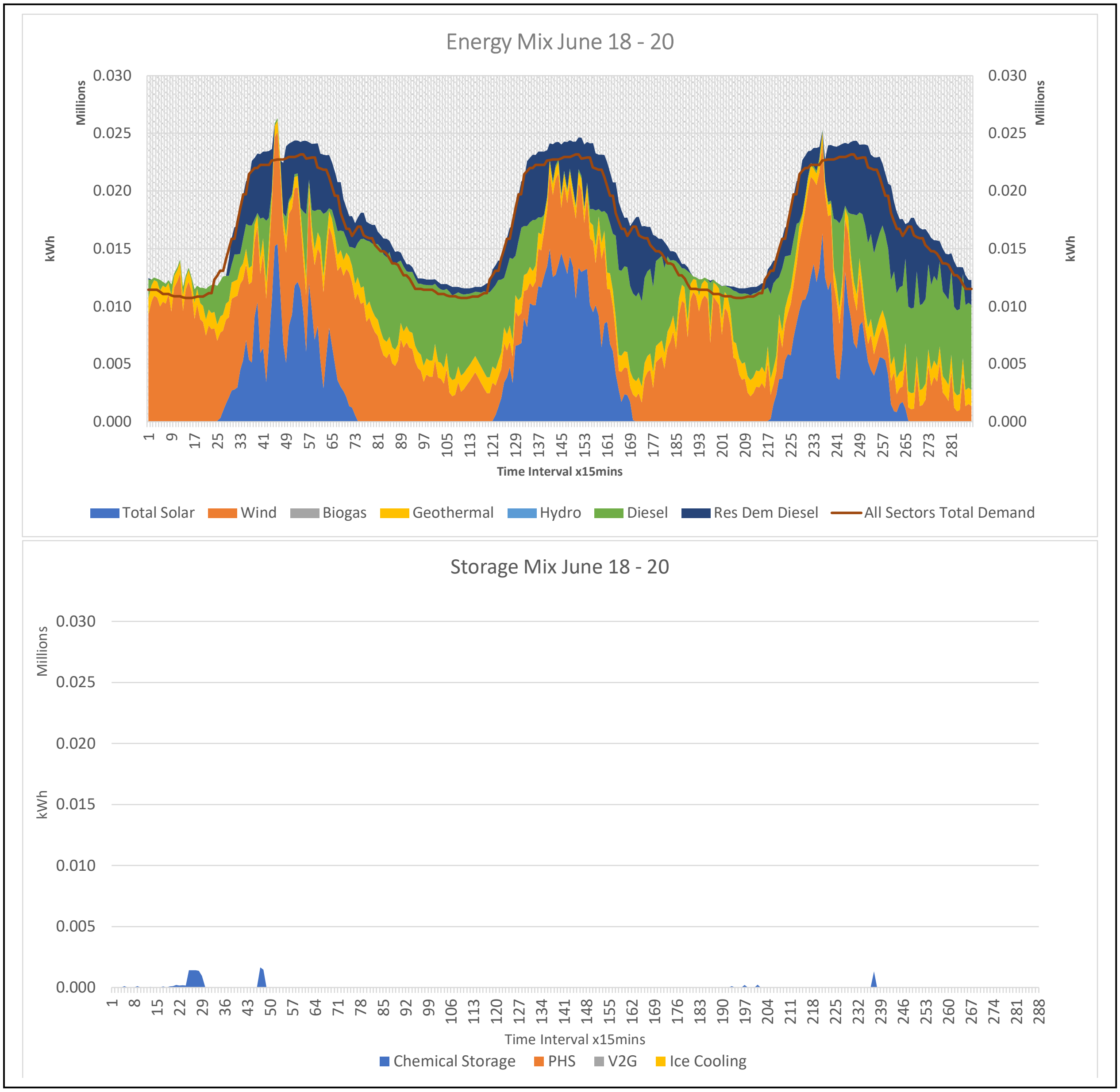


Figure 61 Energy mix at year 10

The energy mix for an indicative period in year 10 is illustrated in Figure 61.

In year 15, long-term storage will become more critical to balancing supply and demand. Hotel ice storage and V2G are enabled in addition to chemical storage. 6.5 MW|1.6 MWh of LDV battery storage capacity is utilised. The discharge and energy demand constraints set in the model do not permit V2G from the HDV fleet. The model is opportunistic in dispatching V2G, i.e., it will only dispatch when there is demand and available battery storage on the network. The model is not intelligent and cannot schedule EV capacity to be available when V2G services will be required. In a real-world scenario, this will be possible and more V2G energy can be dispatched. In addition, charging can be optimized to enable higher charge power and quicker charging of EVs. To achieve the 75% penetration target, 1.8 MW of hydro power is required and battery capacity had to be increased significantly to 47.6 MW|577.1 MWh. Focus is placed on ensuring the maximum amount of solar PV is utilised without any or minimal excess RE production. In practice, the battery storage can be provided through a combination of centralised storage systems and aggregated distributed storage.

The ice storage capacity utilised is 0.9 MW|224.1 MWh in the hotel sector and 1.1 MW|274.7 MWh in the commercial sector. Geothermal energy capacity is increased to 21 MW along with increases to wind and solar PV capacities. The energy mix for an indicative period in year 15 is illustrated in Figure 62.

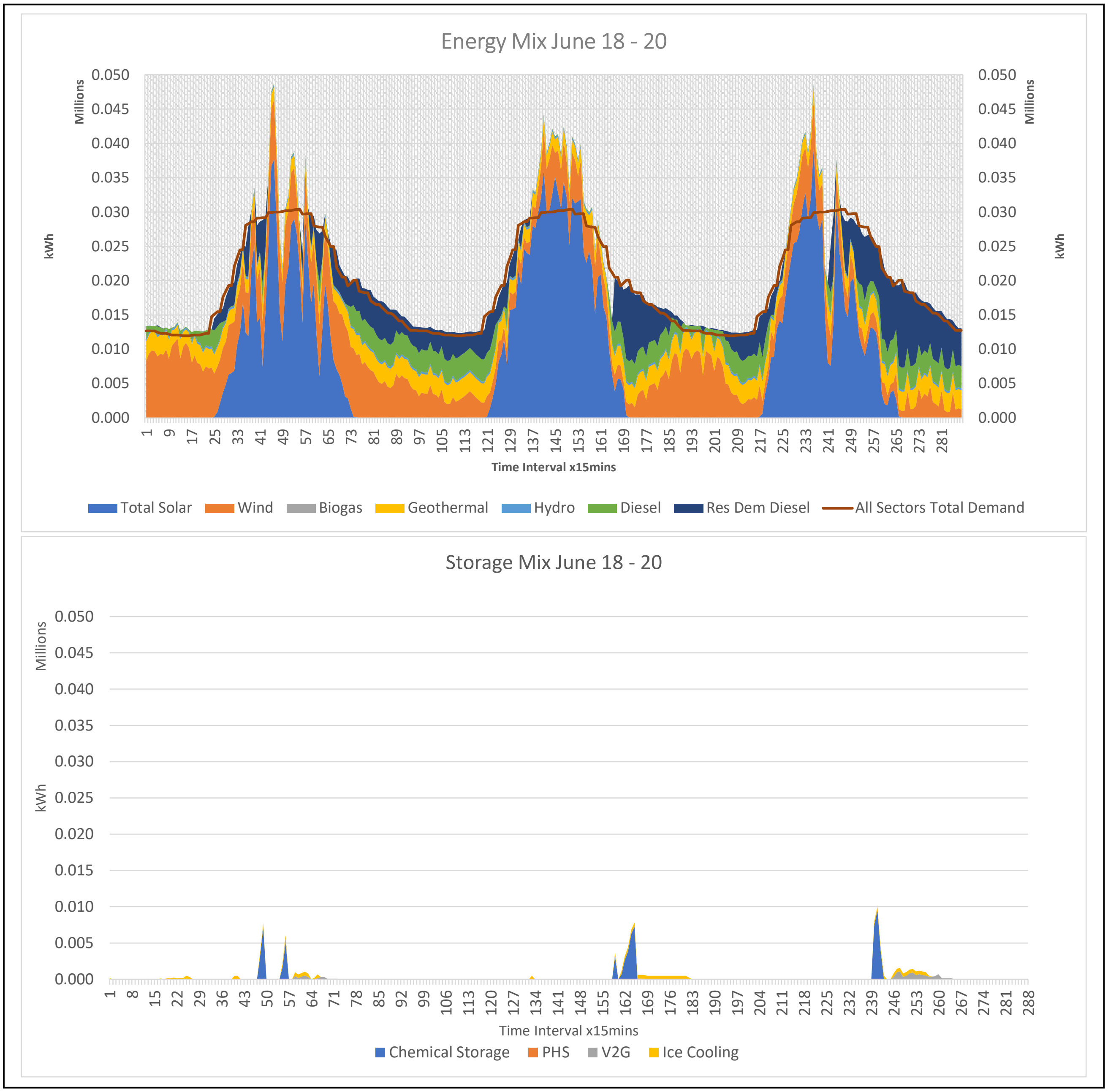


Figure 62 Energy mix at year 15

Chemical battery, V2G and ice storage are all deployed during the period illustrated. Residual demand is supplied using diesel fuel.

To achieve the 100% RE target in year 20, chemical storage was allowed to increase without limit to provide the required storage. 357 MWp of utility solar PV and 33.3 MWp distributed PV capacity was utilised along with 28 MW of geothermal, 0.8 MW biogas and 2.3 MW hydro capacity. The objective in sizing the system was to ensure that excess RE generation was kept to a minimum or 0. The required chemical storage capacity of 63.6 MW|15.6 GWh can be provided through an aggregator of central and distributed storage systems, or through another form of long-term energy storage that is mature and cost competitive in year 25. A flexible generation option that comes online only when storage would be

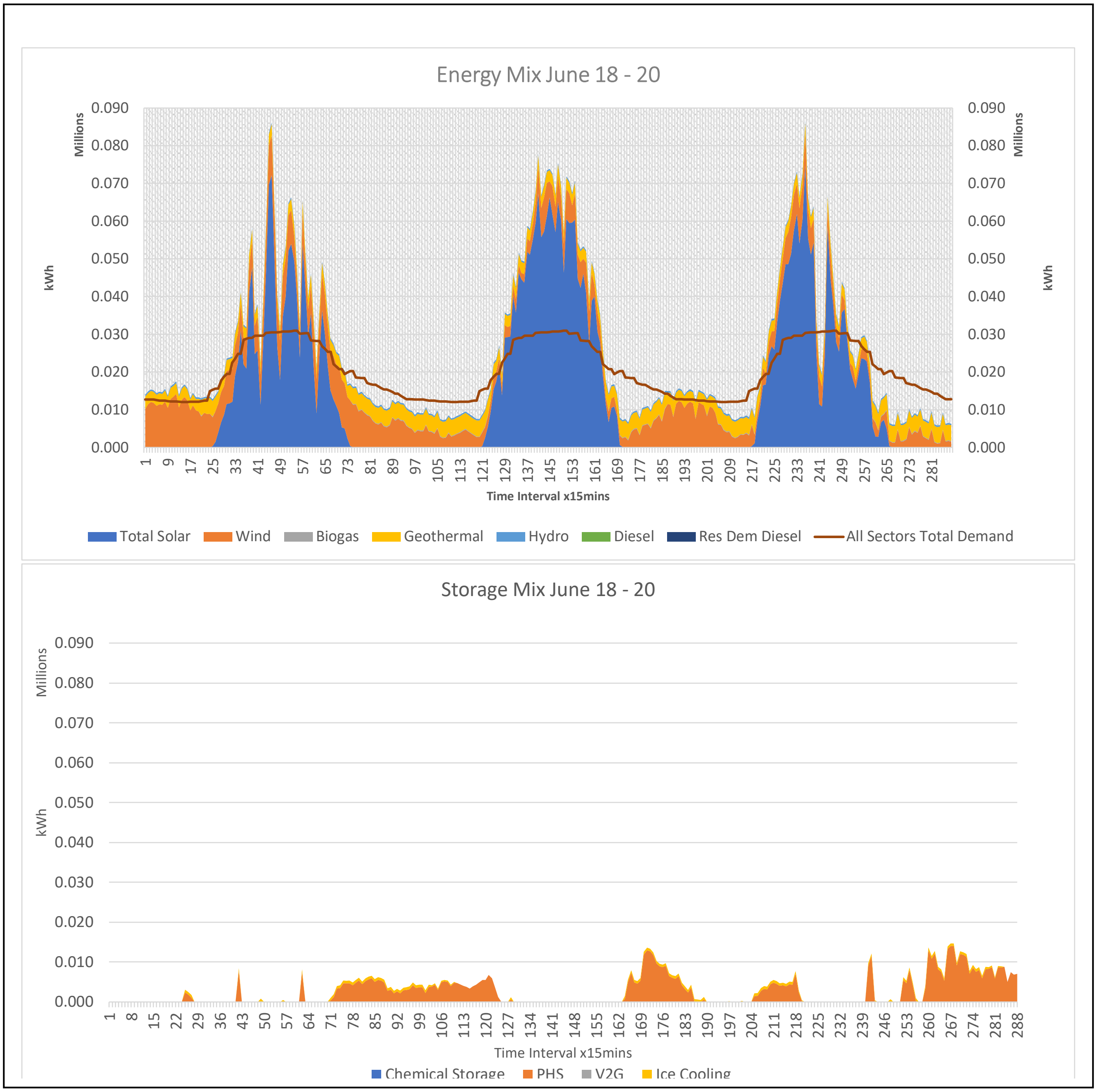


Figure 63 Energy mix at year 20

required can also be considered as an option, e.g., increasing the use of a biofuel such as biodiesel or green hydrogen if it becomes commercially available and cost competitive. Alternatively, the capacity of PHS reservoirs can be increased to provide the required storage. The energy mix for an indicative period in year 20 is illustrated in Figure 63. PHS dominates the energy provided from storage for the illustrated period with 75.0 MW|1.88 GWh of energy. Energy production is dominated by Solar PV.

The energy mix for an indicative period in year 25 is illustrated in Figure 64. The amount of each source of storage and energy was adjusted manually in year 25 to achieve the 100% RE target while minimising excess RE generation, similar to year 20. There is 0% residual demand due to the unlimited storage provided by chemical battery storage. In the energy mix shown in Figure 60 to Figure 64, the progressive

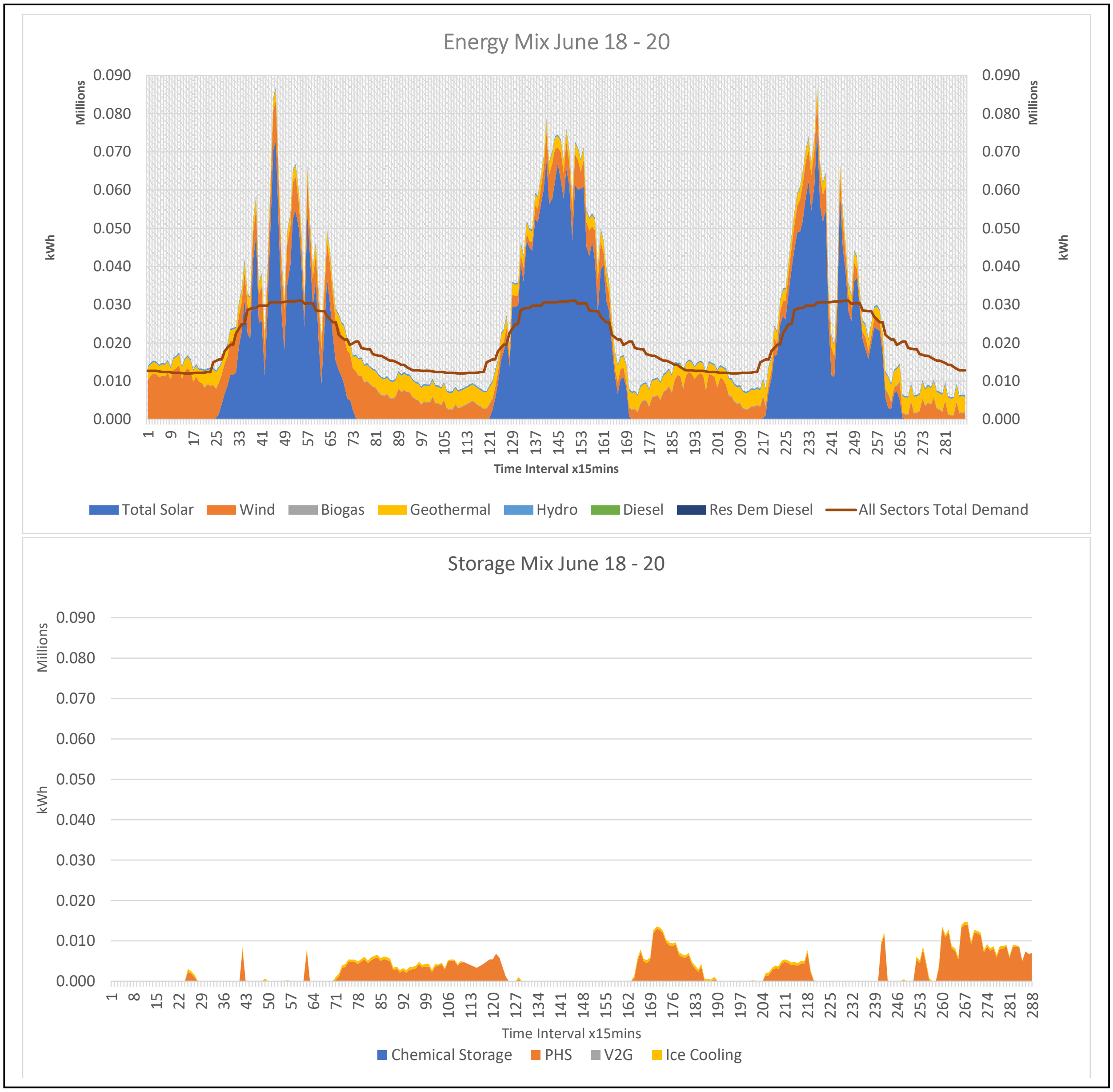


Figure 64 Energy mix at year 25

increase in the contribution of PHS to energy supply can be clearly seen. Maximum ice storage capacities of 1.5 MW|363.2 MWh in the commercial sector and 1.2 MW|299.7 MWh in the hotel sector is utilised in years 20 and 25. For calculations in each year, the substations were run in sequence in the model to ensure a stable result was obtained.

All the biogas, hydro and geothermal potentials are utilised. The maximum geothermal plant size of 28 MW is utilised. 100% of PHS potential is used backed up by 63.7 MW|17.9 GWh of chemical battery storage. In a practical scenario, the battery storage can be used to provide system ancillary services during time intervals less than fifteen (15) minutes. The model is not capable of assessing these requirements for maintaining system frequency, voltage and spinning reserve among others. The use of diesel generation is decreased over time as shown in Table 75. The required installed capacity of biodiesel (res dem diesel) in year 25 is 75.0 MW to supply the residual demand after all other sources of generation and storage have been dispatched. The required capacity in year 20 is 74.8 MW. The residual demand diesel capacity for years 5 to 15 are supplied by diesel fuel in all scenarios, so that the total diesel fuel capacity to be maintained in year 15 is 77.6 MW (12.9+64.7). Most of the energy in year 25 is provided by solar PV, geothermal and wind.

The average EV charge power settings for all years are provided in Table 76 and the amount of charge energy used relative to the displaced fossil fuel demand to meet transport sector energy needs for all 5-year intervals is provided in Table 77. The charge power values were adjusted within the defined constraints for energy consumption.

Table 76 Charge power settings for all substations

Power in kW	Year 5	Year 10	Year 15	Year 20	Year 25
Sc. A - LDV	2.85	2.45	2.41	1.98	1.7
Sc. A - HDV	3.1	2.65	2.46	2.1	1.85

Table 77 Percentage of charge energy used for transport relative to displaced fossil fuel consumption for scenario A

V2G Energy Supply HDV	Year 5	Year 10	Year 15	Year 20	Year 25
Vieux Fort	0%	-1%	9%	6%	8%
Soufriere	0%	-1%	10%	6%	8%
Praslin	0%	-1%	10%	6%	8%
Cul de Sac	0%	-1%	9%	6%	8%
Castries	0%	-1%	9%	6%	8%
Union	0%	-1%	9%	6%	8%
Reduit	0%	-1%	9%	6%	8%
V2G Energy Supply LDV	Year 5	Year 10	Year 15	Year 20	Year 25
Vieux Fort	1%	1%	7%	8%	10%
Soufriere	1%	1%	7%	8%	10%
Praslin	1%	1%	7%	8%	10%
Cul de Sac	1%	1%	6%	8%	10%

Castries	1%	1%	5%	8%	10%
Union	1%	1%	5%	8%	10%
Reduit	1%	1%	0%	9%	10%

Details for energy supplied, demand and load are provided in Table 78. Peak loads are significantly higher compared to the baseline scenario due to demand from EV charging.

Table 78 Scenario A energy, demand and load details

	Total RE Consumed - GWh	Total energy supplied - GWh	RER	Excess RE - GWh	% Res Dem Diesel	Total Demand - GWh	Peak Load - MW	Residual Demand - GWh	Peak Residual Load - MW	Total Peak Load - MW
Year 5	186.6	529.2	35%	0.0	15%	496.6	77	79.8	33	109
Year 10	301.0	602.7	50%	0.0	20%	511.4	80	120.0	48	127
Year 15	546.8	728.1	75%	0.0	16%	651.1	112	114.5	65	177
Year 20	885.9	889.8	100%	0.0	0%	693.6	124	3.9	75	198
Year 25	891.2	894.8	100%	0.0	0%	695.0	124	3.6	75	199

Based on the data provided in Table 78, total energy supplied exceeds demand by about 7% in year 5 due to system losses. This margin increases to 29% in year 25 as 22% of the energy is unutilised in storage.

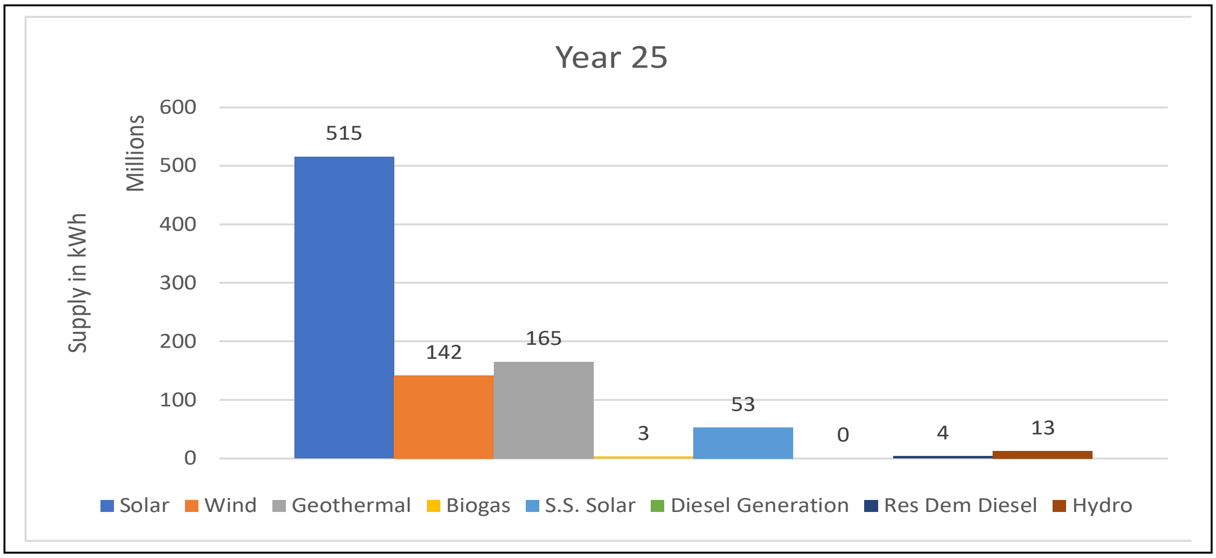


Figure 65 Year 25 energy supplied by source in Scenario A

The year 25 total energy utilised from all sources in this scenario is illustrated in Figure 65. 515 GWh of energy is provided by utility solar PV with the next largest source being geothermal at 165 GWh.

Investments are made gradually in the 5-year intervals to meet the target RE penetration levels. The resulting tariffs over the 5-year intervals and the merit order dispatch curve in year 25 are provided in Figure 66. In this scenario, successive investments have resulted in a gradual increase of the tariff from USD$ $0.338 per kWh in year 5 to a value of USD$ $0.417 per kWh in year 15. In years 20 and 25 a decrease in tariff is observed as 100% RE was achieved in year 20 with a significant amount of the required RE and chemical battery storage already installed in year 20. The marginal cost data is provided in Table 79 for year 25.

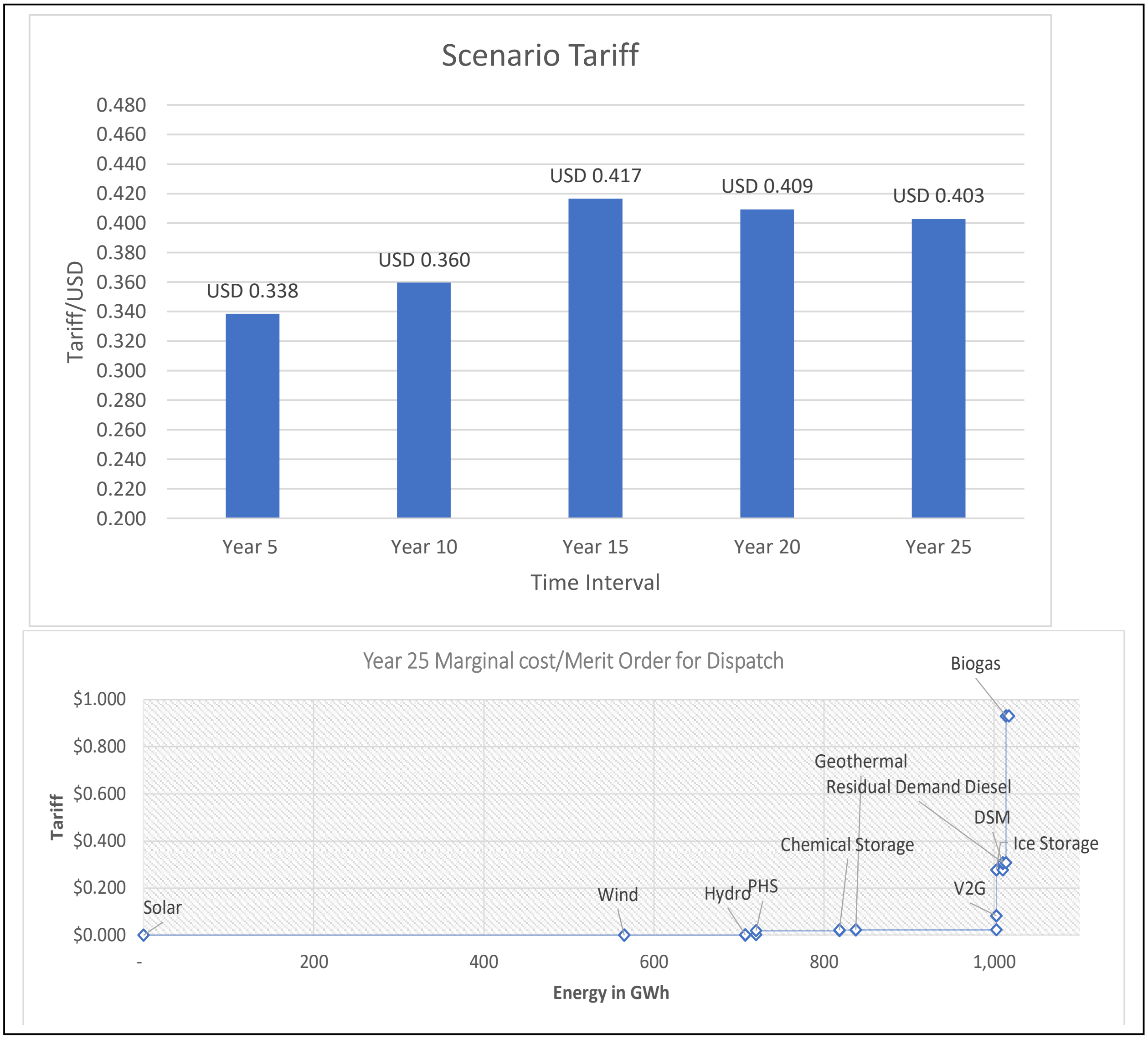


Figure 66 Scenario A tariff in 5-year intervals and merit order dispatch curve at year 25

Table 79 Scenario A merit order dispatch data

Energy Source	GWh supplied	Cumulative Energy (GWh)	Year 25 Marginal cost
Solar	565.2	-	$0.000
Wind	142.0	565	$0.000
Hydro	12.9	707	$0.002
PHS	98.0	720	$0.019
Chemical Storage	19.4	818	$0.022
Geothermal	165.2	837	$0.023
V2G	0.0	1,003	$0.082
Ice Storage	7.5	1,003	$0.276
DSM	0.0	1,010	$0.304
Residual Demand Diesel	3.6	1,010	$0.308
Biogas	3.3	1,014	$0.930

In the dispatch order curve, it can be noted that the most expensive form of generation is biogas followed by residual demand (biodiesel) diesel. Biogas can be dispatched to ensure that all available storage capacity is used, despite the cost. PHS and chemical storage are just marginally less expensive than geothermal. Wind and solar are the cheapest sources of generation with zero (0) marginal cost.

Table 80 provides details of the storage, by five-year intervals, for each storage type. Most of the storage energy is provided by PHS and chemical battery with some contribution from ice cooling. LDV V2G provides 32.5 GWh of stored energy with 1.2 GWh discharged in year 15. Though the storage increases to 41 GWh in years 20 and 25, there is almost no energy discharged for V2G as most of the storage needs are provided by either battery chemical or PHS.

Table 80 Scenario A storage capacity details by type and year

	Energy in GWh				
Storage Type	Year 5	Year 10	Year 15	Year 20	Year 25
Chemical					
Total Stored	0.1	2.1	11.7	23.1	25.1
Total Discharged	0.1	1.9	10.6	20.5	19.4
Losses	0.0	0.2	1.1	2.3	2.2
V2G – HDV					
Total Stored	28.6	56.5	91.1	120.1	122.7
Total Discharged	-	-	-	-	-
Losses	-	-	-	-	-
V2G – LDV					
Total Stored	9.5	19.0	32.5	41.2	41.0
Total Discharged	-	-	1.2	0.1	0.0
Losses	-	-	0.4	0.0	0.0
Storage Ice - Hotel					
Total Stored	-	-	1.9	4.3	4.3
Total Discharged	-	-	1.6	3.2	3.2
Losses	-	-	0.0	0.1	0.1
Storage Ice - Commercial					
Total Stored	-	-	2.3	5.2	5.2
Total Discharged	-	-	2.0	4.3	4.3
Losses	-	-	0.1	0.1	0.1
PHS					
Total Stored	-	-	-	128.6	130.5
Total Discharged	-	-	-	96.6	98.0
Losses	-	-	-	32.0	32.5

7.2.2 Scenario A - Evaluation of achievement of stakeholder objectives

Stakeholder feedback, model inputs and the explanation provided in Table 66 scenario A are reproduced here for ease of reference after each question.

7.2.2.1 R1_7

- What should be the national priorities for improving energy security in the energy sector (electricity, transport, cooking, et cetera)?

Feedback summary	Legislation and improved regulatory framework
Model Inputs	Mandated transition of FF to RE (S11 - 3 Mandated)
Explanation	% of projected fossil fuel demand in domestic, industrial, hotel and commercial sectors converted to electricity demand

This input is achieved by systematically converting all fossil fuel demand into electricity demand assuming a mandate, through legislation, to transition all energy demand to sustainable electricity. Consequently, peak loads significantly increase in each 5-year interval along with increases in RE penetration. Between year 5 and 15, the peak load increased by 62% due to EV demand (Table 78). By 2025, the peak load increased by 82% relative to year 5. The conversion rate from fossil fuels to electricity in domestic, industrial, hotel and commercial sectors was provided in Table 67.

7.2.2.2 R1_8,11

- What environmental aspects should be considered when making decisions on investments in the energy sector?

Feedback summary	Pollution to land, air and water supplies should be minimised
Model Inputs	Ban on ICE transport imports (S8 -1.Immediate ban on ICE imports)
Explanation	% of transport fleet to be converted from fossil fuel to electric vehicles

The projected number of EV along with the penetration rate of EVs is provided in Table 81.

Table 81 Penetration rate and number of EVs

Penetration	Totals	LDV&Cars	HDV	Public Transport	Farming	Total
25%	Year 5	8383	1334	1159	49	10876
50%	Year 10	19438	3094	2685	115	25216
75%	Year 15	33800	5380	4669	198	43850
100%	Year 20	52245	8313	7216	308	67774
100%	Year 25	60563	9635	8365	356	78563

In years 20 and 25, the full transport fleet is converted to EVs. This is reflected by a change in the peak electricity demand compared to BAU.

7.2.2.3 R1_3,10,13

- Should government continue to provide financial support for investments in the energy sector or should all energy investments be financially viable on their own?

Feedback summary	Mixed financing approach
Model Inputs	Blended financing (S10 - 5 Government equity, S13 - 1 Commercial debt) & S4 - 2 Part of profits kept
Explanation	70% debt at 8% for 10 years and 30% equity return of 5%

The debt and equity parameters are applied to the financial calculations. The financial results for this scenario are summarised in Table 82.

Table 82 Summary of financial results

RE and Storage Sources	Average ROE	Year 25 ROE	25 Year IRR	NPV in USD$
Solar	8%	13%	19%	$23,946,816
Wind	23%	43%	29%	$30,144,940
Biogas	6%	27%	16%	$92,855
Geothermal	11%	7%	24%	$10,160,048
PHS	2%	6%	15%	$597,975
DSM	-10%	-73%	NA	($54,412)
Battery Chemical	-1%	12%	16%	$2,476,527
V2G	-9%	-21%	2%	($3,238,921)
Ice Storage	-5%	-15%	13%	$202,530
Hydro	-12%	-17%	10%	($900,870)
Energy Efficiency	26%	5%	4%	($26,093,052)

Average ROE, year 25 ROE, IRR and NPV over the 25-year period are all positive for solar, wind, biogas, geothermal, PHS and energy efficiency investments. Only the IRR is positive for hydro and ice storage, however, it should be noted that investments for these started in year 15 so a longer time period will be required to experience favourable financial results. The average ROE for battery chemical is not favourable as investments occur in every 5-year interval, however, the IRR and NPV values indicate financial viability. DSM came online only in year 20, therefore, a 5-year period is not sufficient to estimate financial performance. EE shows strong financial performance except for IRR due to investments occurring in every 5-year interval. ROE numbers indicate financial viability. DSM and V2G do not display any viable financial metrics mostly due to the very low amount of energy shifted and dispatched. These two (2) investments will require a longer period and an adjustment of operating parameters to improve financial viability.

The value of profits kept in the local economy in year 25 is provided in Table 83. Due to the high depreciation expense, the EAIDT for hydro is negative in year 25.

Table 83 Year 25 value of profits staying in the local economy

RE Source	% of Gross Profits	Amount in USD$
Solar	19%	15,904,294
Wind	41%	11,424,455
Biogas	10%	447,344
Geothermal	14%	4,672,755
Hydro	0%	-
Total		32,448,848

These results show that with a mixed financing approach, containing government support and commercial financing, RE investments for all sources can become commercially viable with hydro requiring more time as the analysed investment period is only fifteen (15) years. V2G and DSM are not viable within the analysed timeframe and ice storage will require more time to yield a favourable financial performance.

To inform a decision on providing financial support to the energy sector, the impact on the economy and tax revenues should be quantified. The overall economic impact for this scenario is estimated at a PV of USD$165.4mn, i.e., an economic gain of USD$165.4mn over twenty-five (25) years at year 0-dollar value. This is very favourable compared to the baseline loss of USD$1,252.9mn dollars. The tax transition is illustrated in Figure 67.

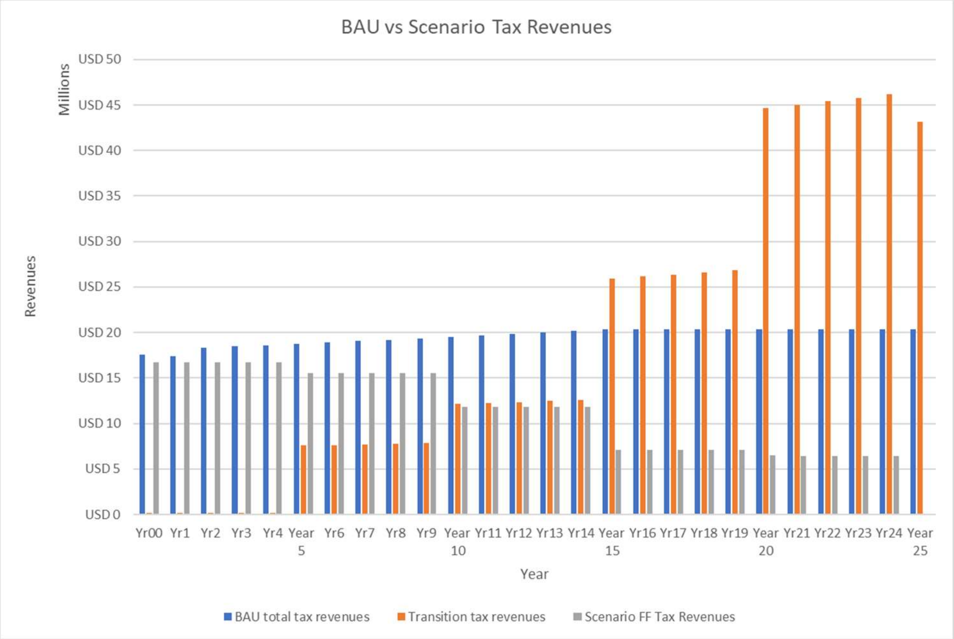


Figure 67 BAU vs scenario A tax revenues

The BAU tax revenues stay relatively constant at an annual amount of about USD$20mn. In the scenario, the revenues decrease over time as the BAU fossil fuel demand is replaced by RE. Between years 20 to 25, the fossil fuel tax revenues are due to biodiesel which is used to achieve the 100% RE target. As the amount of RE in the energy mix increases, the tax revenues also increase. Transition tax revenues exceed BAU tax revenues from year 15, mostly due to the additional electricity demand from the transport sector. A slight drop is seen in year 25 due to the drop in electricity tariff for that year. Transition tax revenues are exclusive of fossil fuel taxes (except for biodiesel).

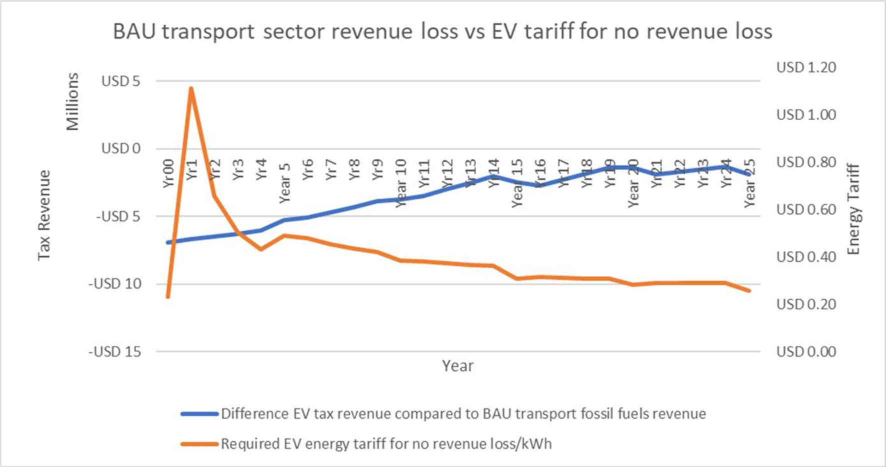


Figure 68 BAU transport sector revenue loss vs EV tariff for no revenue loss

The tariff required for tax parity in the transport sector and a comparison of tax revenues are provided in Figure 68. There is a sharp rise in the tariff from year 00 to year 1 as a few EVs are connected to the network and revenues from those few vehicles are compared to the entire BAU transport fleet tax revenues. As the number of EVs steadily increases over the years, this difference in tariff decreases and appears to be relatively stable between years 15 to 25 at around USD$0.30 per kWh. The tax revenues from EVs remain below the BAU transport sector tax revenues through the entire transition as the tariffs throughout the entire transition period are generally too low to generate enough tax revenue for parity with BAU. The required EV tariff for tax parity appears to stabilise at around USD$0.30 per kWh from year 15.

The tariff generally decreases every five (5) years and gradually decreases in between intervals. This characteristic result occurs because the transport fleet has been modelled to increase in size annually, whereas the transport fuel displaced is held constant during the 5-year interval. Hence, as the EV fleet grows, a lower tariff is required to replace the lost revenues. The tariff is corrected when the displaced fossil fuel is calculated in the following 5-year period.

PV of all RE investments over the 25-year period are provided in Table 84.

Table 84 Present value of all investments

RE and Storage Resource	Present Value of Investment in USD$
Wind	$42,125,173
Solar	$97,466,292
Geothermal	$31,821,786
Diesel	$29,605,173
Biogas	$1,399,190
Hydro	$11,507,632
Ice Storage	$9,364,506
PHS	$15,252,872
V2G	$14,753,626
Battery Chemical	$19,435,536
Energy Efficiency	$82,069,845
Demand Side Management	$84,162
Total	$354,885,794

The largest investments are from solar, wind and energy efficiency. The total PV is USD$354.9mn. Though the total required investment is about double the expected overall economic impact, it is still very favourable compared to the BAU overall economic impact.

7.2.2.4 R1_9

- Are there any sources of renewable energy that may not be socially acceptable?

Feedback summary	Exclusion of nuclear energy
Model Inputs	All RE sources (S9 - 4 All in)
Explanation	Wind, solar PV, geothermal, biogas, hydro

All sources of RE are used in this scenario as indicated in Table 75.

7.2.2.5 R1_4,6

- What benefits to the country would you like to see from sustainable energy investments?

Feedback summary	Improved energy security, reliability and resiliency
Model Inputs	Long duration storage
Explanation	Use of pumped hydro and chemical storage

The full pumped hydro storage potential is utilised in years 20 to 25. Chemical storage is used throughout the entire transition period with the maximum energy and power capacity in year 25 as shown in Table 75. These sources of storage contribute to energy security and reliability by enabling the utilisation of the country's variable RE (solar and wind) potential.

7.2.2.6 R1_2

- What sources of energy for electricity generation should receive priority for development in the electricity sector? Why?

Feedback summary	Solar PV as a source of RE to be given priority
Model Inputs	Maximise utility PV (S2 - 1 Grid connected solar PV with battery backup)
Explanation	Maximise utility solar PV use

85% of the maximum utility solar PV capacity, i.e., 360.9 MWp is utilised in year 25. Chemical battery storage usage ranges from 7.4 MW in year 5 to 63.7 MW in year 25 as provided in Table 75.

7.2.2.7 R2_RE

– The Government of Saint Lucia (GOSL) has set a target of 35% by 2025 and 50% by 2030 for generation of electricity from renewable sources. Are you in agreement with this vision? If not, suggest an alternative.

Feedback summary	Agree with the existing government target
Model Inputs	Government targets agreed (S1 - 1 Government target)
Explanation	Government targets of 35%/2025; 50%/2030 with addition of 75%/2035; 100%/2040)

Targets for all time periods can be achieved. 75 MW peak capacity of biodiesel is required in years 20 and 25 to achieve the 100% RE targets. The full potential capacity of wind and solar PV are not required to achieve the 100% RE target.

7.2.2.8 R2_GH

– The Government of Saint Lucia (GOSL) has set a target of 7% reduction in GHG emissions in the energy sector relative to 2010, by 2030. Are you in agreement with this vision? If not, suggest an alternative.

Feedback summary	The target should be lower
Model Inputs	Output discussion
Explanation	GHG reductions due to RE calculated and discussed as an output.

The CO_2 equivalent emissions in 2010 was estimated at 647 Gigagrams (Government of Saint Lucia, 2015). The chart at Figure 69 shows the CO_2 savings over the transition period and the percentage of the 2010 baseline for the same period.

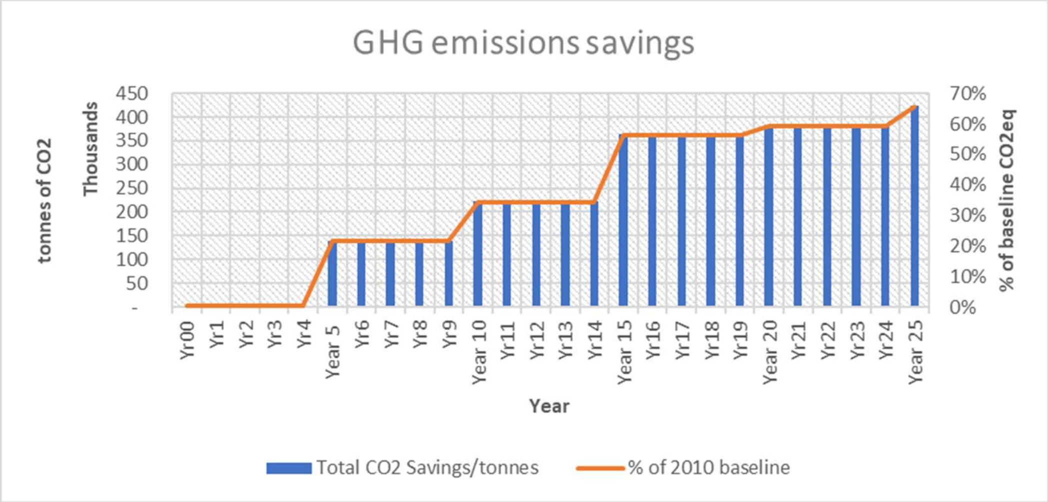


Figure 69 GHG emissions savings

The 7% reduction target is exceeded already between years 5 and 10 at 21.5% of the baseline value in savings. The emissions savings as a percentage of the baseline are provided in Table 85.

Table 85 CO2 emissions savings as a percentage of 2010 baseline

	% of 2010 baseline
Year 5	21.5%
Year 10	34.4%
Year 15	56.4%
Year 20	59.1%
Year 25	65.6%

7.2.2.9 R2_EE

- The Government of Saint Lucia (GOSL) has set a target of 20% reduction in energy consumption in the public sector. Are you in agreement with this vision? If not, suggest an alternative.

The achieved EE savings in year 25 are displayed for the time period Month 6, days 18 to 20 in Figure 70. When demand for EV charging is highest during the day, the impact of EE savings decreases to about 12%. In the evening when EV charging has a much lower effect on total demand, the impact of EE savings increases to around 18%. Though the results show the overall EE savings for all sectors, it is evident that savings of up to 18% are possible under the current scenario. The average EE savings for year 25 was 16% which is just short of the 20% target.

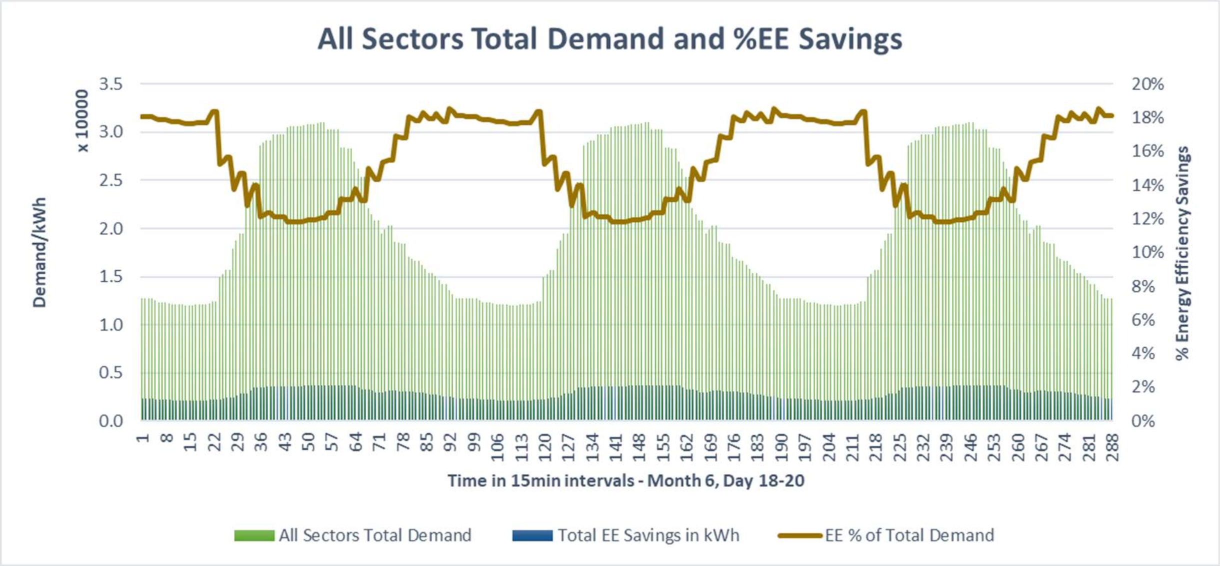


Figure 70 EE Savings across all sectors except street lighting

7.2.2.10 R2_5,8,12

– What economic sectors should receive priority support for improving efficiency of energy consumption, i.e., achieving the same output with less energy?

Feedback summary	The hotel sector should receive priority support
Model Inputs	Ice storage pricing (S5 - 1 Ice storage for cooling in hotel sector)
Explanation	Reduction in VAT on investments by 10%

Table 86 shows the penetration of ice storage capacity in hotel and commercial sectors using the government set RE penetration targets to determine the penetration level for replacement of electricity demand for cooling with ice storage cooling. The capacity is provided in kWh electrical equivalent.

Table 86 Ice storage capacity using government set EE targets

Penetration	Totals	Hotel ice storage capacity in kWhel	Commercial ice storage capacity in kWhel
35%	Year 5	2,083	235,200
50%	Year 10	2,976	336,000
75%	Year 15	4,464	504,000
100%	Year 20	5,952	672,000
100%	Year 25	5,952	672,000

In year 25, energy stored by ice storage in the hotel sector was the electrical equivalent of 4.3 GWh and the energy discharged for cooling was 3.2 GWh as provided in Table 80. The tariff for ice storage energy was still high in year 25 at USD$0.554 per kWh and the total ice cooling discharged from both sectors was 7.52 GWh. The high tariff is due to investments beginning in year 15 consequently, the tariffs are still heavily influenced by the impact of debt payments. The tariff would be higher without a reduction in VAT on the investment cost. Total PV of investments in ice cooling was USD$9.4mn (see Table 84).

7.2.2.11 R3_11,14

– What should be the objectives of developing a resilient energy system in Saint Lucia?

Feedback summary	A more reliable energy system which is resilient to climate change
Model Inputs	Long duration storage
Explanation	Use of hydro and chemical storage

This requirement is met as described at R1_4,6.

7.2.2.12 R4_6,14

- What are your objectives for transitioning the energy sector to sustainable energy (renewable energy and energy efficiency)?

Feedback summary	More control of and to reduce the cost of energy
Model Inputs	Cost driven energy price (S6 - 2 Lifecycle cost plus profit margin; S3 - 2 Based on RE costs for EVs)
Explanation	Energy pricing is based on investment and operations costs of RE plants

The amount of energy delivered from each source and the weighted average tariff based on the lifecycle cost and profit margins for year 25 are provided in Table 87. The amount of energy discharged by V2G is very low, consequently the tariff is extremely high. V2G would not be a viable option under the constraints defined in this research.

Table 87 Energy supplied and associated tariffs in year 25

Energy Source	Energy Generated and Discharged in kWh	Energy tariff USD$/kWh	Weighted average tariff (USD$/kWh)
Solar	565,241,045	0.238	0.132
Wind	141,972,086	0.400	0.056
Biogas	3,346,232	2.154	0.007
Geothermal	165,189,876	0.309	0.050
Diesel	-	0.461	0.000
Hydro	12,870,665	0.757	0.010
DSM	8,506	0.798	0.000
V2G	41,839	2100.313	0.086
Ice Storage	7,526,423	0.554	0.004
Chemical Storage	19,369,255	0.436	0.008
PHS	97,960,562	0.493	0.047
Residual Demand Diesel	3,628,946	0.530	0.002
Total	1,017,155,434		0.403
		Average Tariff	XCD$1.08
			USD$ 0.40

The 5-year interval tariffs were provided in Figure 66. The debt in year 25 is provided in Figure 71 in millions of USD$. The largest investment of USD$23mn is for solar PV as required under this scenario. The next largest debt of USD$9.6mn is for biodiesel generation to cover residual demand.

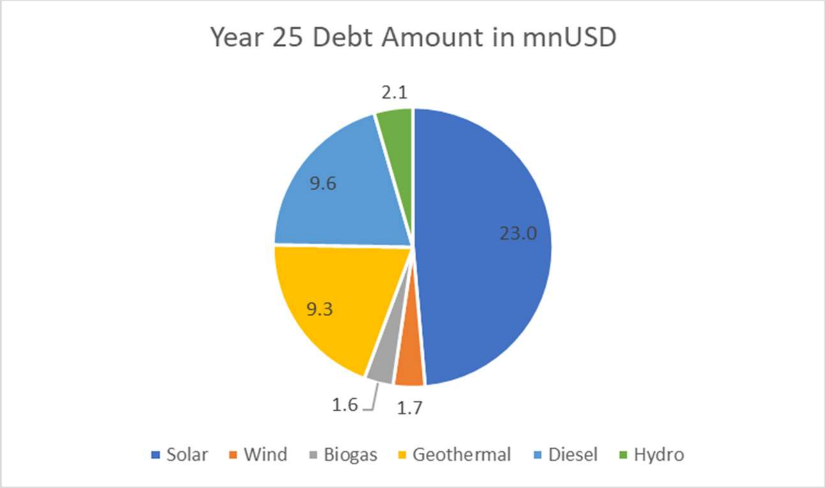


Figure 71 Year 25 debt amount for all generation sources

This USD$47.4mn debt burden will be reduced in the years following year 25 though some investments can be expected for repowering of equipment that comes to the end of their service life, e.g., solar PV plant installed in year 0 may need to be repowered in year 30.

7.2.2.13 R4_1,10

– How should the general public participate in a transition to sustainable energy?

Feedback summary	Public consultation, education and awareness building
Model Inputs	Stakeholder engagement
Explanation	Discussion of inputs/outputs

Results from this scenario were shared with stakeholders as part of a consultation process to determine which scenario best meets the stakeholder defined objectives.

7.2.3 Scenario A Sensitivity Analysis

Results of a sensitivity analysis for Scenario A are provided in Figure 72. The tariff is most sensitive to the variations in amount of RE resource and to financial parameters. As the amount of RE utilised decreases, the tariff is seen to increase. Increase in the amount of RE used conversely results in a decrease to the tariff, though less than the effect of a reduction in RE. This may be due to the technical limit in the amount of energy that is needed to meet demand. A 10% drop in the RE resources results in an impact on the tariff of around USD$0.13 increase whereas a 10% increase in RE results in a tariff decrease of just about USD$0.05 per kWh. The impact of a drop in RE production is higher as less energy is produced for the same investment cost.

Favourable financial parameters provide significant positive benefits to both tariffs and economic impact. A drop in the tariff of just over USD$0.04 is seen with a 10% decrease in the financial parameters as this results in a lower cost of financing of RE investments. Likewise, an increase of 10% in financial parameters results in an increase in the tariff of just around USD$0.04 per kWh. Variations in peak load and price of fossil fuels, in this case, biodiesel, have a lesser impact on the energy tariff. An increase in peak load results in more use of biodiesel resulting in a tariff increase of USD$0.02 per kWh. A decrease in the peak load results in more unutilised RE with a drop in the tariff of USD$0.01 per kWh.

Variations in financial parameters have the strongest effect on the economic impact, as can be expected. Lower cost of financing results in more positive financial benefits. The greatest effect on economic impact is seen from increasing the financial parameters by 10% which results in a lowering of economic impact by about USD$40.3mn. A decrease of 10% in financial parameters results in increasing the economic impact by about USD$33.2mn. In order of their effect, the economic impact is less sensitive to variations in peak load, RE resource and price of fossil fuel (biodiesel). Both an increase and decrease in the RE resource result in a lowering of the economic impact. A decrease in RE lowers the economic impact by about USD$9.8mn as more biodiesel has to be used to meet the residual demand. An increase in RE results in dumping of excess energy, hence the decrease in economic impact of USD$0.3mn. Both an increase and decrease in peak load also result in a lowering of the economic impact. A 10% decrease in peak load lowers the economic impact by about USD$6.4mn as some of the RE generated will be unutilised. An increase in the peak load would require more biodiesel to meet the demand resulting in a lowering of the economic impact. The price of fossil fuels in year 25 refers to the price of biodiesel. A decrease results in lower taxes and a lower economic impact whereas an increase results in a benefit to the economic impact.

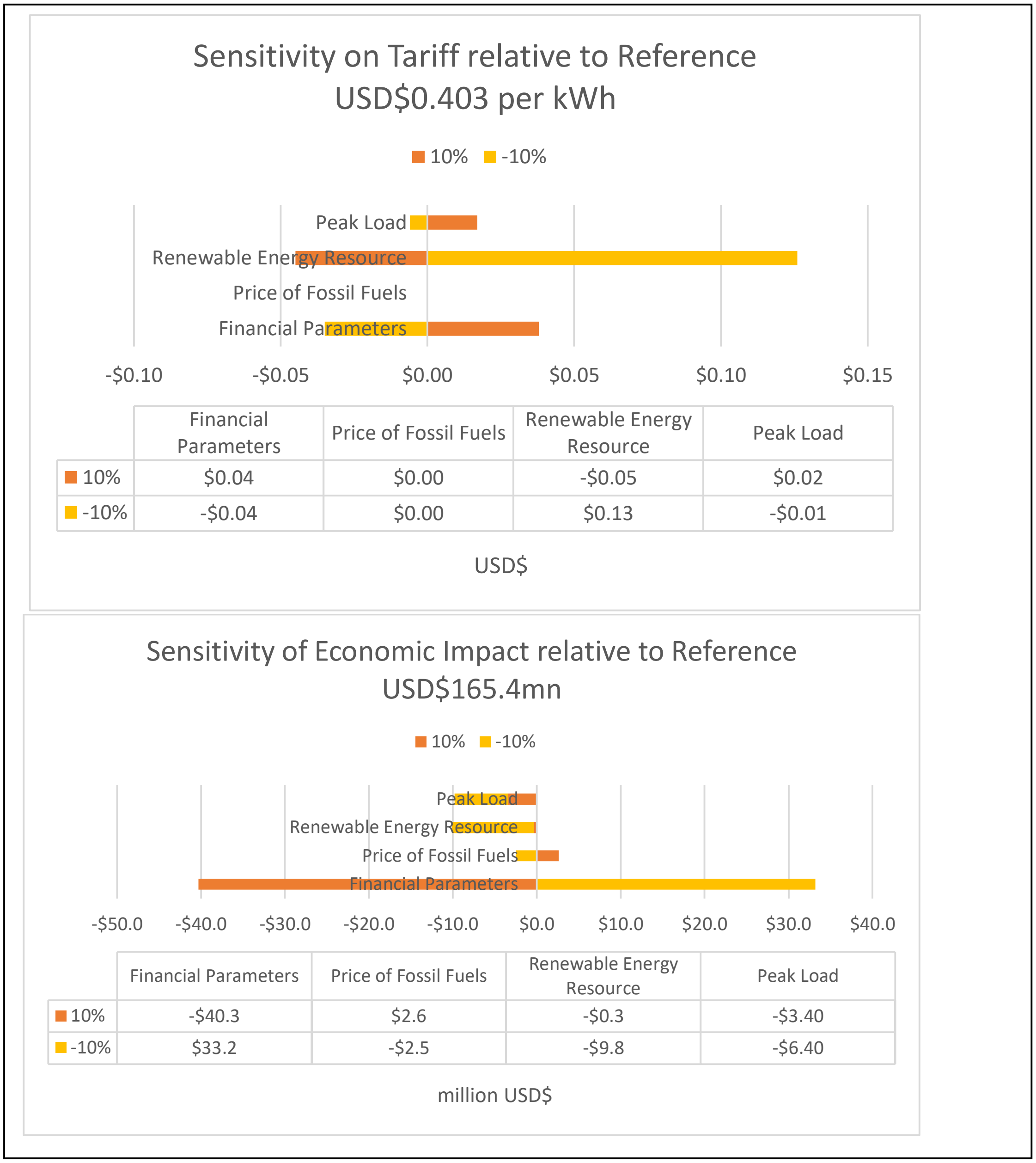


Figure 72 Scenario A results of sensitivity analysis

7.2.4 Comparison of Scenario A to BAU

Table 88 Comparison of Baseline and Scenario A

	Parameter	Baseline	Scenario A
Year 25	Energy Output - GWh	553.4	894.8
	Demand – GWh	514.5	695.0
	Storage Capacity - GWh	0	18.9

	Solar IRR	12%	19%
	Wind IRR	NA	29%
	Geothermal IRR	NA	24%
	Hydro IRR	NA	10%
	Biogas IRR	NA	16%
	Total Excess Generation - GWh	NA	0
	Residual Demand - GWh	NA	3.6
	Tariff - USD$ per kWh	0.462	0.403
	Dominant RE Source	Solar	Solar
	Dominant RE Supply - GWh	4.3	565
	Value of profits remaining in local economy - USD$mn	NA	32.4
	Tax revenue - USD$mn	20	113.9
	Average EE Savings	NA	16%
Overall	PV of Tax Revenues (No FF in Scenarios) - USD$mn	NA	116.4
	Economic Impact - USD$mn	(1,252.90)	165.4
	PV of Investment Costs - USD$mn	NA	354.9
	RER (without Biodiesel)	1%	100%
	Exclusions	NA	None
	Year to exceed BAU tax revenues	NA	15

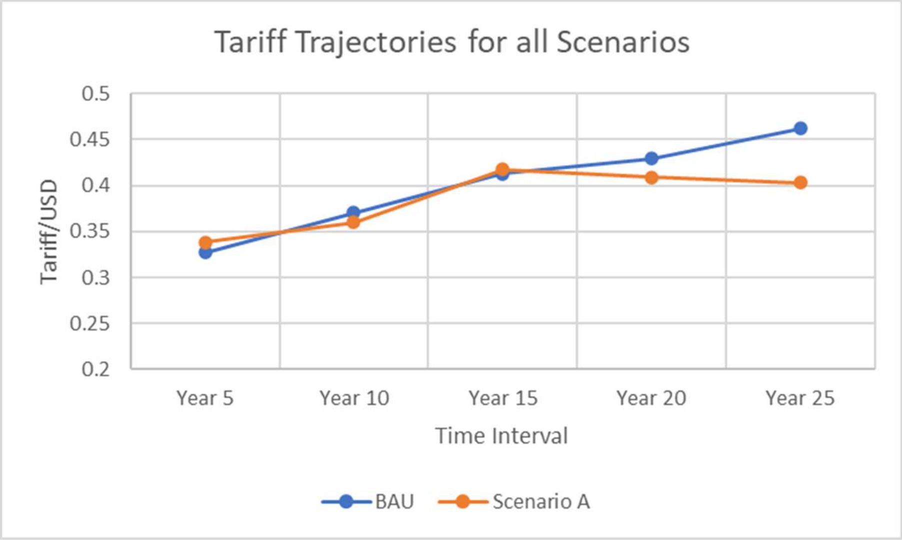


Figure 73 Tariff trajectories baseline and Scenario A

Data for comparison of the baseline and scenario A is provided in Table 88. Demand and energy output for Scenario A are 35% and 62% respectively greater than the baseline scenario due mainly to the demand in the transport sector. Solar PV has an increased IRR of 19% compared to the baseline of 12% as scenario A has significantly more installed capacity and generation from PV. The most significant difference between the baseline and scenario A is the economic impact which is a loss to the economy of over a billion USD$ in the baseline scenario versus a gain of USD$165.4mn in scenario A. This is despite the tariff for scenario A being almost the same as the baseline for the period year 5 to year 15 as shown in Figure 73. Scenario A tariffs at year 20 and year 25 are lower than the baseline. The tariff for scenario A can be expected to continue a downward trend beyond year 25 as assets become fully amortised and debts are paid off. Savings to consumers and other benefits are higher in scenario A than the baseline.

7.2.5 Scenario B - Transition Pathway

The transition pathway defined by stakeholder scenario B is summarised in Table 89. This scenario focuses on maximising wind energy utilisation. No geothermal generation is included as required by stakeholders.

Table 89 Scenario B transition pathway

Maximum Energy or Capacity by Source	Year 5	Year 10	Year 15	Year 20	Year 25
Solar – Utility (MWp)	19.0	52.0	67.0	138.0	143.0
Solar - Distributed (MWp)	7.7	13.7	20.0	40.5	41.2
Wind (MW)	23.0	41.4	82.8	266.8	266.8
Biogas (MW)	0.2	0.3	0.4	0.8	0.8
Geothermal (MW)	-	-	-	-	-
Hydro (MW)	0.5	0.8	1.2	2.3	2.3
Diesel (MW)	40.0	32.5	17.1	-	-
DSM (MW)	0.9	1.6	2.4	5.0	5.2
DSM Energy (MWh)	-	0.4	0.6	1.2	1.2
V2G - HDV (MW)	-	-	-	-	-
HDV V2G Energy (kWh)	-	-	-	-	-
V2G - LDV (MW)	-	-	10.3	10.3	8.5
LDV V2G Energy (kWh)	-	-	2,581.2	2,568.4	2,121.9
Ice Storage - Commercial (MW)	-	-	0.7	1.5	1.5
Ice Storage - Commercial (kWh)	-	-	183.9	363.2	363.2

Ice Storage - Hotel (MW)	-	-	0.6	1.2	1.2
Ice Storage - Hotel (kWh)	-	-	154.2	299.7	299.7
Chemical Storage (MW)	-	1.6	47.9	104.3	104.7
Chemical Storage (MWh)	-	0.4	402.3	70,381.9	77,421.0
PHS (MW)	-	-	-	97.2	97.3
PHS (MWh)	-	-	-	1,884.7	1,884.7
Peak Residual Demand Diesel (MW)	34.2	53.9	89.0	75.1	74.3

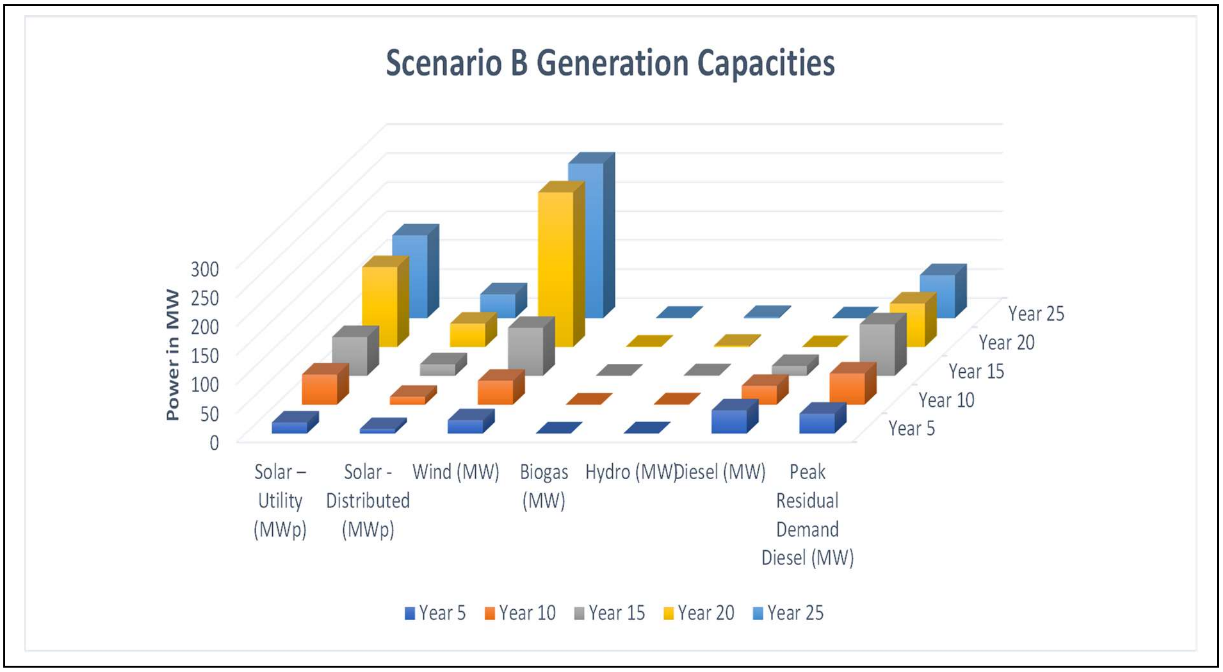


Figure 74 Scenario B generation capacities by year

The generation and storage capacities for the transition scenario are illustrated in Figure 74 and Figure 75.

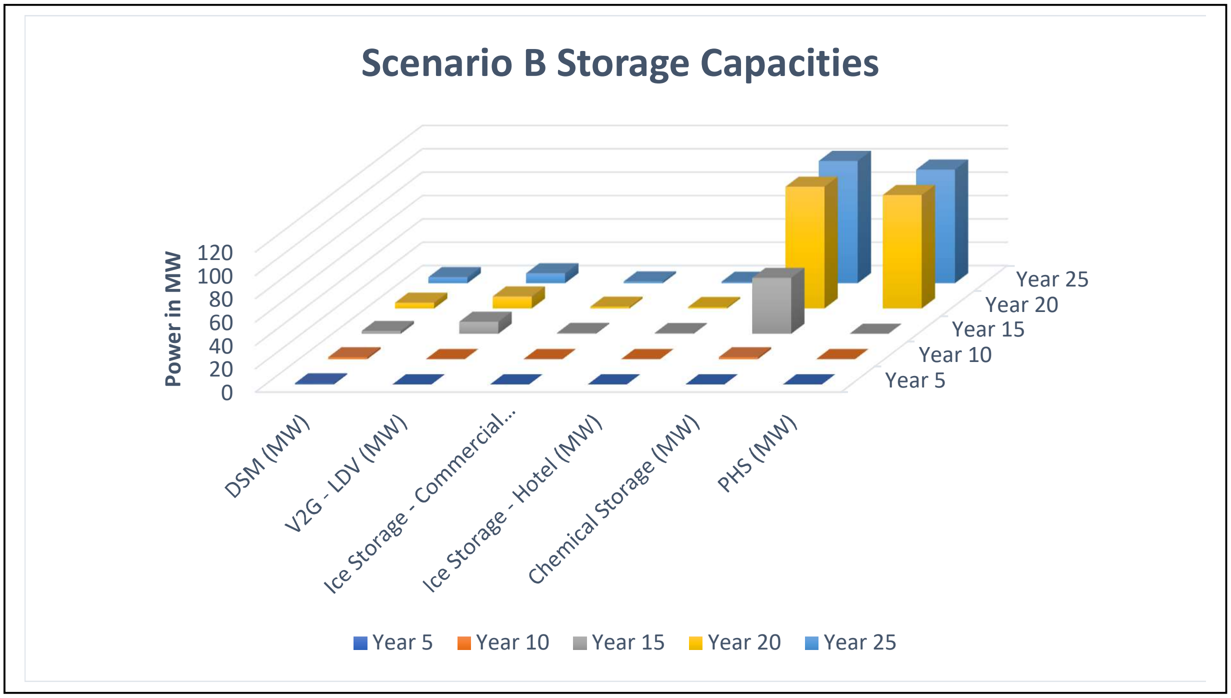


Figure 75 Scenario B storage capacities by year

Generation in this scenario is dominated by utility solar PV and wind energy as required by the stakeholders. Diesel generation is gradually faded out and peak residual demand diesel is converted to biodiesel in years 20 and 25.

As with scenario A, storage is dominated by PHS and chemical storage. Chemical storage is phased in sooner in scenario A.

The energy mix at year 5 is illustrated in Figure 76. The dominant source of RE is wind energy at 23 MW capacity. This is accompanied by 19 MWp of utility solar PV, 7.7 MWp of distributed solar PV, 0.2 MW of biogas and 0.5 MW of hydro generation. Initial capacity values were set by the target average RE penetration for this scenario at 20% for year 5. The amount of wind energy was then adjusted until the target RE penetration was achieved. Though DSM was enabled, there was no need for shifting of demand. Due to the low RE penetration, no form of storage was required to achieve the RE penetration target. Diesel generation was used to meet the residual demand.

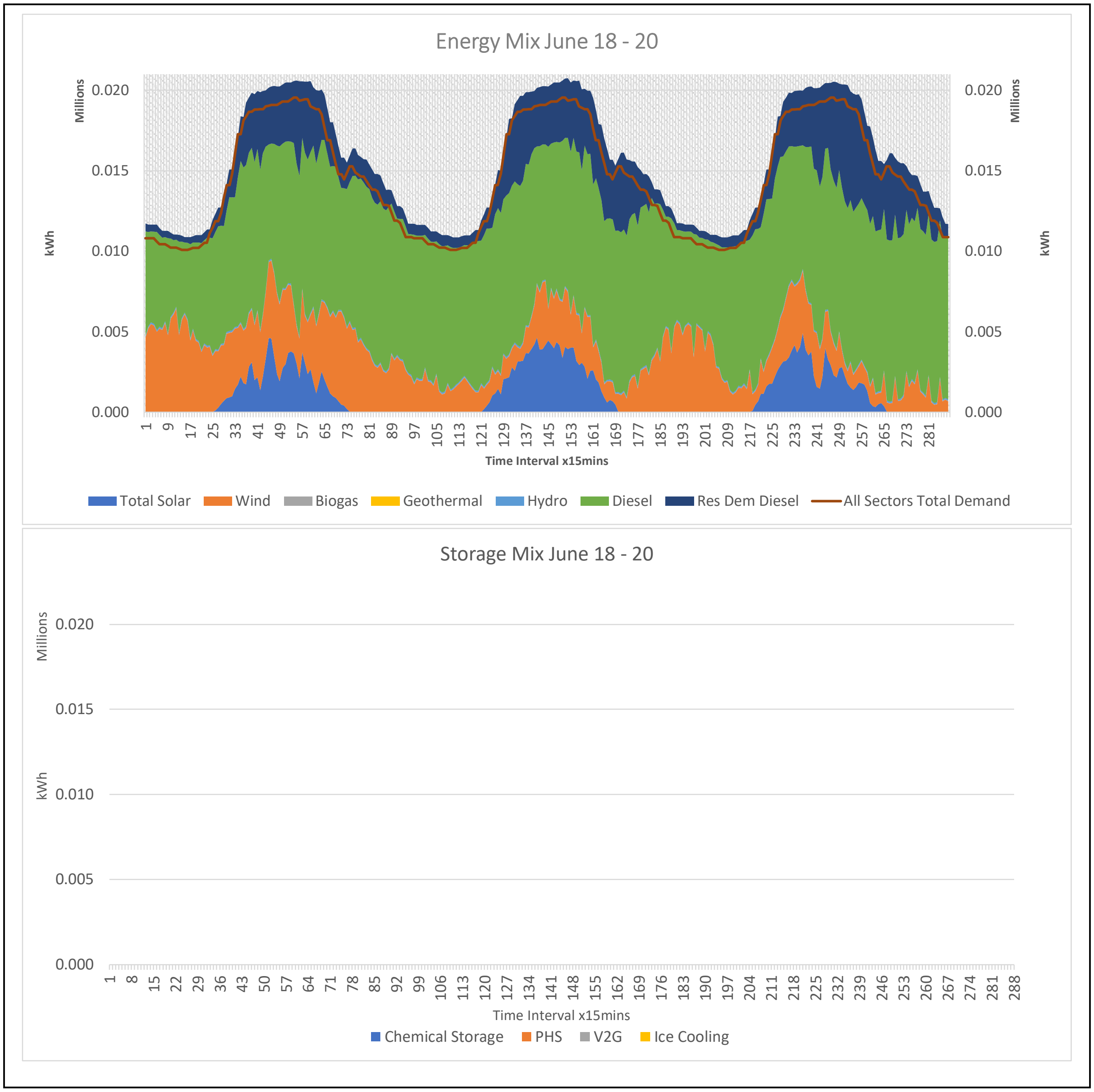


Figure 76 Scenario B Energy mix at year 5

In year 10, similarly to year 5, the amount of each source of RE generation was set by the target RE penetration of 35% and the amount of wind energy was adjusted to achieve the target. The wind energy capacity was increased to 41.4 MW. This was exceeded by the utility solar PV capacity of 52 MW. Biogas capacity was increased to 0.3 MW and hydro capacity to 0.8 MW. DSM and battery chemical storage both had capacity of 1.6 MW|0.4 MWh. Residual demand was supplied by diesel generation. The energy mix for year 10 is illustrated in Figure 77. No storage energy was deployed during the illustrated time period. Diesel, wind and solar PV provide the majority of energy.

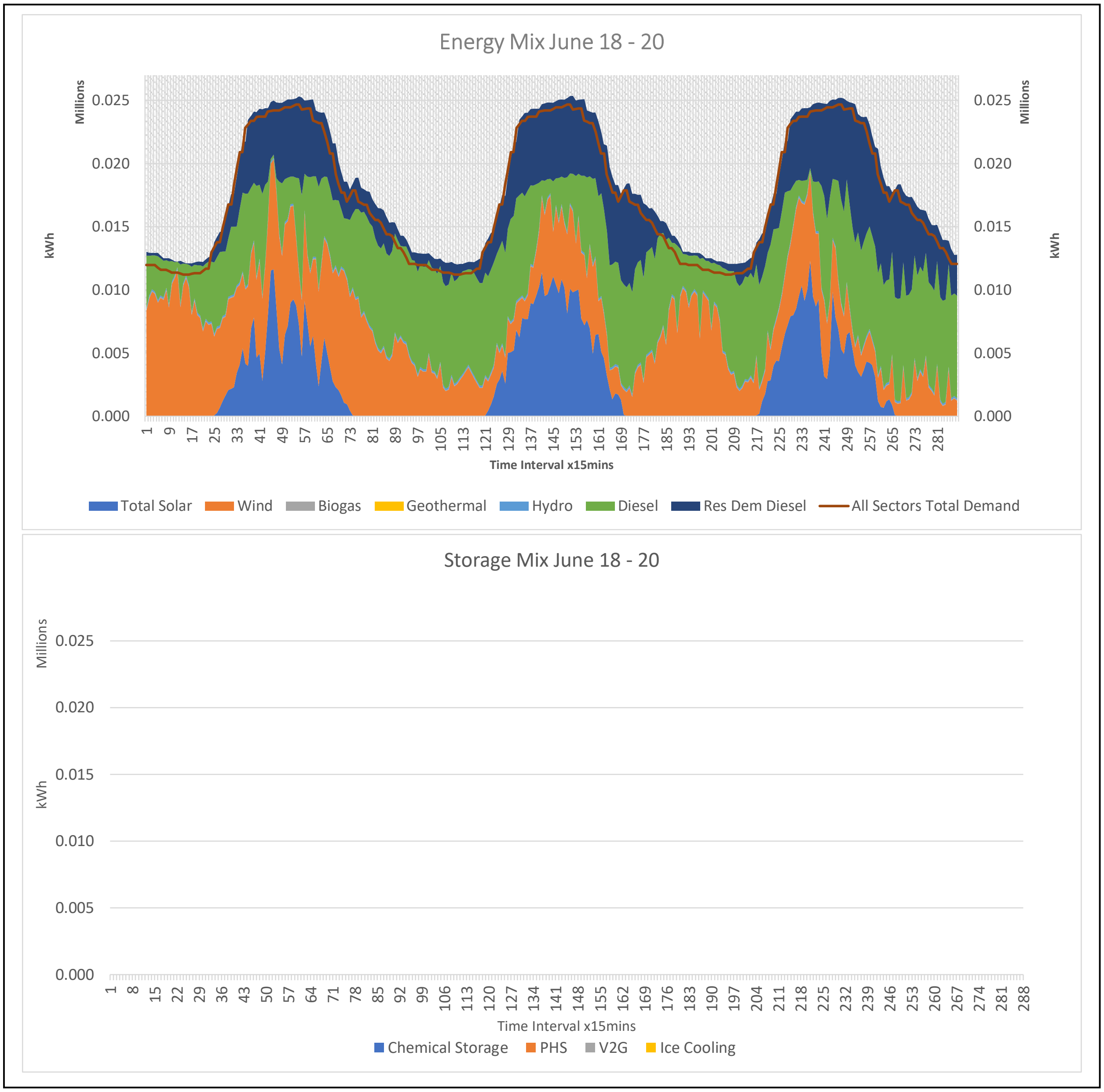


Figure 77 Scenario B Energy mix at year 10

The highest RE installed capacity in year 15 is wind at 82.8 MW. As with the other years, the amount of each RE supply source, except wind, is first set by the target penetration level of 50% applied to the evaluated capacity. The amount of installed wind capacity is then adjusted to achieve the RE penetration target. 67 MWp and 20 MWp of utility solar PV and distributed PV respectively along with 0.4 MW of biogas and 1.2 MW hydro were utilised. Storage capacities used were DSM at 2.4 MW|0.6 MWh, LDV V2G at 10.3 MW|2.58 MWh, commercial ice storage at 0.7 MW|183.9 kWh, hotel ice storage at 0.6 MW|154.2

kWh and chemical storage of 47.9 MW|402 MWh. Residual demand was satisfied using 89 MW of diesel capacity. The energy mix for year 15 is illustrated in Figure 78.

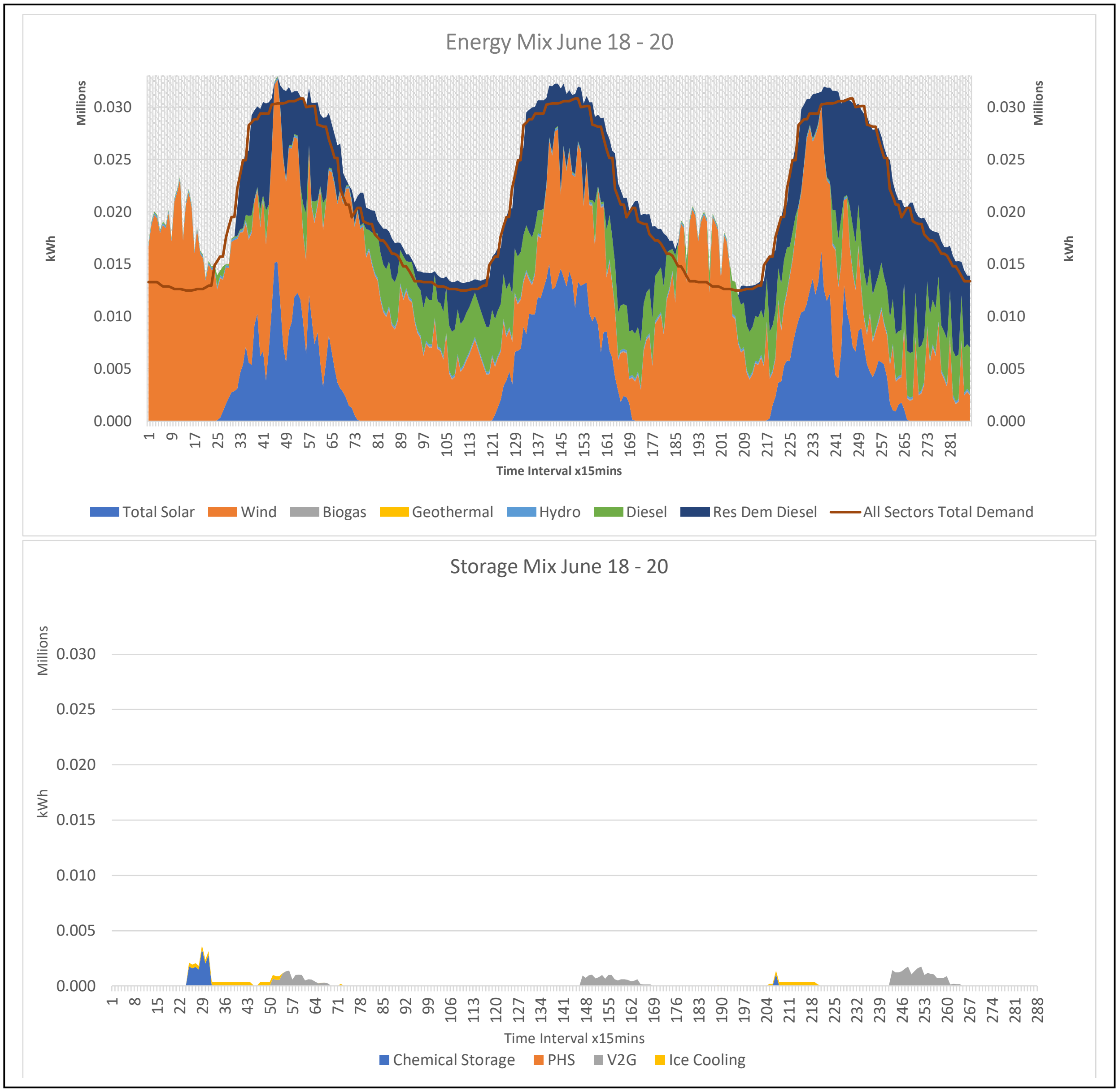


Figure 78 Scenario B Energy mix for year 15

Chemical, ice cooling and V2G storage are all deployed during the time period illustrated. The energy supply is dominated by wind, solar and diesel generation.

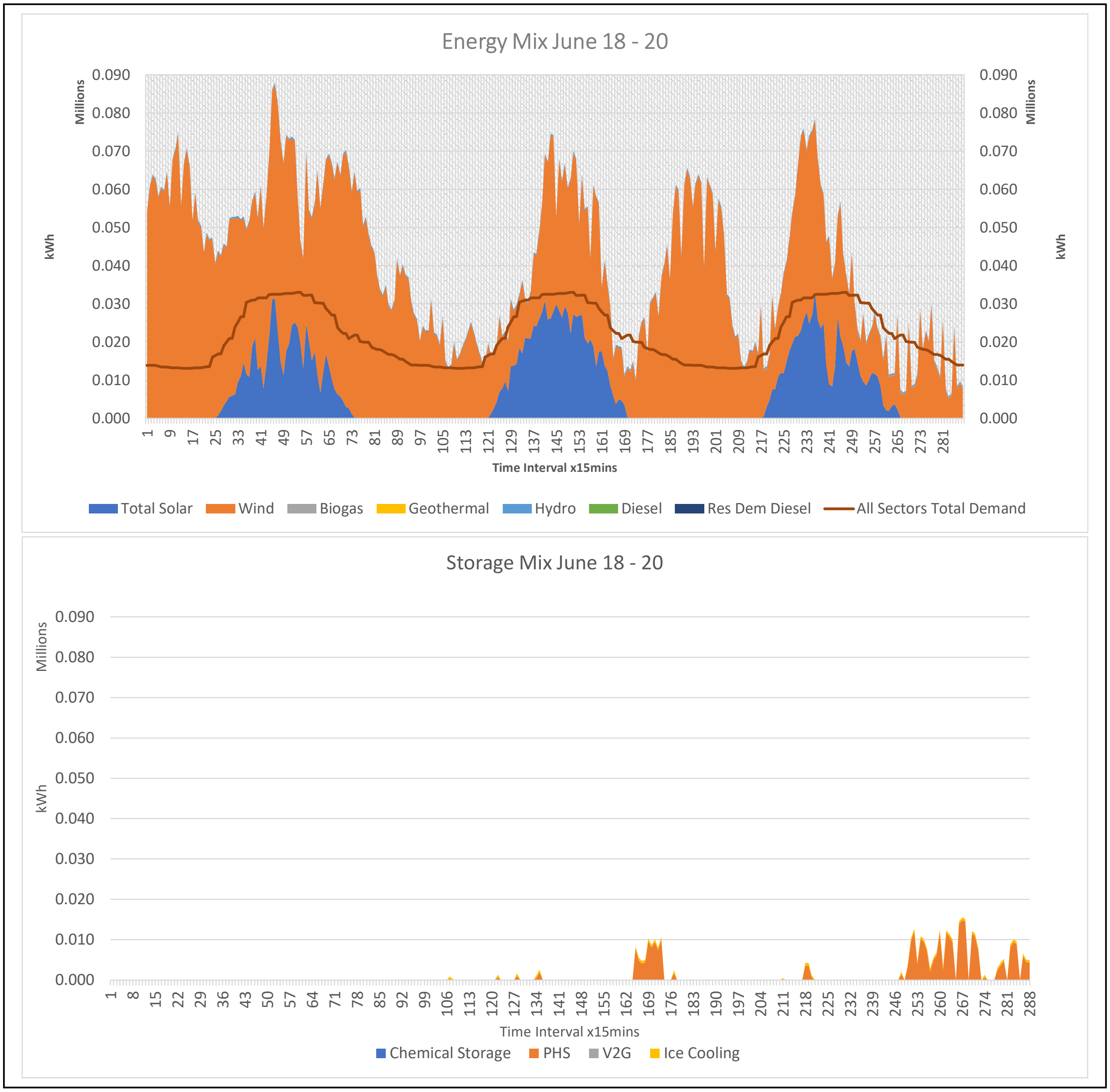


Figure 79 Scenario B Energy mix for year 20

To achieve the year 20 target of 100% RE, the total wind power potential capacity of 266.8 MW was used. In addition, a capacity of 138 MWp of utility solar PV and 40.5 MWp of distributed solar PV are utilised. Biogas and hydro are at full capacity at 0.8 MW and 2.3 MW respectively. A DSM capacity of 5 MW|1.2 MWh is used. The required storage capacities are LDV V2G 10.3 MW|2.57 MWh, commercial ice storage 1.5 MW|363.2 kWh, hotel ice storage 1.2 MW|299.7 kWh, chemical battery 104.3 MW|70.4 GWh and PHS 97.2 MW|1.88 GWh. The required chemical battery storage is very large so alternatives would need to be considered, e.g., using flexible RE generation from green hydrogen or increasing the PHS capacity. 75.1 MW

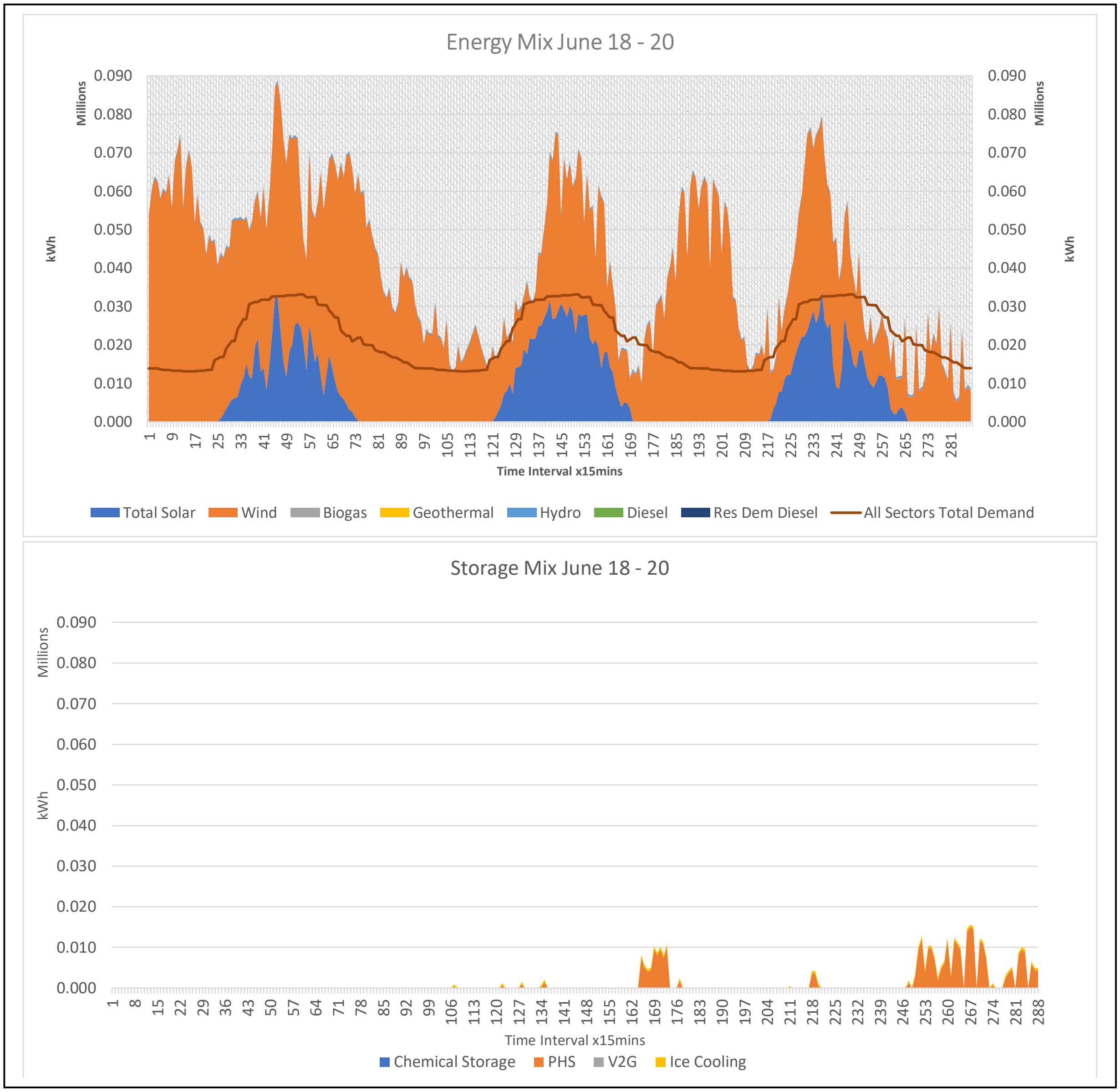


Figure 80 Scenario B Energy mix for year 25

of biodiesel generation capacity is required to cover residual demand. PHS dominates the storage energy discharge during the time period illustrated in Figure 79.

The energy mix at year 25 provided in Figure 80, is similar to year 20. Maximum wind energy potential capacity of 266.8 MW is used along with maximum capacity of hydro and biogas generation. DSM capacity has remained almost unchanged at 5.2 MW|1.2 MWh. LDV V2G has decreased in capacity to 8.5 MW|2.1 MWh. Energy capacity of the battery chemical storage has increased with capacity now rated at 104.7 MW|77.4 GWh. PHS capacity remains almost unchanged from year 20 at 97.3 MW|1.88 GWh. Commercial and hotel ice storage remain unchanged from year 20. 74.3 MW of biodiesel capacity is required to cover residual demand. This capacity should be served by biodiesel to ensure a 100% RE mix. Most of the storage deployed during the period illustrated in Figure 80 is from PHS.

The EV charge power settings and percentage of electrical energy used relative to projected transport fossil fuel demand are provided in Table 90 and Table 91 respectively. No V2G is provided by the HDV as the charge power is too low and the minimum state of charge too high for sufficient storage capacity to be available when needed for V2G. Excess consumption occurs if the charge power is increased. This is a shortcoming of the Microsoft Excel model.

Table 90 Average charge power used per 5-year interval

Power in kW	Year 5	Year 10	Year 15	Year 20	Year 25
Sc. B - LDV	2.84	2.45	3.27	2.08	1.8
Sc. B - HDV	3.1	2.65	2.52	2.1	1.85

Table 91 Percentage of charge energy used for transport relative to projected FF consumption for scenario B

HDV V2G Energy Supply	Year 5	Year 10	Year 15	Year 20	Year 25
Vieux Fort	0%	-1%	9%	6%	8%
Soufriere	0%	-1%	10%	6%	8%
Praslin	0%	-1%	10%	6%	8%
Cul de Sac	0%	-1%	9%	6%	8%
Castries	0%	-1%	9%	6%	8%
Union	0%	-1%	9%	6%	8%
Reduit	0%	-1%	9%	6%	8%
LDV V2G Energy Supply	Year 5	Year 10	Year 15	Year 20	Year 25
Vieux Fort	1%	1%	0%	9%	10%
Soufriere	1%	1%	0%	9%	10%
Praslin	1%	1%	0%	9%	10%
Cul de Sac	1%	1%	0%	9%	10%
Castries	1%	1%	0%	9%	10%
Union	1%	1%	0%	9%	10%
Reduit	1%	1%	0%	9%	10%

Table 92 Scenario B Energy, demand and load details

	Total RE Consumed - GWh	Total energy supplied - GWh	RER	Excess RE - GWh	% Res Dem Diesel	Total Demand - GWh	Peak Load - MW	Residual Demand - GWh	Peak Residual Load - MW	Total Peak Load - MW
Year 5	107.4	539.3	20 %	0.0	19%	507.4	78	102.9	34	112
Year 10	218.3	624.9	35 %	0.0	26%	591.7	96	162.7	54	150
Year 15	367.9	739.7	50 %	0.0	35%	703.3	123	258.9	89	212

Year 20	1,024.9	1,030.0	100 %	0.0	0%	746.8	132	5.1	75	207
Year 25	1,033.0	1,037.9	100 %	0.0	0%	749.1	133	4.9	74	207

Energy demand and load details are provided in Table 92. Between year 5 and year 25, the peak load has grown from 112 MW to 207 MW, i.e., approximately 85%. This is due to addition of sector and transport fossil fuel energy demand converted to electrical energy. The RE penetration target for each 5-year interval was achieved without excess RE generation. In year 5, total generation exceeded total demand by about 6.3% due to system losses. The difference in year 25 was 38.5% due mostly to energy held in the various forms of storage and not utilised.

Total energy supplied in year 25 by source is provided in Figure 81. 749 GWh is provided by wind energy with the next largest source solar PV providing 205 GWh.

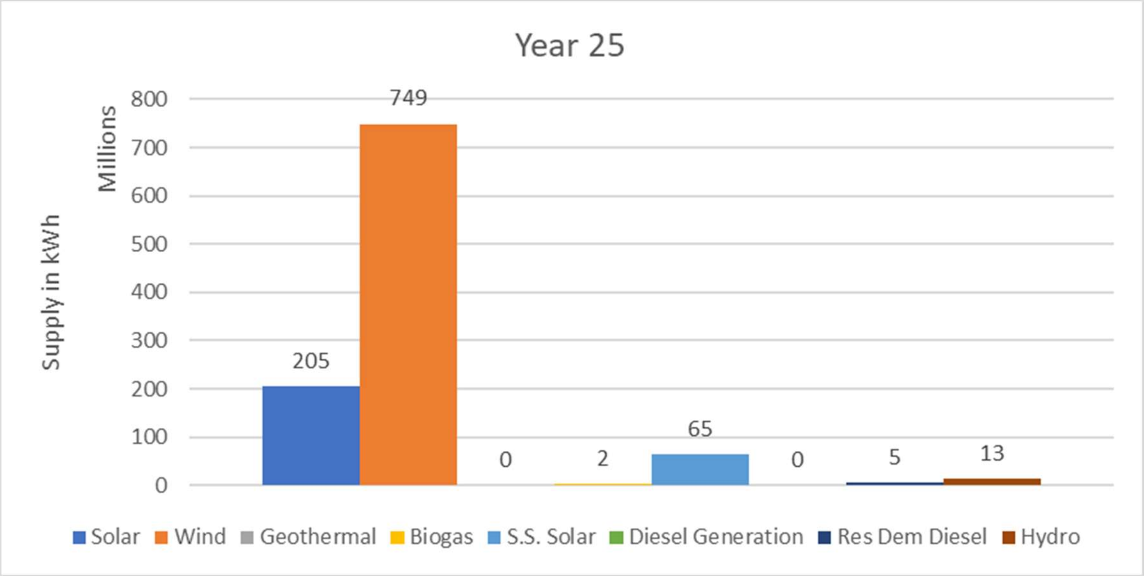


Figure 81 Year 25 energy supplied by source in scenario B

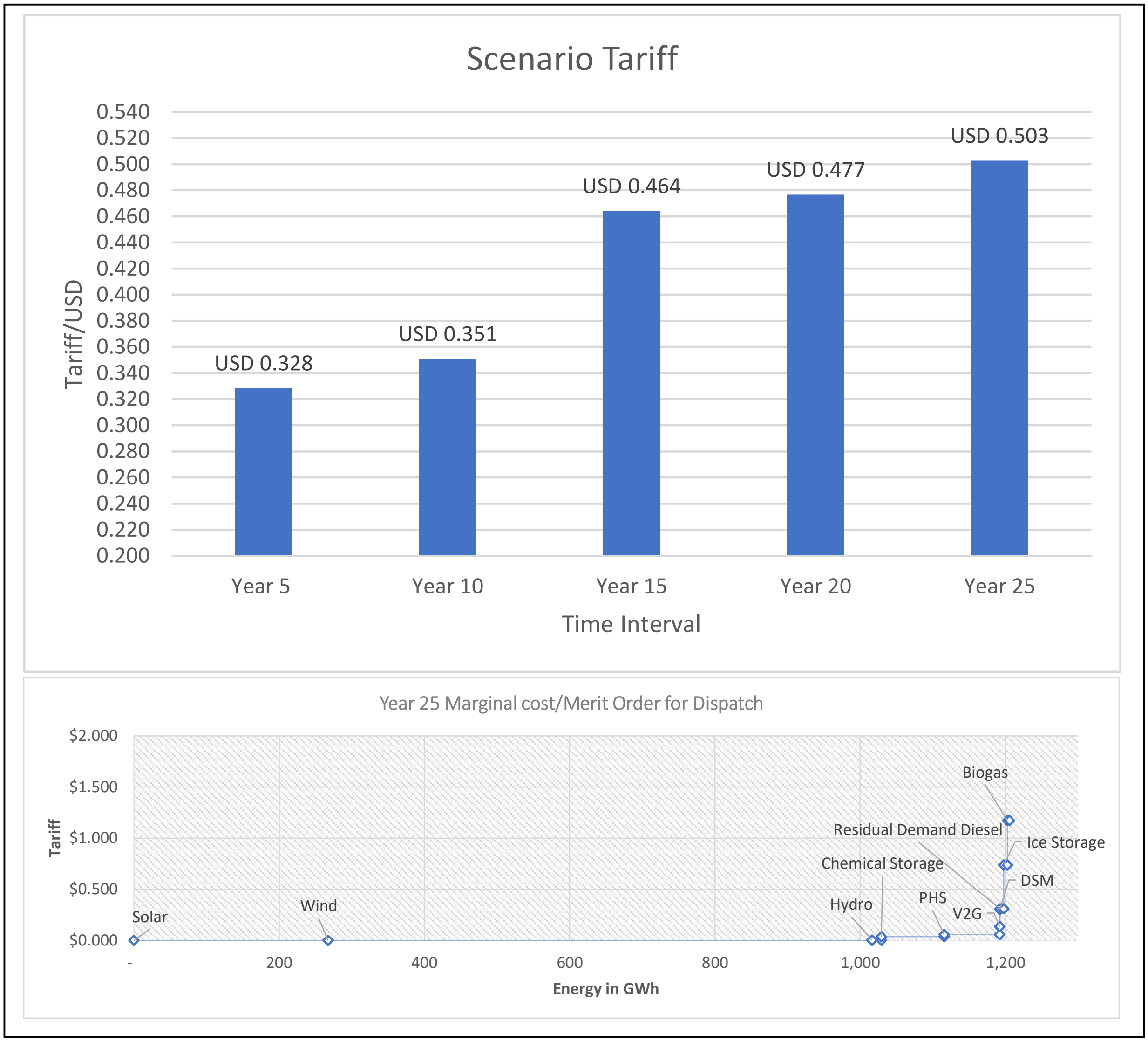


Figure 82 Scenario B tariff in 5-year intervals and merit order dispatch curve at year 25

Tariffs in 5-year intervals and the merit order dispatch curve are provided in Figure 82. In this scenario, the tariff grows in each 5-year interval due primarily to increasing investments in energy storage. The biggest change is seen between years 10 and 15 with the introduction of V2G, ice storage and significant amounts of battery chemical storage as shown at Table 89. The change in tariff between years 15 to 25 is only 8.4% compared to 32% between years 10 and 15. It is possible that the tariff will stabilise and remain consistent beyond year 25.

Biogas and ice storage are the most expensive sources of energy in the dispatch order. Marginal cost data is provided in Table 93. Chemical storage is lower cost than PHS due to the very large amount utilised and the large amount of energy stored and dispatched relative to PHS.

Table 93 Scenario B merit order dispatch data

Energy Source	GWh supplied	Cumulative Energy in GWh	Year 25 Marginal cost
Solar	267.6	-	$0.000
Wind	748.6	268	$0.000
Hydro	12.9	1,016	$0.002
Chemical Storage	86.5	1,029	$0.036
PHS	76.1	1,116	$0.057
V2G	0.6	1,192	$0.134
DSM	0.2	1,192	$0.304
Residual Demand Diesel	4.9	1,192	$0.308
Ice Storage	5.2	1,197	$0.735
Biogas	2.6	1,203	$1.172

Details of storage capacity by type and year are provided in Table 94. In both year 20 and year 25 the largest storage and dispatch capacities are from chemical storage followed by PHS.

Table 94 Scenario B storage capacity details by type and year

	Energy in GWh				
Storage Type	Year 5	Year 10	Year 15	Year 20	Year 25
Chemical					
Total Stored	-	0.0	2.4	153.8	161.1
Total Discharged	-	0.0	2.1	88.6	86.5
Losses	-	0.0	0.2	9.8	9.6
V2G - HDV					
Total Stored	28.6	56.5	93.3	120.1	122.7
Total Discharged	-	-	-	-	-
Losses	-	-	-	-	-
V2G - LDV					
Total Stored	9.5	19.0	44.0	43.3	43.4
Total Discharged	-	-	5.3	0.8	0.6
Losses	-	-	1.8	0.3	0.2
Storage Ice - Hotel					
Total Stored	-	-	0.5	4.9	4.9

Total Discharged	-	-	0.4	2.2	2.3
Losses	-	-	0.0	0.1	0.1
Storage Ice - Commercial					
Total Stored	-	-	0.6	6.2	5.8
Total Discharged	-	-	0.5	2.9	3.0
Losses	-	-	0.0	0.1	0.1
PHS					
Total Stored	-	-	-	101.5	102.6
Total Discharged	-	-	-	75.3	76.1
Losses	-	-	-	24.5	24.8

No energy is dispatched from the HDV for V2G due to the constraints of minimum required SOC of the battery packs and the average charge rate. If the charge rate is increased energy becomes available for V2G but overall consumption exceeds the projections for fossil fuel demand in the fleet. The energy model is not capable of intelligently managing the charge and V2G discharge rates to avoid over consumption of energy.

7.2.6 Scenario B - Evaluation of achievement of stakeholder objectives

Stakeholder feedback, model inputs and the explanation provided in Table 66 scenario B are reproduced here for ease of reference after each question.

7.2.6.1 R1_7

- What should be the national priorities for improving energy security in the energy sector (electricity, transport, cooking, et cetera)?

Feedback summary	Increased generation from RE options available to Saint Lucia
Model Inputs	All RE sources/no geothermal (S9 -2 No geothermal)
Explanation	Solar PV, wind, biogas and hydro

The RE penetration targets for this scenario were provided in Table 70. No geothermal energy was utilised in achieving the targets as shown in Table 89. The total debt burden of USD$49mn incurred by investments in RE infrastructure are provided in Figure 83. The largest debt is for wind energy investments followed by solar PV and diesel generation.

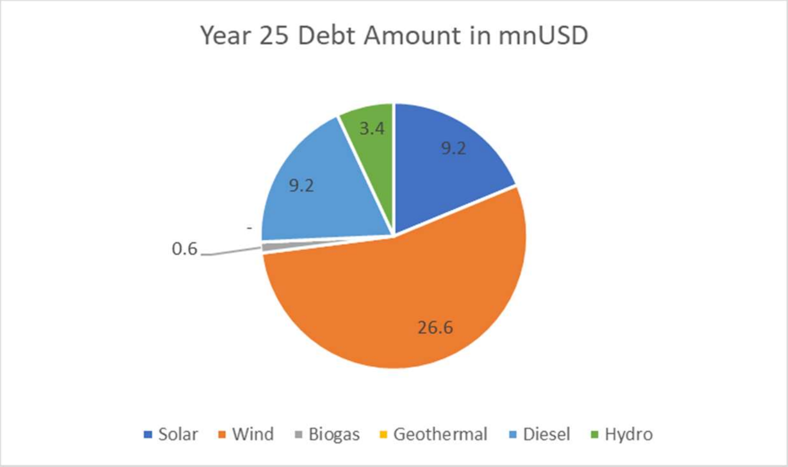


Figure 83 Year 25 debt amount for all generation sources in year 25

7.2.6.2 R1_8,11

- What environmental aspects should be considered when making decisions on investments in the energy sector?

Feedback summary	Reduction of greenhouse gas emissions
Model Inputs	All RE sources/no geothermal (S9 -2 No geothermal)
Explanation	Solar PV, wind, biogas and hydro

All available RE sources except geothermal were utilised for electricity production to reduce GHG emissions. In addition, the transport sector was transitioned to electric mobility at the conversion rates set out at Table 81. Details on GHG reductions are provided in Section R2_GH.

7.2.6.3 R1_3,10,13

- Should government continue to provide financial support for investments in the energy sector or should all energy investments be financially viable on their own?

Feedback summary	Government provides financial support
Model Inputs	Government financed (S10 - 5 Government, S13 - 2 Development bank) & S4 - 3 All profits kept in local economy
Explanation	70% debt at 4.5% for 15 years and 30% equity return of 5%

The debt and equity parameters were applied to the financial calculations with the results obtained in Table 95. Solar PV, wind, biogas, DSM, battery chemical and energy efficiency all have favourable financial parameters with ROE and IRR values over 5%. The ROE for DMS is very high because the amount of equity invested is quite low relative to returns.

Table 95 Scenario B summary of financial results

RE and Storage Sources	Average ROE	Year 25 ROE	25 Year IRR	NPV in USD$
Solar	8%	13%	14%	$2,571,542
Wind	16%	25%	23%	$23,721,137
Biogas	26%	34%	31%	$2,237,915
Geothermal	0%	0%	NA	$0
PHS	2%	7%	4%	($3,186,367)
DSM	725%	322%	102%	$3,450,951
Battery Chemical	24%	123%	29%	$7,864,525
V2G	-9%	-20%	-11%	($6,075,721)
Ice Storage	-6%	-12%	1%	($2,556,064)
Hydro	-12%	-10%	2%	($4,655,748)
Energy Efficiency	41%	31%	17%	$22,937,425

PHS has marginally positive IRR and ROE metrics, however, the NPV is negative. This is because PHS came online in year 20 and the financial parameters reflect only 6 years of operations. The figures are likely to be more attractive if the financial performance is analysed over at least 25 years of operations. For battery chemical in year 25, the cumulative equity invested is low relative to the returns, hence the high ROE. V2G and ice storage both came online in year 15. A longer period of operation may be required to experience positive financial metrics. Though hydro has been in operation for the full transition period, the financial metrics are still quite poor with only the IRR being positive, yet below the threshold of 5%. The NPV is negative signaling that this is not a favourable investment choice.

The value of profits remaining in the local economy in year 25 is provided in Table 96.

Table 96 Scenario B value of profits staying in the local economy in year 25

RE Source	% of Gross Profits	Amount USD$
Solar	24%	8,724,456
Wind	24%	36,240,934
Biogas	36%	1,526,599
Hydro	0%	-
Total		46,491,989

All utilised RE sources except for hydro contribute to profits remaining in the local economy with a total of USD$46.5mn in year 25. This number is higher than in scenario A as all the profits are kept in the local economy.

The overall economic impact for this scenario is estimated at a PV of -USD$135.5mn. Though this represents an overall loss, it is much more favourable than the baseline. It is not as favourable as scenario A which has a positive overall economic impact. The negative economic impact may be due to the higher tariffs which result in less savings to consumers. The tax transition is illustrated in Figure 84.

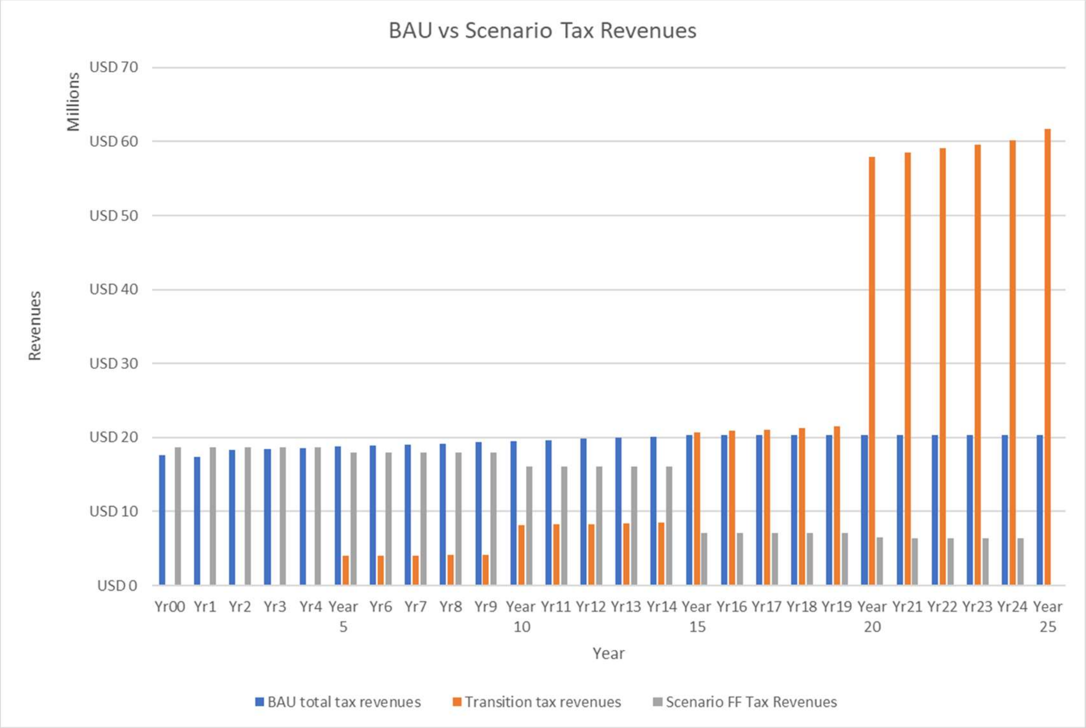


Figure 84 BAU vs scenario B tax revenues

Tax parity is achieved in year 15 and transition tax revenues begin to exceed BAU tax revenues from year 20. Fossil fuel tax revenue gradually decreases to zero (0) over the transition period. From year 20 to year 25, tax revenues are around USD$60mn annually. Transition tax revenues exceed BAU later in this scenario as the transition rate is lower than in scenario A. Tax revenues keep increasing from year 20 to 25 due to increasing revenues from RE sales.

The tariff required for tax parity in the transport sector and a comparison of tax revenues are provided in Figure 85. Revenue loss from taxes in the transport sector reaches zero (0) at year 18. This does not occur in scenario A. After this year, there are sufficient EVs on the network consuming electricity that the tax revenues begin to exceed the projected BAU transport sector fossil fuel tax revenues. By year 25, tax revenues from the EV transport sector exceed BAU by around USD$1.4mn per annum.

EV energy tariff required for tax revenue parity stabilises at around USD$0.41 per kWh between years 20 and 25. A gradual increase is seen due to the impact of projected rising fossil fuel prices over the same period.

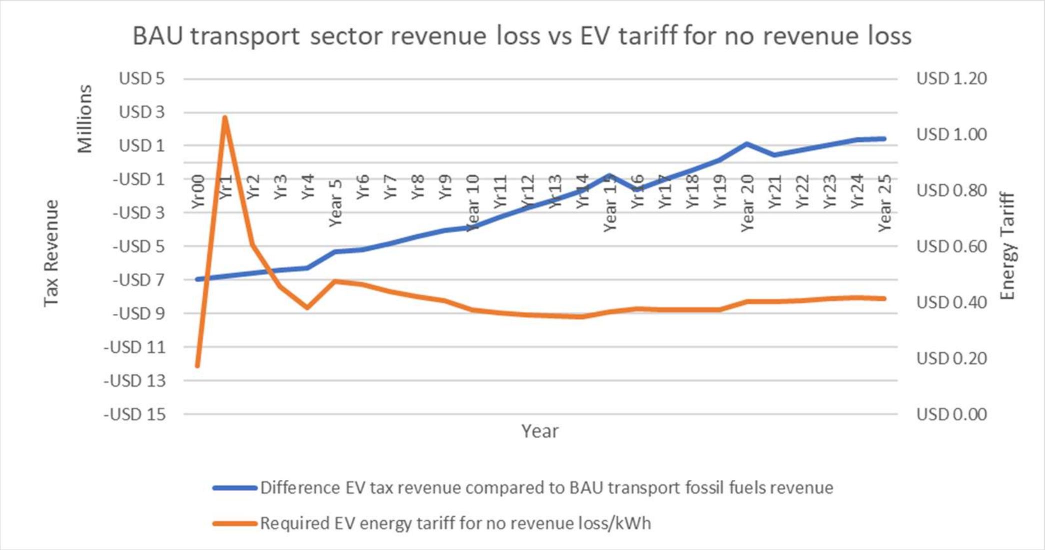


Figure 85 BAU transport sector revenue loss vs EV tariff for no revenue loss

PV of all RE investments over the 25-year period are provided in Table 97.

Table 97 Present value of all investments

RE and Storage Resource	Present Value of Investment in USD$
Wind	$74,621,569
Solar	$52,851,664
Geothermal	$0
Diesel	$38,023,344
Biogas	$3,320,954
Hydro	$16,619,914
Ice Storage	$8,586,774
PHS	$19,750,692
V2G	$14,753,626
Battery Chemical	$8,087,859
Energy Efficiency	$87,284,858
Demand Side Management	$178,516
Total	$324,079,769

PV of investments is USD$324mn which is lower than for scenario A. The largest investments in this scenario are for wind and energy efficiency. No investments were made for geothermal generation. Diesel generators are installed to replace those that reach end of life as biodiesel capacity is required to meet the 100% RE target. The required investment is USD$38mn.

7.2.6.4 R1_9

- Are there any sources of renewable energy that may not be socially acceptable?

Feedback summary	Exclude geothermal energy
Model Inputs	No geothermal (S9 - 2 No geothermal)
Explanation	Wind, solar PV, biogas, hydro

In this scenario, stakeholders have indicated that geothermal energy should be excluded due to concerns about volcanic eruptions and seismic activity. This was done with the sources of generation provided in Table 89.

7.2.6.5 R1_4,6

- What benefits to the country would you like to see from sustainable energy investments?

Feedback summary	Reduction in energy tariffs and fossil fuel-based energy production
Model Inputs	Cost driven energy price (S6 - 2 Lifecycle cost plus profit margin; S3 - 2 Based on RE costs for EVs)
Explanation	Energy pricing is based on investment and operations costs of RE plants

This scenario has succeeded in reducing fossil fuel-based energy production by substitution with RE for up to 100% energy consumption however, it has not succeeded in reducing energy tariffs. Scenario A has succeeded in reduction of the energy tariff relative to BAU as shown at Figure 86. Scenario B exceeds BAU tariffs from year 15 through year 25 as shown in Figure 86. This is due to the high investment in and cost of storage.

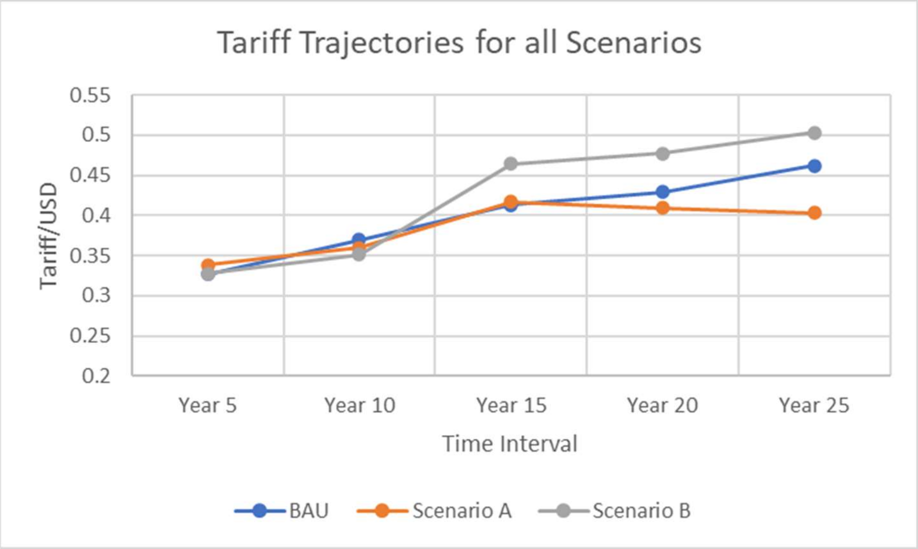


Figure 86 Tariff trajectories for BAU, scenarios A and B

The amount of energy delivered from each source and the weighted average tariff based on the lifecycle cost and profit margins for year 25 are provided in Table 98. The highest tariff is from V2G which is in operation from year 15. The tariff is high as the amount of energy discharged is low relative to the total investment in infrastructure. Biogas and ice storage are the two (2) next highest tariffs. A reduction of all tariffs can be expected as the assets become fully amortised over time beyond year 25. Debt payments are a significant contributor to the high tariffs.

Table 98 Energy supplied and associated tariffs in year 25

Energy Source	Energy generated and discharged - GWh	Energy tariff USD$ per kWh	Weighted average tariff (USD$ per kWh)
Solar	267.6	0.229	0.051
Wind	748.6	0.436	0.271
Biogas	2.6	2.178	0.005
Geothermal	-	0.191	0.000
Diesel	-	0.461	0.000
Hydro	12.9	0.877	0.009
DSM	0.2	0.330	0.000
V2G	0.6	142.813	0.075
Ice Storage	5.2	1.449	0.006
Chemical Storage	86.5	0.510	0.037
PHS	76.1	0.740	0.047
Residual Demand Diesel	4.9	0.530	0.002
Total	1,205.2		0.503
		Average Tariff	XCD$1.35
			USD$ 0.50

7.2.6.6 R1_2

- What sources of energy for electricity generation should receive priority for development in the electricity sector? Why?

Feedback summary	Use of solar PV and wind energy
Model Inputs	Maximise wind and distributed PV (S2 - 2 Utility wind)
Explanation	Up to maximum wind potential plus distributed and utility solar PV (increase solar PV to 2.5 kWp per domestic customer)

In this scenario, the average size of domestic PV systems was increased to 2.5kWp. This is reasonable as some customers can be expected to charge their EVs at home thereby increasing the average consumption per customer. The total distributed solar PV capacity in year 25 was 41.2 MWp. The maximum wind capacity of 266.8 MW was also utilised.

7.2.6.7 R2_RE

– The Government of Saint Lucia (GOSL) has set a target of 35% by 2025 and 50% by 2030 for generation of electricity from renewable sources. Are you in agreement with this vision? If not, suggest an alternative.

Feedback summary	Target for RE penetration should be lower
Model Inputs	Lower targets (S1 -2 Lower target)
Explanation	Stakeholder targets of 20%/2025; 35%/2030 with addition of 50%/2035; 100%/2040)

The lower targets suggested by stakeholders can be achieved even without geothermal energy as shown at Table 92. 74 MW of biodiesel is required in year 25 to meet a residual demand of 4.9 GWh, i.e., less than 1% of total demand.

7.2.6.8 R2_GH

– The Government of Saint Lucia (GOSL) has set a target of 7% reduction in GHG emissions in the energy sector relative to 2010, by 2030. Are you in agreement with this vision? If not, suggest an alternative.

Feedback summary	The target is adequate
Model Inputs	Output discussion
Explanation	GHG reductions due to RE calculated and discussed as an output.

The chart in Figure 87 shows the CO_2 savings over the transition period and the percentage savings against the 2010 baseline for the same period. Double the target savings, i.e., 14% are achieved from the first investments in year 5. The savings exceed 60% of the baseline in year 25 at just over 400 kilotonnes of CO_2 per annum.

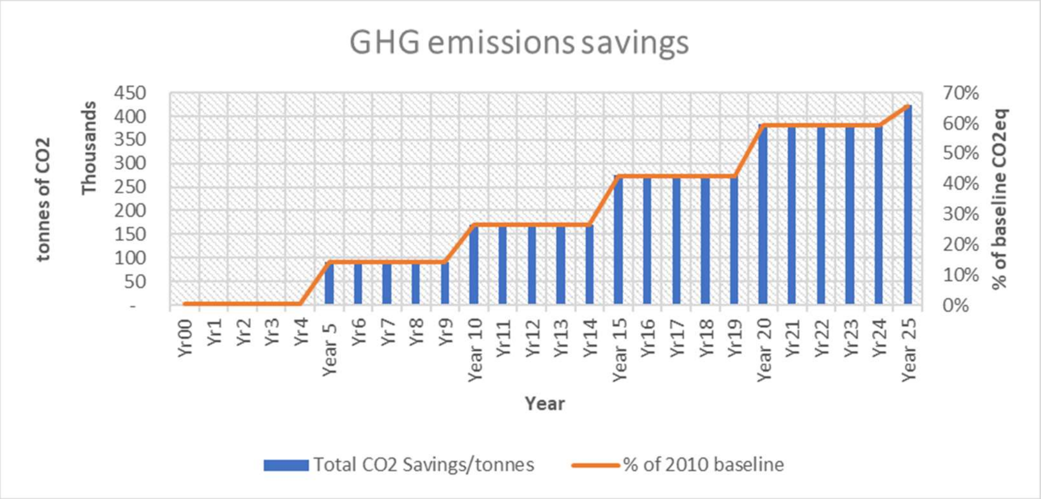


Figure 87 GHG emission savings

The emissions savings as a percentage of the 2010 baseline are provided in Table 99.

Table 99 CO2 emissions savings as a percentage of 2010 baseline

	% of 2010 baseline
Year 5	14.0%
Year 10	26.4%
Year 15	42.5%
Year 20	59.1%
Year 25	65.6%

7.2.6.9 R2_EE

- The Government of Saint Lucia (GOSL) has set a target of 20% reduction in energy consumption in the public sector. Are you in agreement with this vision? If not, suggest an alternative.

Feedback summary	Target should be lower
Model Inputs	Lower than target (S12 - 3 Less)
Explanation	10% EE target for domestic, hotel, industrial and commercial sectors

The achieved EE savings in year 25 are displayed for the time period Month 6, days 18 to 20 in Figure 88. When demand for EV charging is highest during the day, the impact of EE savings decreases to just over 5%. In the evening when EV charging has a much lower effect on total demand, the impact of EE savings increases to around 8.5%. Under the conditions in this scenario, the target savings of 10% across all sectors appears not to be achieved in the illustrated time period. The average EE savings over year 25 is 7%.

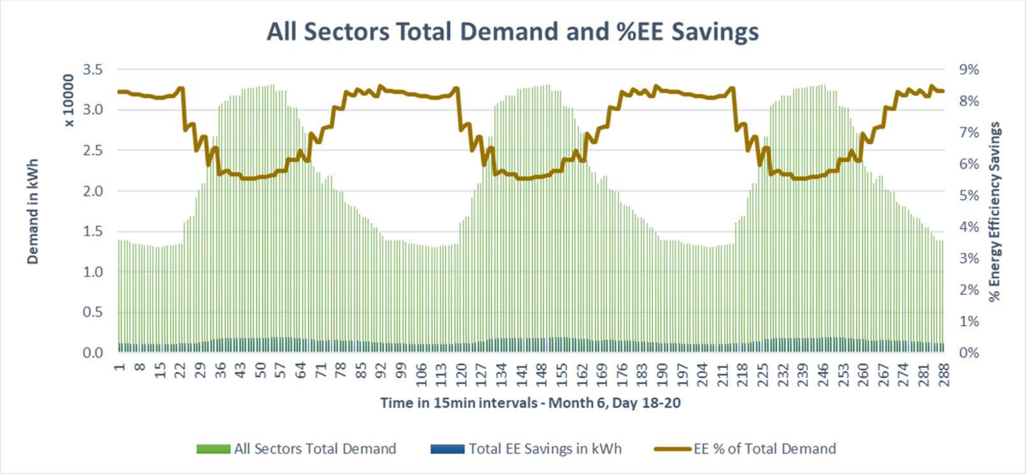


Figure 88 EE savings across all sectors except street lighting

7.2.6.10 R2_5,8,12

– What economic sectors should receive priority support for improving efficiency of energy consumption, i.e., achieving the same output with less energy?

Feedback summary	The commercial sector should receive priority support
Model Inputs	Ice storage pricing (S5 - 1 Ice storage for cooling in commercial sector)
Explanation	Reduction in VAT on investments by 10%

Table 100 shows the penetration of ice storage capacity in hotel and commercial sectors using the stakeholder defined lower RE penetration targets to determine the penetration level for replacement of electricity demand for cooling with ice storage cooling. The capacity is provided in kWh electrical equivalent.

Table 100 Ice storage capacity set with lower RE targets

Penetration	Totals	Hotel ice storage capacity in kWhel	Commercial ice storage capacity in kWhel
20%	Year 5	1,190	134,400
35%	Year 10	2,083	235,200
50%	Year 15	2,976	336,000
100%	Year 20	5,952	672,000
100%	Year 25	5,952	672,000

In year 25, energy stored for cooling and discharged in the commercial sector were 5.8 GWh and 3.0 GWh respectively, as provided in Table 94. Total ice storage cooling energy dispatched in year 25 was 5.3 GWh. The tariff for ice storage cooling in year 25 was USD$1.45 per kWh (Table 98). The tariff was quite high since investments for ice storage cooling started in year 15 and assets have not been fully amortised. The tariff would be higher without a reduction in VAT on the investment cost. Total PV of investments in ice cooling was USD$8.6mn (see Table 97).

7.2.6.11 R3_11,14

– What should be the objectives of developing a resilient energy system in Saint Lucia?

Feedback summary	Cleaner, sustainable and more affordable sources of energy with reduced carbon emissions
Model Inputs	Maximise wind and distributed PV (S2 - 2 Utility wind)
Explanation	Up to maximum wind potential plus distributed and utility solar PV

The maximum wind energy potential of 266.8 MW is utilised starting from year 20 as shown in Table 89. To achieve the 100% RE target in years 20 and 25, 138 MWp utility with 40.5 MWp distributed solar PV and 143 MWp utility with 41.2 MWp distributed solar PV were utilised respectively. Utilisation of these sustainable sources of RE have resulted in a reduction in carbon emissions.

7.2.6.12 R4_6,14

- What are your objectives for transitioning the energy sector to sustainable energy (RE and energy efficiency)?

Feedback summary	More reliable energy system with higher energy security
Model Inputs	Long duration storage
Explanation	Use of PHS and chemical storage

Full PHS capacity of 97.2 MW|1.88 GWh and 97.3 MW|1.88 GWh and battery chemical storage capacity of 104.3 MW|70.4 GWh and 104.7 MW|77.4 GWh were utilised in years 20 and 25 respectively as provided in Table 89. Ice storage was also used to provide long-term storage.

7.2.6.13 R4_1,10

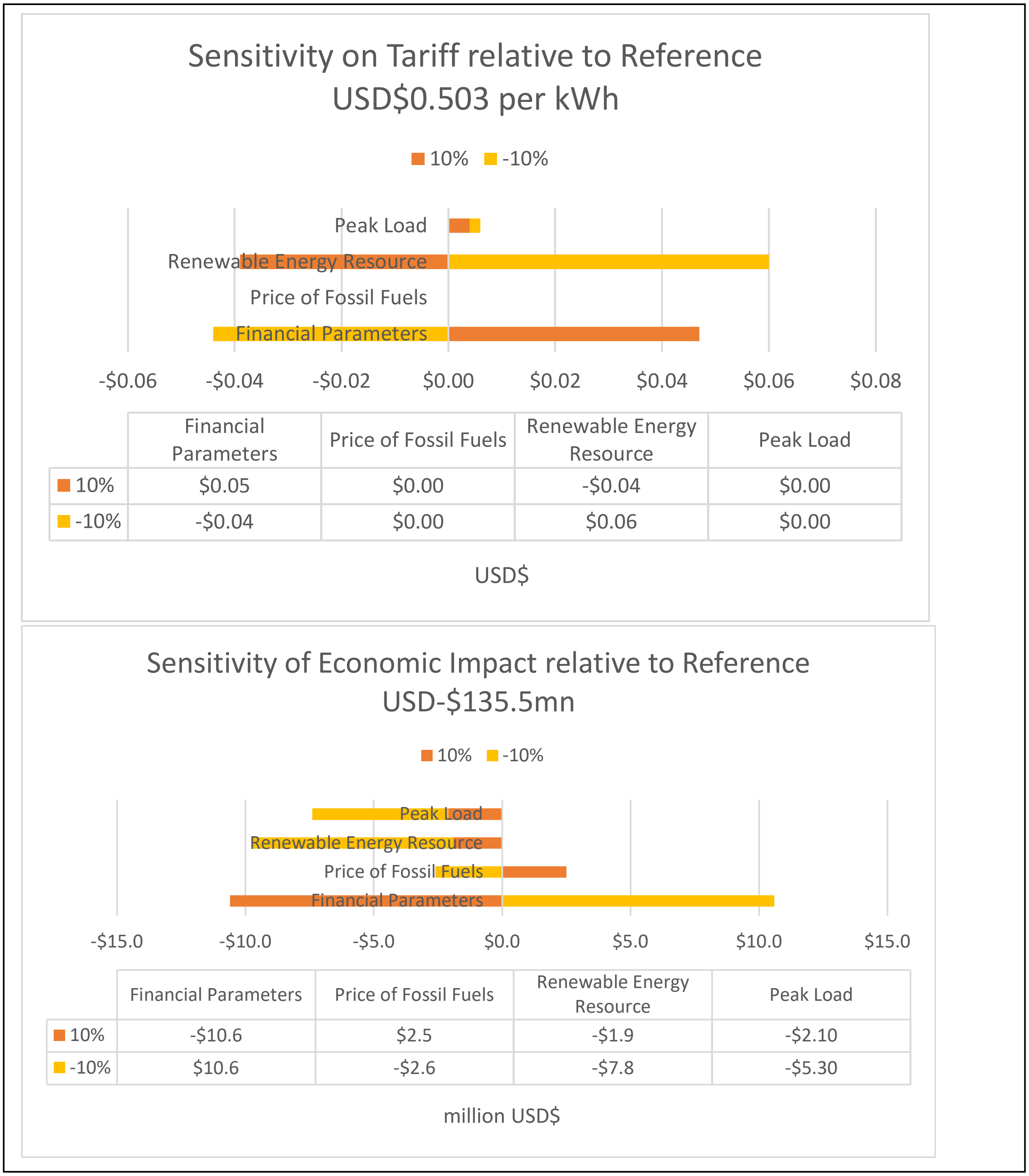
– How should the general public participate in a transition to sustainable energy?

Feedback summary	Higher energy efficiency
Model Inputs	Mandated transition of FF to RE (S11 - 3 Mandated)/Conversion to EV fleet (S8 - 1 Immediate ban on ICE imports)
Explanation	% of projected fossil fuel demand in domestic, industrial, hotel and commercial sectors converted to electricity demand/% of transport fleet to be converted from fossil fuel to electric vehicles

The transition rate from fossil fuel to electricity demand for the various sectors is provided in Table 67. In years 20 and 25, 100% of all fossil fuel demand is converted to electrical energy demand. The conversion rate of the transport fleet to EVs is provided in Table 81. The total energy efficiency realised by the scenario is illustrated in Figure 88.

7.2.7 Scenario B Sensitivity Analysis

Results of a sensitivity analysis are provided in Figure 89.



	Financial Parameters	Price of Fossil Fuels	Renewable Energy Resource	Peak Load
10%	$0.05	$0.00	-$0.04	$0.00
-10%	-$0.04	$0.00	$0.06	$0.00

	Financial Parameters	Price of Fossil Fuels	Renewable Energy Resource	Peak Load
10%	-$10.6	$2.5	-$1.9	-$2.10
-10%	$10.6	-$2.6	-$7.8	-$5.30

Figure 89 Scenario B results of sensitivity analysis

The tariff is most sensitive to changes in the RE resource. With a 10% decrease in RE resource, the tariff increases by about USD$0.06 per kWh whereas a 10% increase in the RE resource results in a drop in the tariff of about USD$0.04 per kWh. The decrease in RE resource has a higher impact as less energy is being produced for the same investment. With an increase in RE resource, the impact on the tariff is limited by the ability of the energy system to absorb the additional energy. There may be excess generation which generates no revenue hence this creates a limit to the impact on the tariff.

Variations to the financial parameters have the next highest impact on the tariff. With a 10% decrease in the value of the parameters, the tariff is reduced by about USD$0.04 per kWh. This is due to a lower cost of investment and debt burden. Conversely, a 10% increase in the value of the financial parameters results in a tariff increase of about USD$0.05 per kWh. Increase in cost of investment has a marginally higher impact on the tariff.

Variations in peak load, both positive and negative, result in a slight increase to the tariff. If the peak load increases, the amount of RE generation is insufficient to satisfy the demand, hence more biodiesel will be used and the tariff will increase. With a decrease in peak load, there is more wasted RE generation and less revenue generated. This will also result in an increase to the tariff.

Variations to the price of fossil fuels have no impact on the tariff as no fossil fuel generation is used in year 25.

Variations in the financial parameters have the largest effect on the economic impact. The value of the impact is symmetric for a 10% increase and decrease in values. As the cost of investment increases the economic impact reduces due to higher tariffs and lower savings. The converse is also true. As the cost of investment decreases, for the same RE output, the economic impact increases due to lower tariffs and higher savings.

RE is the next input to which the economic impact is most sensitive. A decrease of 10% in RE resource has the higher impact with a decrease in economic impact of about -USD$7.8mn whereas an increase in output results in a decrease in economic impact of -USD$1.9mn. The decreased output is at the same investment cost; hence the tariff will be higher. Due to a finite demand, an increase in RE output can be absorbed to a limited extent with excess energy being dumped. This results in a lower economic impact as the variable cost of operations will be higher for the same financial returns on the energy produced.

The results from variations to peak load behave similarly to the RE resource with a higher effect occurring on a decrease to the peak load. This situation results in a dumping of excess generation at higher variable cost of operations, hence reducing the economic impact by about -USD$5.3mn. An increase in peak load results in increased biodiesel consumption, also resulting in a decrease to the economic impact though less than observed with the decrease in peak load.

Variations to the price of fossil fuels have a symmetric effect on the economic impact as the price of biodiesel is based on the fossil fuel price. Increasing the cost of biodiesel increases the economic impact due to higher revenues from taxation. Likewise, decreasing the cost of biodiesel results in lower tax revenues. As the amount of biodiesel used is very low, the effect of savings due to lower tariffs is not observable.

Similar to scenario A, variations to the financial parameters and RE resource have the largest effects on both the tariff and the economic impact.

7.2.8 Comparison of Scenarios to BAU

Table 101 Comparison of BAU, scenarios A and B

	Parameter	Baseline	Scenario A	Scenario B
Year 25	Energy Output - GWh	553.4	894.8	1037.9
	Demand - GWh	514.5	695.0	749.1
	Storage Capacity - GWh	0	18.9	79.3
	Solar IRR	12%	19%	14%
	Wind IRR	NA	29%	23%
	Geothermal IRR	NA	24%	NA
	Hydro IRR	NA	10%	2%
	Biogas IRR	NA	16%	31%
	Total Excess Generation - GWh	NA	0	0
	Residual Demand - GWh	NA	3.6	4.9
	Tariff - USD$ per kWh	0.462	0.403	0.503
	Dominant RE Source	Solar	Solar	Wind
	Dominant RE Supply - GWh	4.3	565	748.6
	Value of profits remaining in local economy -USD$mn	NA	32.4	46.5
	Tax revenue - USD$mn	20	113.9	62
	Average EE Savings	NA	16%	7%
Overall	PV of Tax Revenues (No FF in Scenarios) - USD$mn	NA	116.4	102.9
	Economic Impact - USD$mn	(1,252.90)	165.4	-135.5
	PV of Investment Costs - USD$mn	NA	354.9	324.1
	RER (without Biodiesel)	1%	100%	100%
	Exclusions	NA	None	Geothermal
	Year to exceed BAU tax revenues	NA	15	20

A comparison among BAU, scenarios A and B is provided in Table 101. The energy output of scenario B is higher than for scenario A due to the exclusion of geothermal energy. A larger amount of variable RE, particularly wind (748.6 GWh), was generated requiring a large amount of storage, 79.3 GWh compared to 565 GWh of solar generation and 18.9 GWh of storage in scenario A. The economic impact of scenario A is positive relative to scenario B. This is because the annual economic impact becomes positive after year 10 in scenario A compared to year 15 in scenario B as illustrated in Figure 90. The annual economic impact amount converges for the two (2) scenarios between years 20 and 25 as the 100% RE transition is completed for both scenarios in that timeframe.

Hydro has a stronger IRR under the assumptions in scenario A where it comes online in year 15 at almost maximum capacity compared to scenario B where it comes online earlier at much lower capacity and hence lower output energy. Biogas has a more favourable IRR in scenario B since it operates for a longer period in that scenario. The year 25 tax revenue is higher in scenario A at USD$113.9mn compared to scenario B at USD$62mn and the baseline at USD$20mn. Annual tax revenue is five (5) times in scenario A and tripled in scenario B compared to BAU, however, tariffs are also highest in scenario B as illustrated in Figure 86.

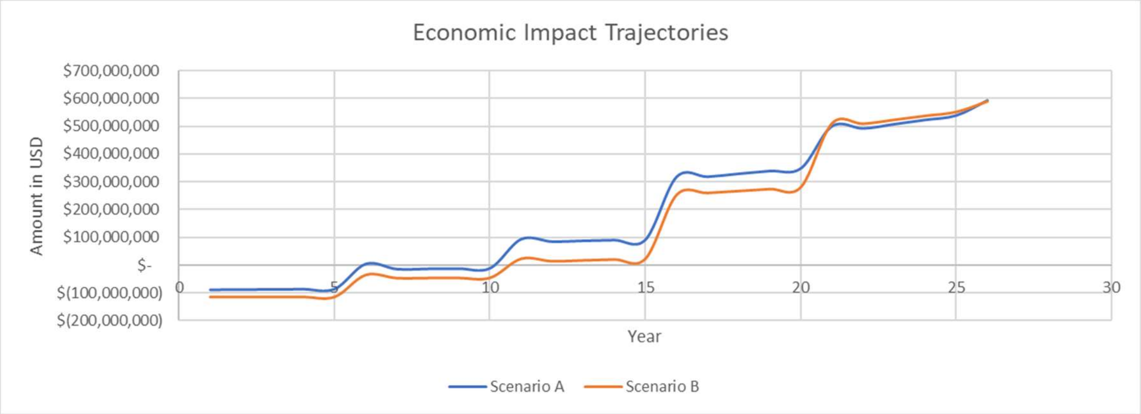


Figure 90 Comparison of annual economic impact for scenarios A and B

The average charge power for the EV fleet for the two (2) scenarios are compared in Figure 91. The LDV average for year 15 is higher than for scenario A as more EV battery storage and V2G are required to match the large amount of variable wind energy supply to demand. This was not the case for scenario A. The charge power is similar to scenario A for years 20 and 25 as most storage is provided by chemical battery.

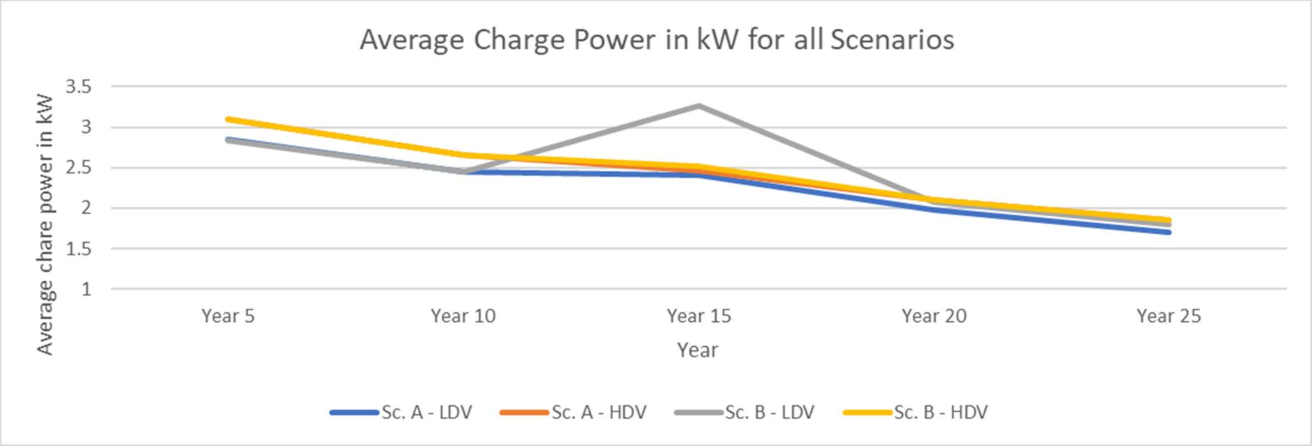


Figure 91 Comparison of average charge power for the EV fleet

7.2.9 Scenario C - Transition Pathway

In this scenario, stakeholders have placed no restriction on the use of RE sources, however, a focus on both wind and solar PV has been indicated. Considering the observed high tariffs for V2G in scenarios A and B, V2G has been excluded. The transition pathway is summarised at Table 102.

Table 102 Scenario C transition pathway

Maximum Energy or Capacity by Source	Year 5	Year 10	Year 15	Year 20	Year 25
Solar – Utility (MWp)	7.9	14.6	22.0	23.0	23.0
Solar - Distributed (MWp)	11.3	26.0	31.3	33.3	33.7
Wind (MW)	18.4	96.6	179.4	225.4	225.4
Biogas (MW)	0.3	0.6	0.8	0.8	0.8
Geothermal (MW)	14.0	28.0	28.0	28.0	28.0
Hydro (MW)	0.8	1.9	2.2	2.3	2.3
Diesel (MW)	35.0	20.9	11.0	-	-
DSM (MW)	1.6	3.8	4.6	5.0	5.2
DSM Energy (MWh)	-	0.9	1.1	1.2	1.2
V2G - HDV (MW)	-	-	-	-	-
HDV V2G Energy (kWh)	-	-	-	-	-
V2G - LDV (MW)	-	-	-	-	-
LDV V2G Energy (kWh)	-	-	-	-	-
Ice Storage - Commercial (MW)	-	1.1	1.4	1.5	1.5
Ice Storage - Commercial (kWh)	-	272.4	351.5	363.2	363.2
Ice Storage - Hotel (MW)	-	0.9	1.2	1.2	1.2
Ice Storage - Hotel (kWh)	-	224.1	288.1	299.7	299.7
Chemical Storage (MW)	-	36.7	60.9	81.9	81.6
Chemical Storage (MWh)	-	1,624.0	26,119.4	38,233.4	40,897.6

PHS (MW)	-	38.2	59.3	79.7	79.4
PHS (MWh)	-	1,884.7	1,884.7	1,884.7	1,884.7
Peak Residual Demand Diesel (MW)	30.9	39.5	55.1	75.8	75.6

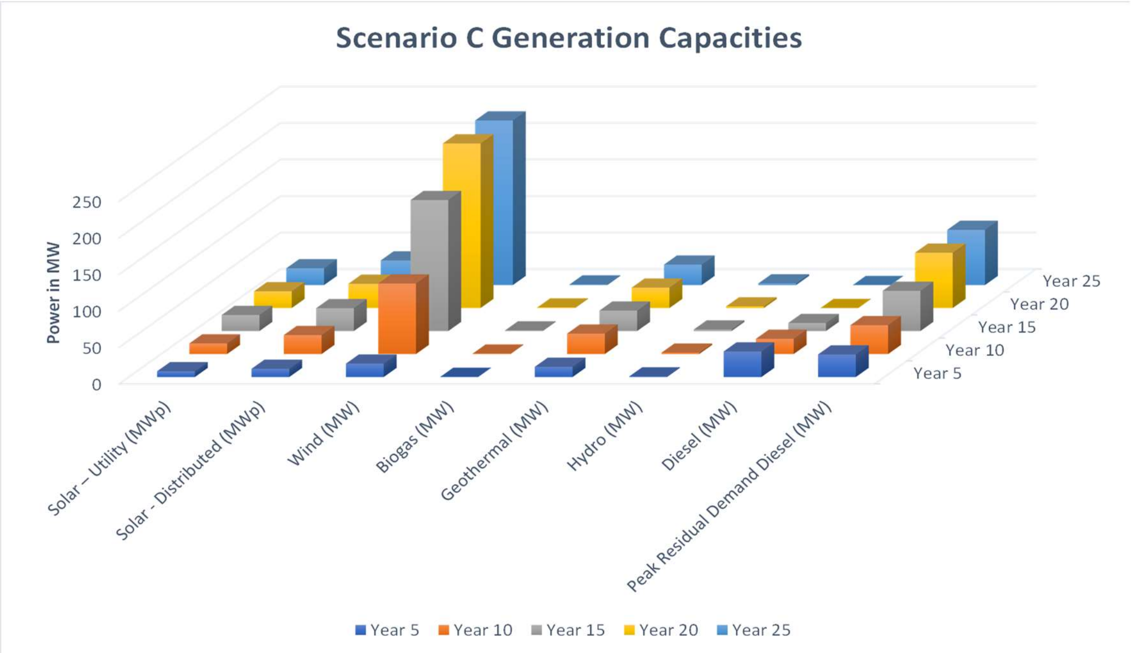


Figure 92 Scenario C generation capacities by year

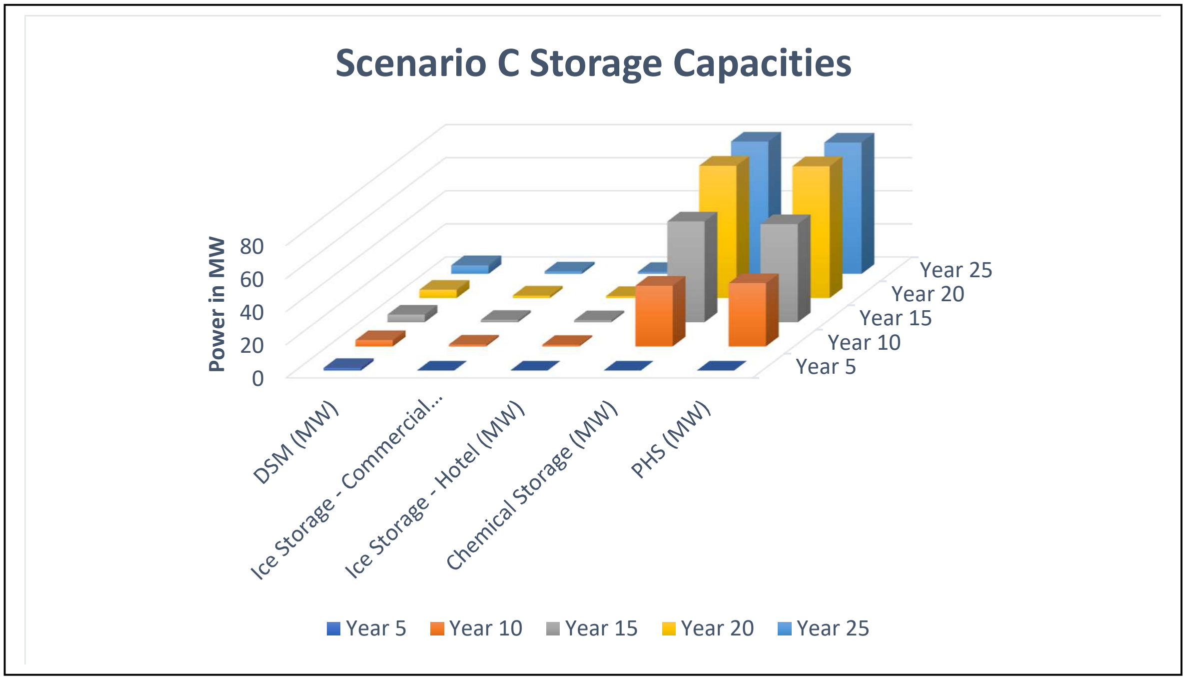


Figure 93 Scenario C storage capacities by year

The generation and storage capacities for the transition scenario are illustrated in Figure 92 and Figure 93. Wind is the dominant generation source as required by the stakeholders. Diesel generation gradually decreases to zero (0) over time and in years 20 and 25 peak residual demand diesel is supplied by biodiesel. As with previous scenarios, storage is dominated by chemical storage and PHS which both come online in year 10.

The energy mix for an indicative period at year 5 is illustrated in Figure 94. As with the other scenarios, the RE penetration target was used to set the amount of each RE generation source installed based on the total estimated potential. The largest installed capacity was for wind energy at 18.4 MW followed by 14 MW of geothermal and 11.3 MWp of distributed solar PV. DSM capacity was available; however, no demand was shifted as there was no situation meeting the requirements for demand shifting. A total of 65.9 MW of diesel generation was also used. No storage was required and this is illustrated in the second graph in Figure 94.

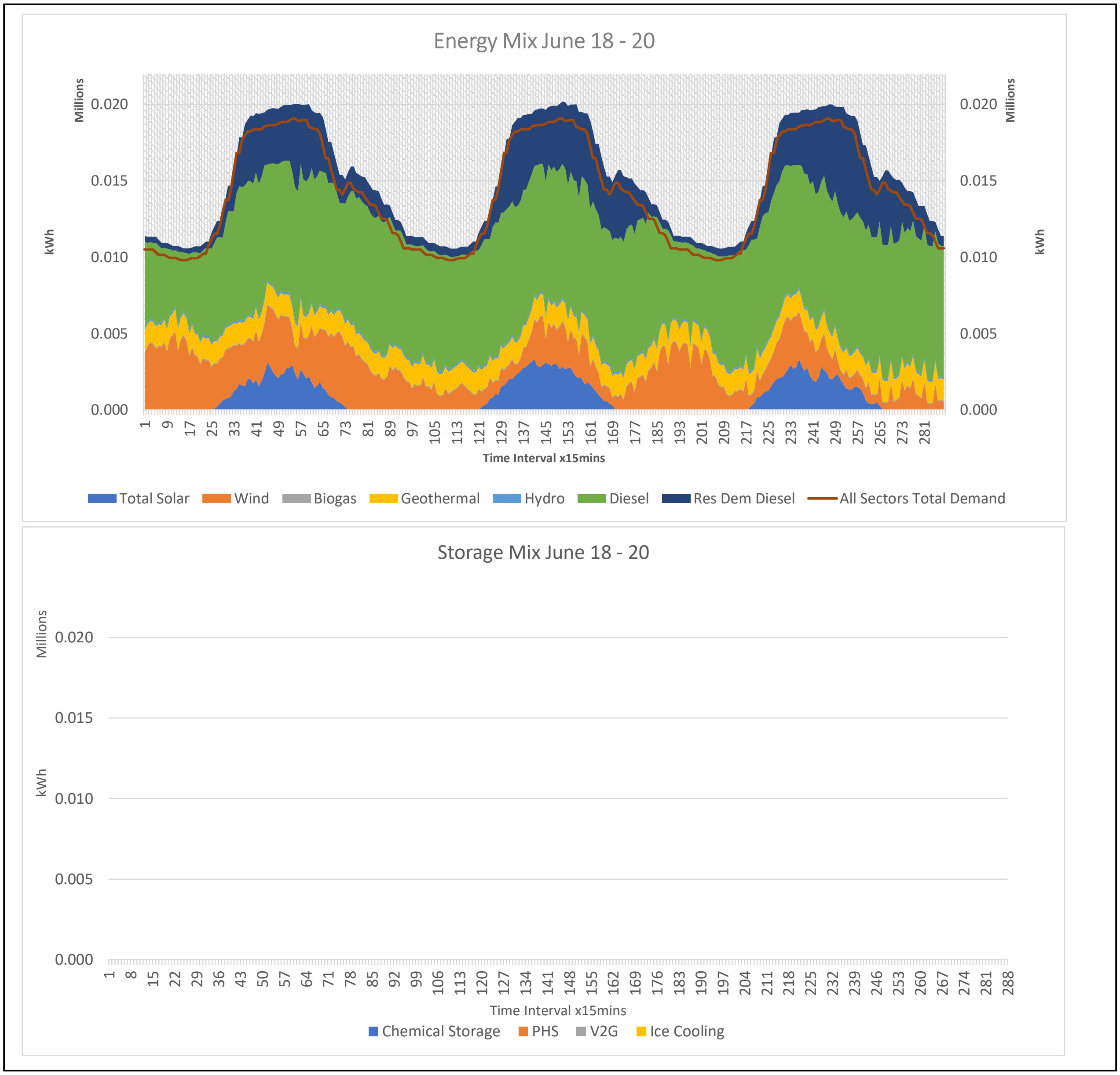


Figure 94 Energy mix at year 5

The energy mix at year 10 is illustrated in Figure 95 for an indicative period. There was a significant increase in wind energy utilisation to 96.6 MW and geothermal was increased to 28 MW. To achieve the 80% RE target, both utility and distributed solar PV capacities were increased to 14.6 MWp and 26 MWp respectively. Biogas and hydro capacities were increased from 0.3 MW to 0.6 MW and from 0.8 MW to 1.9 MW respectively. A significant investment in storage was required with capacities of commercial ice storage at 1.1 MW|272.4 kWh, hotel ice storage at 0.9 MW|224.1 kWh, chemical battery at 36.7 MW|1.6 GWh and PHS at 38.2 MW|1.88 GWh. This large amount of storage was required to store the variable energy from wind generation as can be seen in Figure 95 in which RE generation can be seen to exceed demand at certain points in time. Discharge of stored PHS and ice cooling energy can also be seen for the illustrated time period.

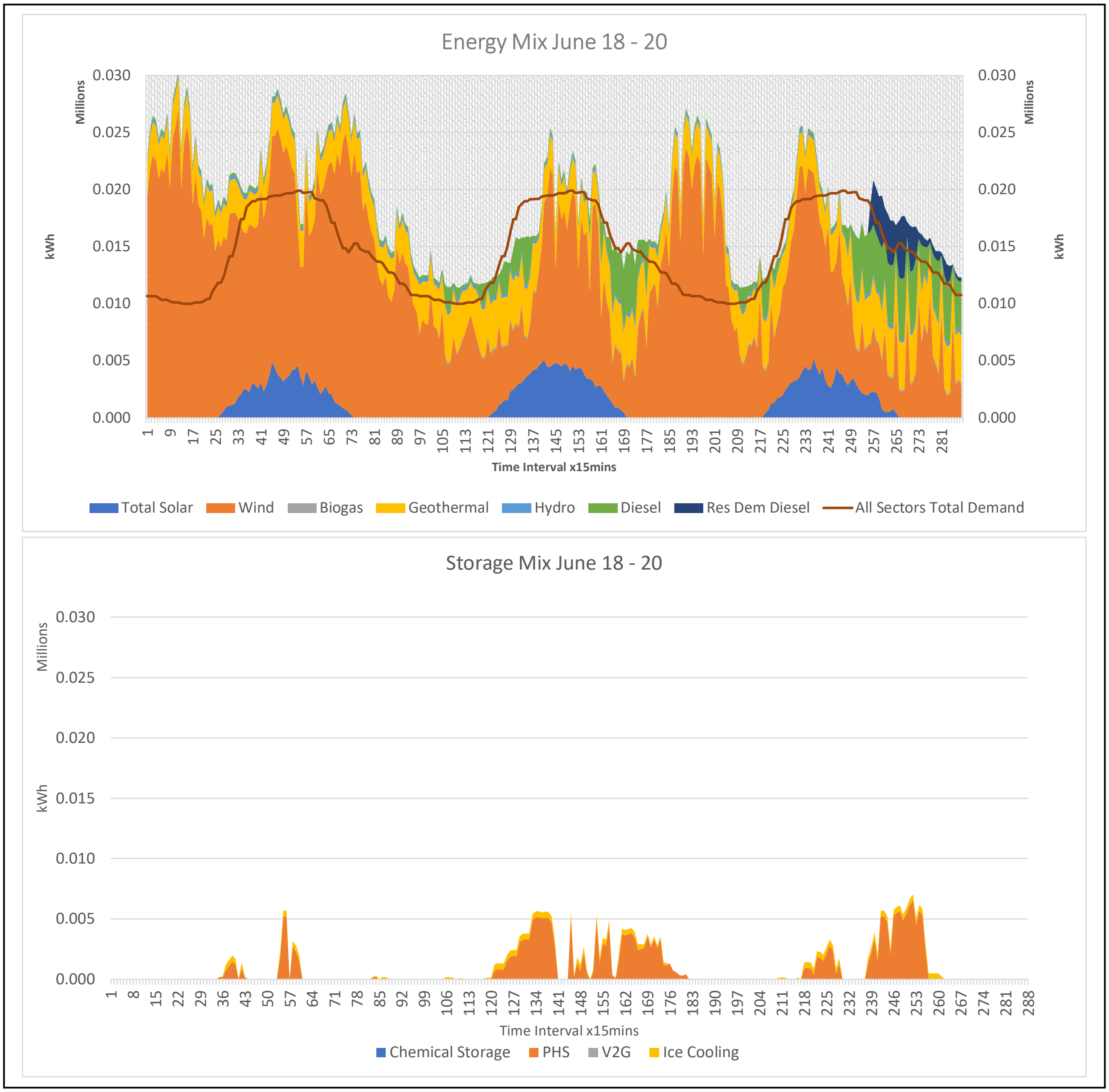


Figure 95 Energy mix at year 10

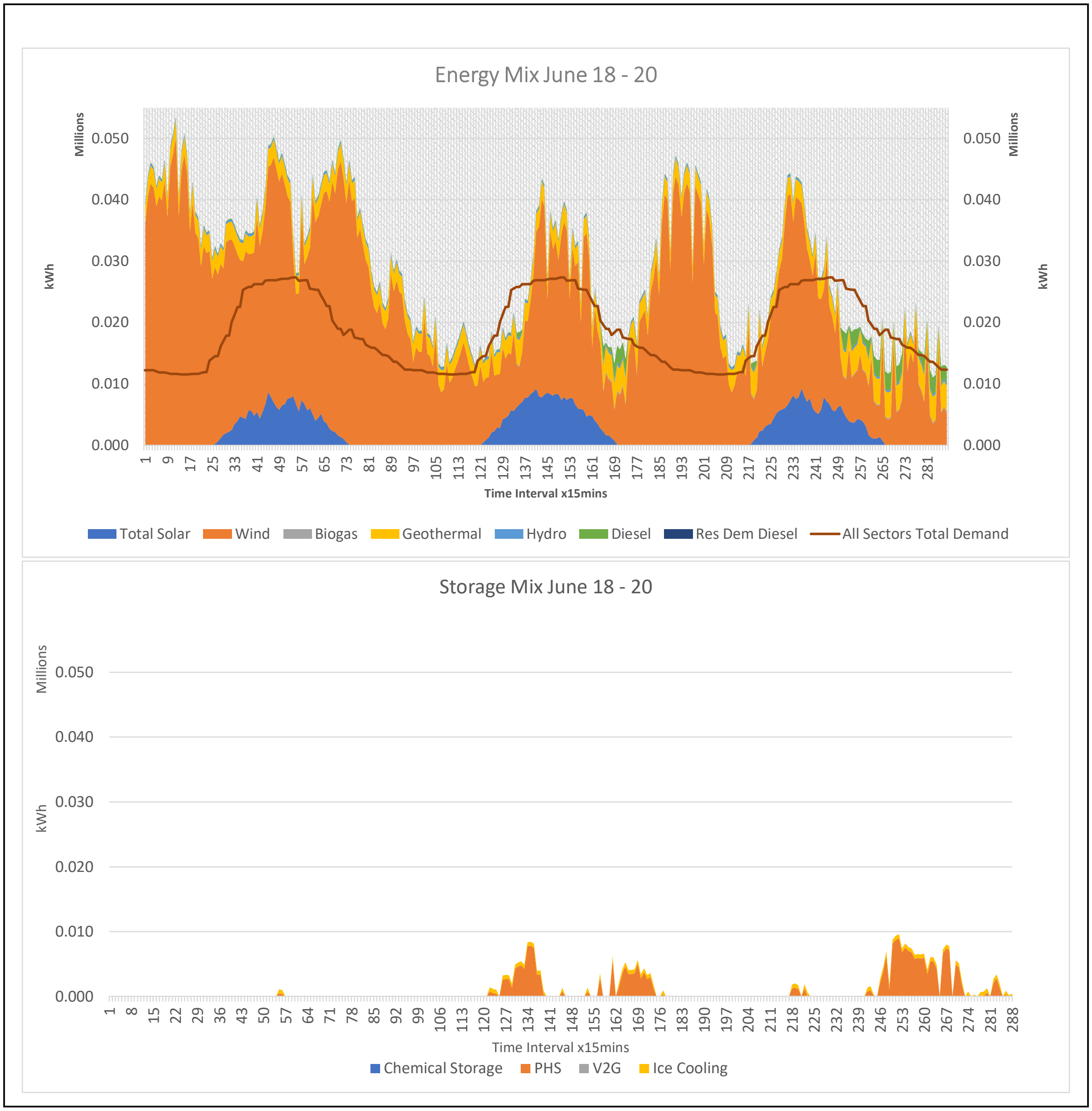


Figure 96 Energy mix at year 15

The energy mix for year 15 is illustrated in Figure 96 for a 95% RE target. The generation sources include an increase in wind capacity from 96.6 MW to 179.4 MW. Utility and distributed solar PV capacities increase to 22 MWp and 31.3 MWp respectively. Biogas and hydro capacities are also increased to 0.8 MW and 2.2 MW respectively. Geothermal capacity remains unchanged at 28 MW, which is the maximum available capacity.

DSM capacity increased to 4.6 MW|1.1 MWh. Ice storage capacities increase to 1.4 MW|351.5 kWh for the commercial sector and 1.2 MW|288.1 kWh for the hotel sector. Battery chemical storage has increased significantly to 60.9 MW|26.1 GWh and PHS to 59.3 MW|1.88 GWh. PHS and ice cooling dispatch can be seen for the illustrated time period.

A 100% RE mix is achieved in year 20. The most significant generation increase was in wind energy at 225.4 MW. Hydro and biogas capacities are at the maximum at 2.3 MW and 0.8 MW respectively. DSM capacity is increased slightly to 5.0 MW|1.2 MWh. There is significant increase in battery chemical capacity at 81.9 MW|38.2 GWh as well as PHS capacity to 79.7 MW|1.88 GWh. The amount of battery storage is very large and may be achieved through aggregated distributed storage systems or replaced by other flexible RE generation from sources that are mature and affordable in year 20. PHS dispatch can be observed in the illustration.

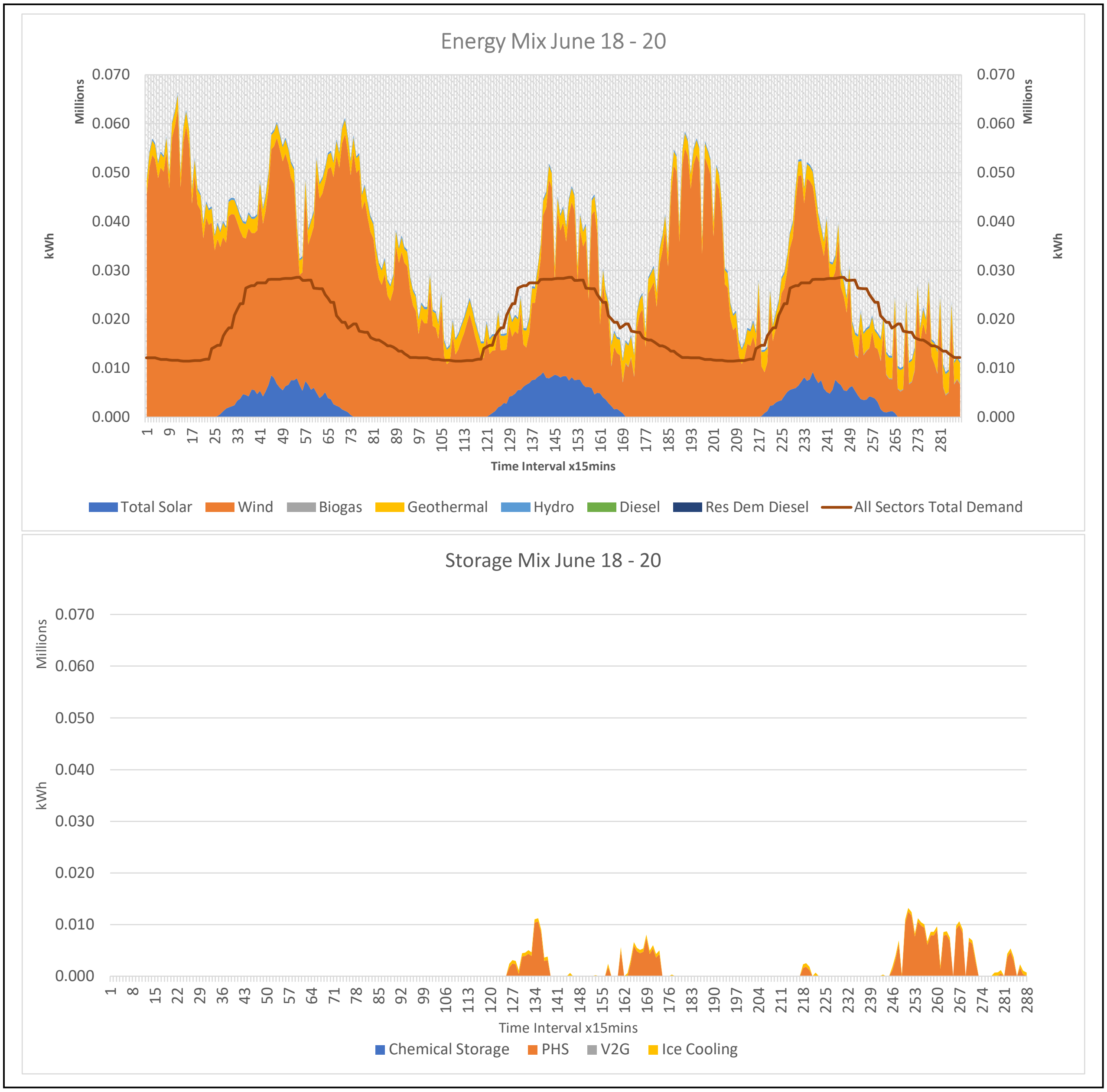


Figure 97 Energy mix at year 20

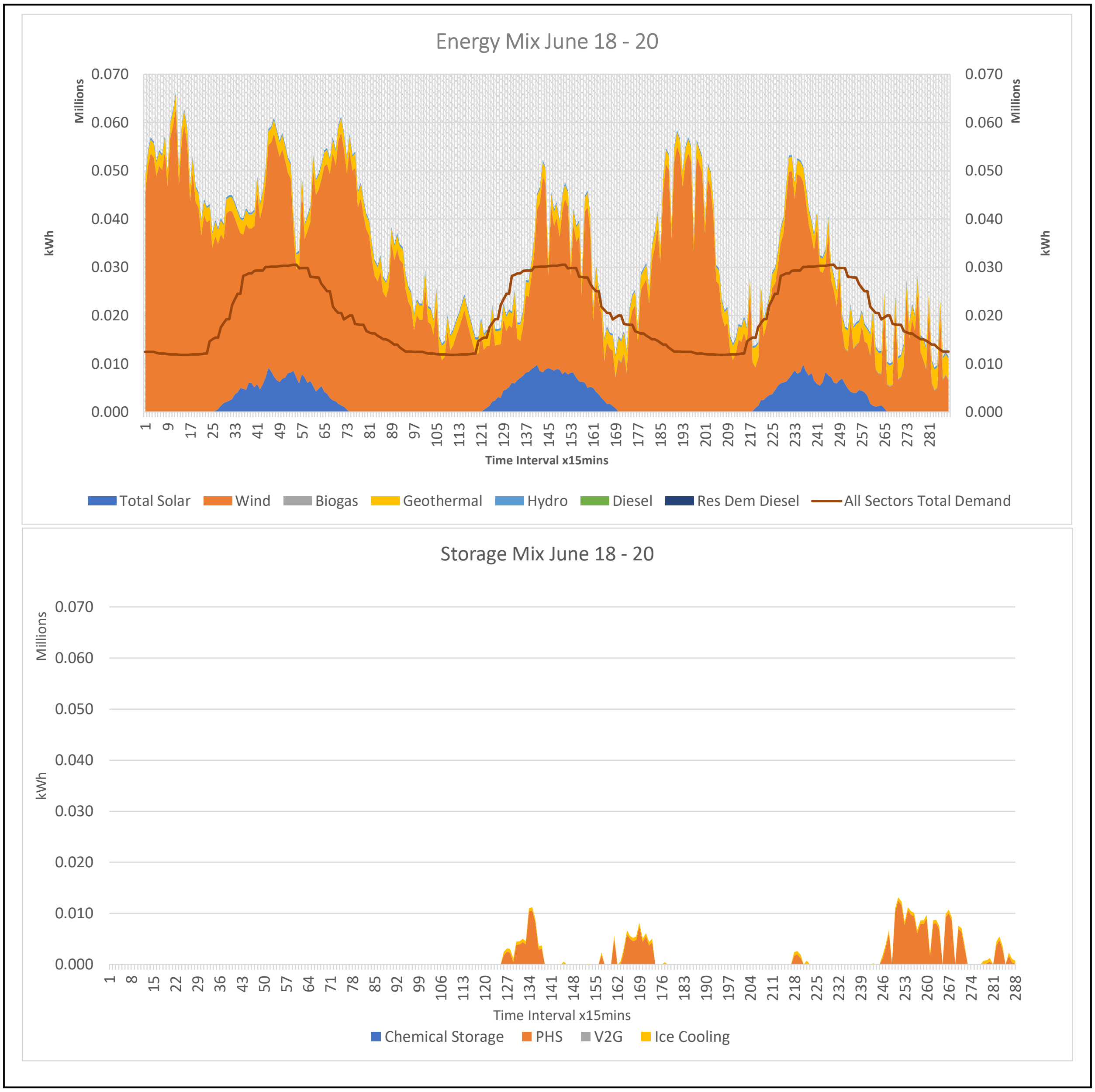


Figure 98 Energy mix at year 25

The 100% RE mix is maintained in year 25 as illustrated in Figure 98 with an increase in chemical battery storage energy capacity from 38.2 GWh to 40.9 GWh. All other parameters remain relatively unchanged. PHS dispatch can be seen in the time period illustrated. Most of the RE is provided by wind and solar PV. Generation exceeds demand for most of the illustrated time period requiring the very large amounts of storage exhibited in this scenario. Required biodiesel capacity is 75.6 MW.

The average charge power settings for all years are provided in Table 103 and the amount of charge energy used relative to the displaced projected fossil fuel demand to meet transport sector energy needs for all 5-year intervals are provided in Table 104.

Table 103 Average charge power used per 5-year interval

Power in kW	Year 5	Year 10	Year 15	Year 20	Year 25
Sc. C - LDV	2.85	2.45	2.2	1.97	1.6
Sc. C - HDV	3.1	2.65	2.4	2.1	1.85

Table 104 Percentage of charge energy used for transport relative to displaced fossil fuel consumption for scenario C

V2G Energy Supply HDV	Year 5	Year 10	Year 15	Year 20	Year 25
Vieux Fort-	0%	-1%	4%	6%	8%
Soufriere	0%	-1%	4%	6%	8%
Praslin	0%	-1%	4%	6%	8%
Cul de Sac	0%	-1%	4%	6%	8%
Castries	0%	-1%	4%	6%	8%
Union	0%	-1%	4%	6%	8%
Reduit	0%	-1%	4%	6%	8%
V2G Energy Supply LDV	Year 5	Year 10	Year 15	Year 20	Year 25
Vieux Fort	1%	1%	5%	9%	3%
Soufriere	1%	1%	5%	9%	3%
Praslin	1%	1%	5%	9%	3%
Cul de Sac	1%	1%	5%	9%	3%
Castries	1%	1%	5%	9%	3%
Union	1%	1%	5%	9%	3%
Reduit	1%	1%	5%	9%	3%

Electrical energy consumption by the EV fleet is kept within reasonable limits of the projected fossil fuel demand for each year.

Details of energy supplied, demand and load are provided in Table 105. Peak loads are significantly higher compared to the baseline scenario due to demand from EV charging, however, peak load at year 25 of 198 MW is similar to scenario A at 199 MW and scenario B at 207 MW.

Table 105 Scenario C energy, demand and load details

	Total RE Consumed - GWh	Total energy supplied - GWh	RER	Excess RE - GWh	% Res Dem Diesel	Total Demand - GWh	Peak Load - MW	Residual Demand - GWh	Peak Residual Load - MW	Total Peak Load - MW
Year 5	181.9	526.7	35%	0.0	15%	494.4	76	77.6	31	107

Year 10	517.3	647.4	80%	0.0	7%	563.1	92	45.0	40	132
Year 15	762.0	805.7	95%	0.0	0%	638.4	109	3.2	55	165
Year 20	893.6	897.9	100%	0.0	0%	683.1	122	4.3	76	198
Year 25	894.2	898.5	100%	0.0	0%	683.5	122	4.3	76	198

Total energy supplied exceeded demand by 31% in year 25 due to energy kept in storage as compared to 6.5% in year 5 due to system losses. Residual demand supplied by biodiesel was 4.3 GWh. The peak residual load of 76 MW is also similar to scenario A at 75 MW and scenario B at 74 MW.

The year 25 total energy utilised from all sources in this scenario is illustrated in Figure 99. Most of the energy is provided by wind at 632 GWh followed by geothermal at 159 GWh. Utility and distributed solar supply 34 GWh and 53 GWh respectively.

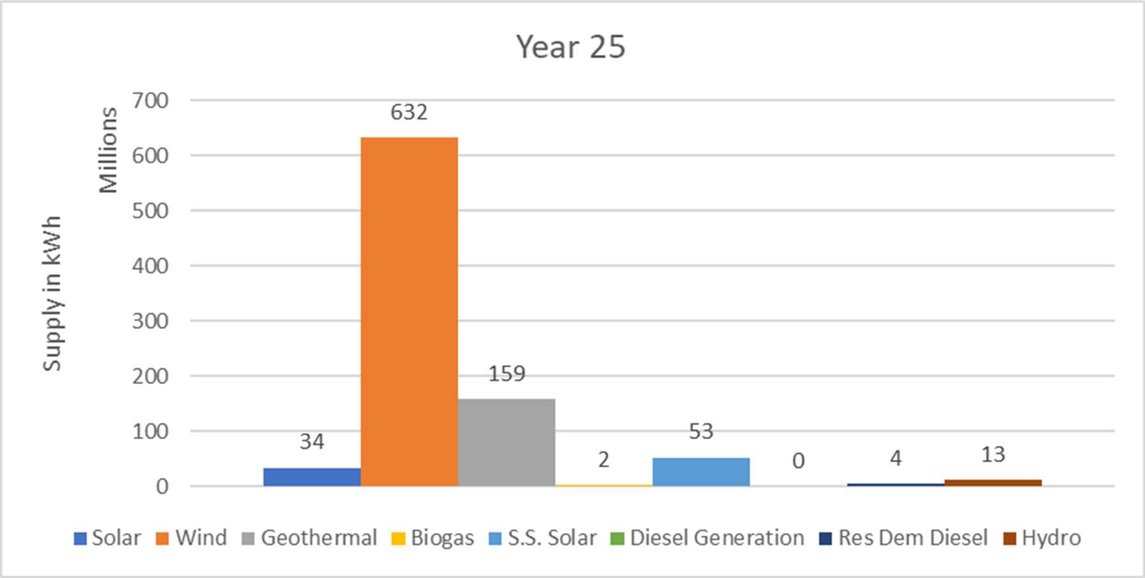


Figure 99 Year 25 energy supplied by source in scenario C

The 5-year interval tariffs and merit order dispatch curve for year 25 are provided in Figure 100. The tariff increases progressively from year 5 to year 15 during which most of the investments are made to achieve the 95% RE target. As most of the investment is made by this time, a progressive decrease in the tariff is realised between years 15 to 25. As already seen in scenarios A and B, biogas has the highest marginal cost of all generation sources. Ice storage has the highest marginal cost of all storage technologies, likely due to being at a smaller scale compared to other storage technologies.

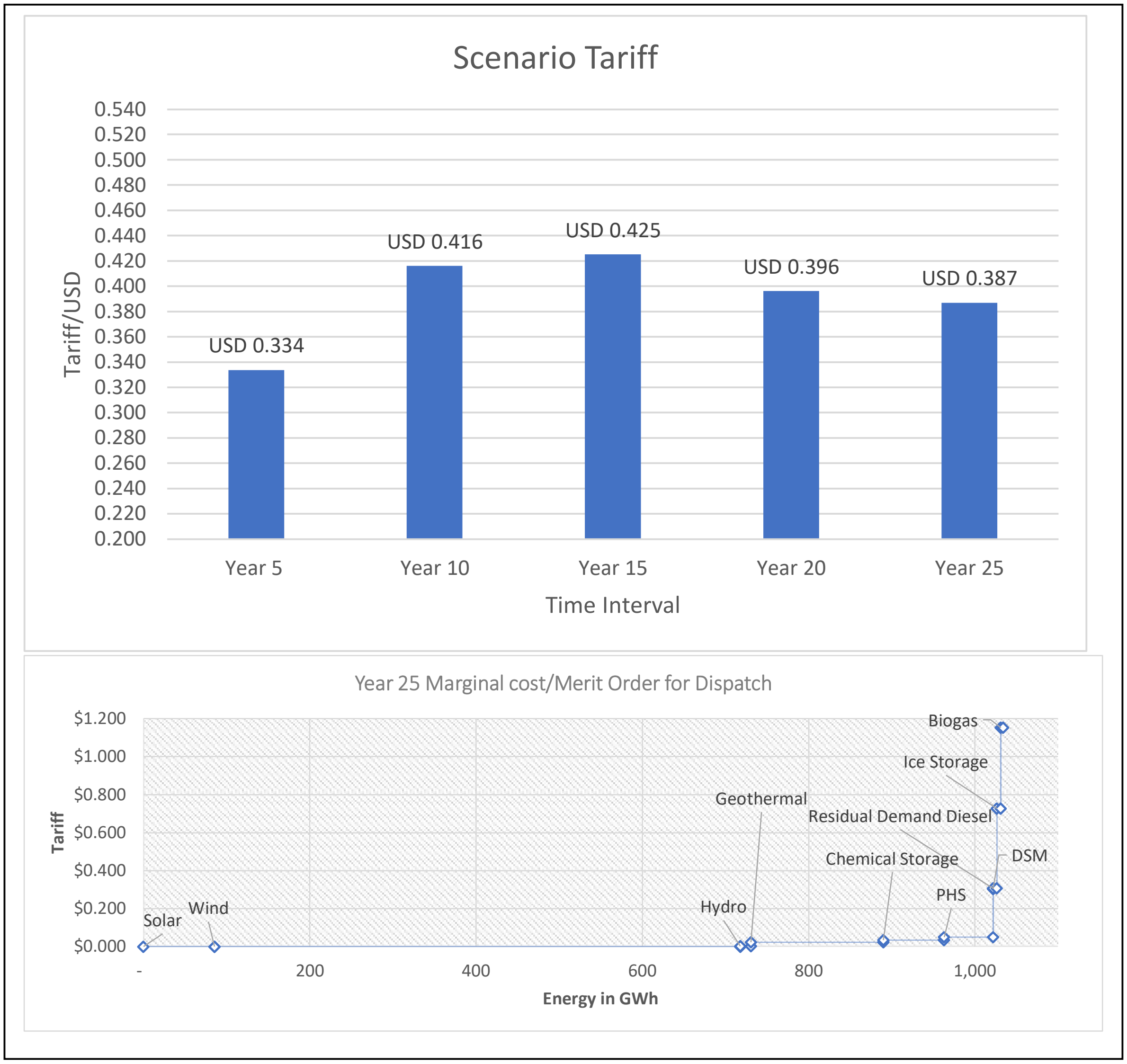


Figure 100 Scenario C tariff in 5-year intervals and merit order dispatch curve at year 25

The marginal cost data is provided in Table 106.

Table 106 Merit order dispatch data for scenario C

Energy Source	GWh supplied	Cumulative Energy in GWh	Year 25 Marginal cost
Solar	85.3	-	$0.000
Wind	632.4	85	$0.000
Hydro	12.9	718	$0.002
Geothermal	159.3	731	$0.023

Chemical Storage	72.9	890	$0.035
PHS	59.1	963	$0.050
DSM	0.1	1,022	$0.304
Residual Demand Diesel	4.3	1,022	$0.308
Ice Storage	4.7	1,026	$0.727
Biogas	2.7	1,031	$1.152

Due to the very large amount of chemical storage, the marginal cost is lower than for PHS. Considering also that biodiesel (residual demand diesel in year 25) is cheaper to dispatch than ice storage and biogas, a decision would need to be taken on whether these more expensive resources should be dispatched to ensure enough energy throughput to be financially viable. In addition, if biodiesel must be imported, a potential policy could be to use the locally available sources of energy in preference to imports, provided that the overall tariff is within an acceptable limit.

Table 107 provides details of the storage by five-year intervals for each storage type. Total energy stored and discharged are dominated by chemical storage and PHS. V2G is not used in this scenario. Ice storage performs consistently between years 20 and 25 discharging a total of 4.7 GWh of energy annually.

Table 107 Scenario C storage capacity details by type and year

	Energy in GWh				
Storage Type	Year 5	Year 10	Year 15	Year 20	Year 25
Chemical					
Total Stored	-	3.1	60.8	102.0	103.6
Total Discharged	-	2.8	45.7	72.8	72.9
Losses	-	0.3	5.1	8.1	8.1
V2G - HDV					
Total Stored	28.6	56.5	88.9	120.1	122.7
Total Discharged	-	-	-	-	-
Losses	-	-	-	-	-
V2G - LDV					
Total Stored	9.5	19.0	29.6	41.0	38.6

Total Discharged	-	-	-	-	-
Losses	-	-	-	-	-
Storage Ice - Hotel					
Total Stored	-	1.9	3.6	4.2	4.2
Total Discharged	-	1.0	1.8	2.0	2.0
Losses	-	0.0	0.1	0.1	0.1
Storage Ice - Commercial					
Total Stored	-	2.4	4.5	5.5	5.4
Total Discharged	-	1.4	2.4	2.7	2.7
Losses	-	0.0	0.1	0.1	0.1
PHS					
Total Stored	-	24.5	63.2	80.8	80.4
Total Discharged	-	18.3	46.4	59.4	59.1
Losses	-	6.1	15.4	19.6	19.5

7.2.10 Scenario C - Evaluation of Achievement of Stakeholder Objectives

Stakeholder feedback, model inputs and the explanation provided in Table 66 scenario C are reproduced here for ease of reference after each question.

7.2.10.1 R1_7

- What should be the national priorities for improving energy security in the energy sector (electricity, transport, cooking, et cetera)?

Feedback summary	High costs, improving efficiency and reducing carbon footprint
Model Inputs	EV pricing (S5 - 2 EV fleet)/Mandated transition of FF to RE (S11 - 3 Mandated)/Conversion to EV fleet (S8 - 1 Immediate ban on ICE imports)
Explanation	Reduction in VAT on investments in EVs/projected fossil fuel demand in domestic, industrial, hotel and commercial sectors converted to electricity demand/% of transport fleet to be converted from fossil fuel to electric vehicles

A 10% VAT reduction is applied on all investments in EV infrastructure. Details of the fleet conversion are provided in Table 81. The PV of investments in the EV fleet was USD$4.6bn as compared to USD$5.0bn in both scenarios A and B as V2G is not used in this scenario. The conversion rate for fossil fuel demand in domestic, industrial, hotel and commercial sectors is provided in Table 67. Impact on the carbon footprint is discussed at R2_GH.

7.2.10.2 R1_8,11

- What environmental aspects should be considered when making decisions on investments in the energy sector?

Feedback summary	Minimise land use conflicts and negative impacts
Model Inputs	Maximise utility wind (S2 - 2 Utility wind)
Explanation	Add the maximum amount of wind energy to achieve RE targets

Land requirement for the wind farms will be about 383,000m^2 at 1,700m^2 per MW compared to a requirement of 2.4mn m^2 in scenario A for solar PV at 0.1526 m^2 per kWp. About 85% of the total wind energy potential capacity is utilised at 225.4 MW. In addition, the potential wind farm sites are located in sparsely populated areas, thereby minimising the potential for land use conflicts.

7.2.10.3 R1_3,10,13

- Should government continue to provide financial support for investments in the energy sector or should all energy investments be financially viable on their own?

Table 108 Scenario C value of profits staying in the local economy in year 25

Feedback summary	Energy investments must be viable on their own
Model Inputs	Commercial finance (S10 - 3 Local Investor, S13 - 1 Commercial) & (S4 -2 Part of profits kept)
Explanation	70% debt at 8% for 10 years and 30% equity return of 13%

The debt and equity financial parameters were applied to all calculations. Financial results for this scenario are provided in Table 109. The following RE and energy storage investments all have adequate financial parameters to be considered financially viable: solar, wind, biogas, geothermal, PHS, battery chemical and energy efficiency.

Table 109 Summary of financial results

RE and Storage Sources	Average ROE	Year 25 ROE	25 Year IRR	NPV in USD$
Solar	5%	12%	16%	$4,298,275
Wind	17%	32%	30%	$60,309,931
Biogas	27%	45%	24%	$2,357,467

Geothermal	23%	21%	24%	$28,637,997
PHS	6%	14%	23%	$12,498,412
DSM	132%	-26%	NA	($3,929,142)
Battery Chemical	29%	85%	15%	$1,420,087
V2G	0%	0%	NA	$0
Ice Storage	-10%	1%	11%	($1,662,240)
Hydro	-8%	1%	11%	($1,322,563)
Energy Efficiency	35%	16%	6%	($24,266,898)

Investments in DSM were made in each 5-year interval. The average ROE is favourable, however, more demand shifting will be required to realise long-term favourable financial metrics such as IRR and NPV. DSM is not a viable investment option in the 25-year period analysed. The average ROE is high as the investment is low compared to the returns, though the amount of demand shifted is very low. Ice storage investments begin in year 10 and all investments are completed in year 15. The IRR is over 5%, however the average ROE is still negative. This indicates that a longer time of operation is required to experience positive average ROE. Investments in hydro started in year 5 and were completed in year 20. Though an IRR of 11% is calculated, more operation time is required for a positive NPV and average ROE. Investments in hydro are, therefore, not viable during the 25-year period analysed, however, the metrics may be more favourable over a longer period of operation.

The value of profits kept in the local economy in year 25 is provided in Table 110.

Table 110 Scenario C value of profits staying in the local economy in year 25

RE Source	% of Gross Profits	Amount USD$
Solar	33%	2,745,072
Wind	31%	37,940,851
Biogas	13%	547,719
Geothermal	30%	9,098,408
Hydro	6%	176,777
Total		50,508,827

Scenario C results in the highest value of profits kept in the local economy at USD$50.5mn compared to scenario A at USD$32.4mn and scenario B at USD$46.5mn. This is due to the transition rate happening fastest in scenario C. The largest contribution is from wind which provides the most energy in this scenario. The profits from hydro are lowest due to the depreciation expense.

The overall economic impact for this scenario is estimated at a PV of USD$317.5mn which is the highest of all the scenarios with scenario A at USD$165.4mn and scenario B at -USD$135.5mn. As this scenario has the fastest transition rate among the three (3) scenarios, it is quicker to achieve a higher economic impact.

The tax transition is illustrated in Figure 101.

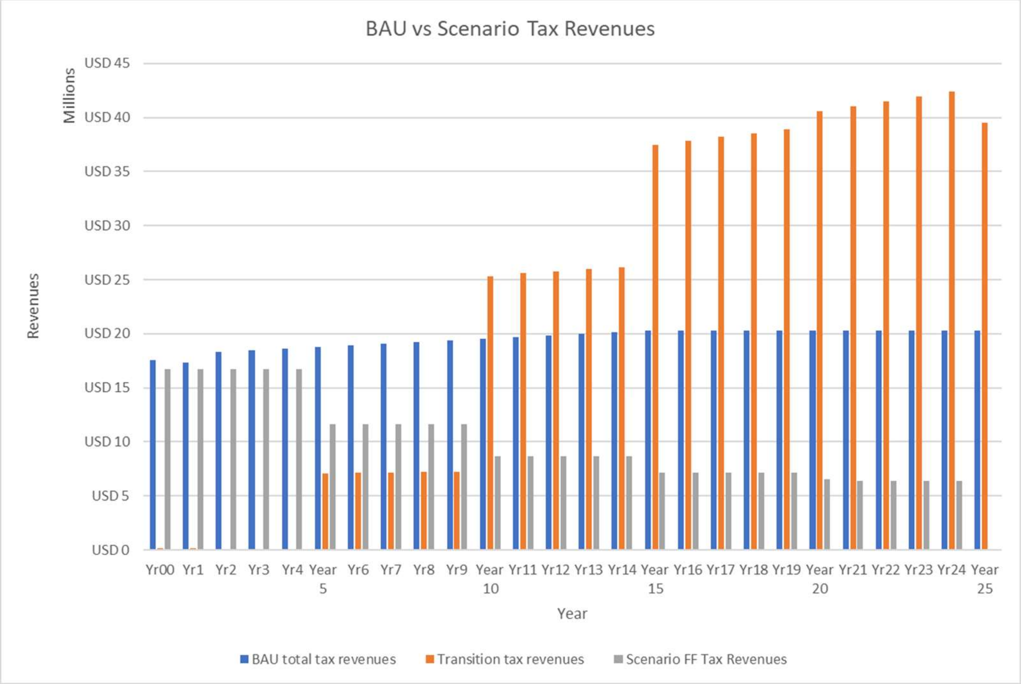


Figure 101 BAU vs scenario C tax revenues

The transition tax revenues exceed BAU tax revenues in year 10 compared to year 15 in scenario A and year 20 in scenario B. This indicates that a quicker transition results in a higher net positive economic impact on the local economy. In year 25, the transition tax revenues exceed BAU by about USD$20mn. There is a small drop in the year 25 tax revenue as the tariff decreases in that year.

The tariff required for tax parity in the transport sector and a comparison of tax revenues are provided in Figure 102. The EV energy tariff required for parity with projected transport sector tax revenue stablises at about USD$0.41 per kWh from year 15. Parity in tax revenues is achieved between years 15 and 16 and by year 25 exceeds BAU by about USD$1mn per annum. The observed drop in revenues in year 20 is due to a lowering of the energy tariff in that year.

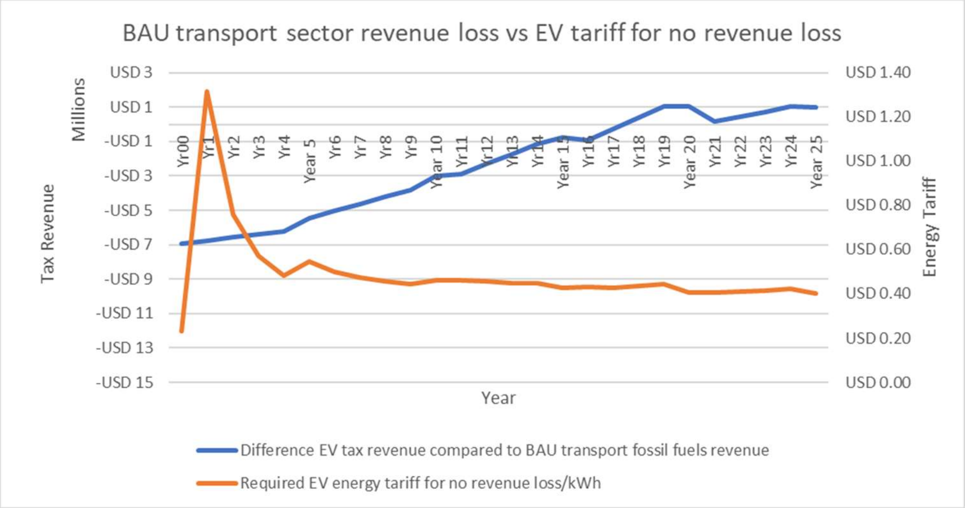


Figure 102 BAU transport sector revenue loss vs EV tariff for no revenue loss

PV of all RE investments over the 25-year period are provided in Table 111.

Table 111 Present value of all investments

RE and Storage Resource	Present Value of Investment in USD$
Wind	$91,486,531
Solar	$30,276,567
Geothermal	$66,836,825
Diesel	$24,712,705
Biogas	$5,210,910
Hydro	$25,638,336
Ice Storage	$17,229,240
PHS	$34,539,200
V2G	$0
Battery Chemical	$17,769,680
Energy Efficiency	$82,069,845
Demand Side Management	$271,609
Total	$396,041,447

The largest investments are made in wind, energy efficiency and geothermal. No investments are made in V2G technology. USD$24mn in investments are made in diesel plant for biodiesel generation to meet residual demand. The PV of all investments is USD$396mn which is higher than for scenario B at USD$324mn and scenario A at USD$354mn.

The total debt burden incurred by investments in RE infrastructure at year 25 are provided in Figure 103. The largest debt is for diesel generation plants used for generation with biodiesel at an amount of USD$12.7mn. The next highest debt is for wind at USD$8.7mn. Total debt in year 25 is USD$27.1mn.

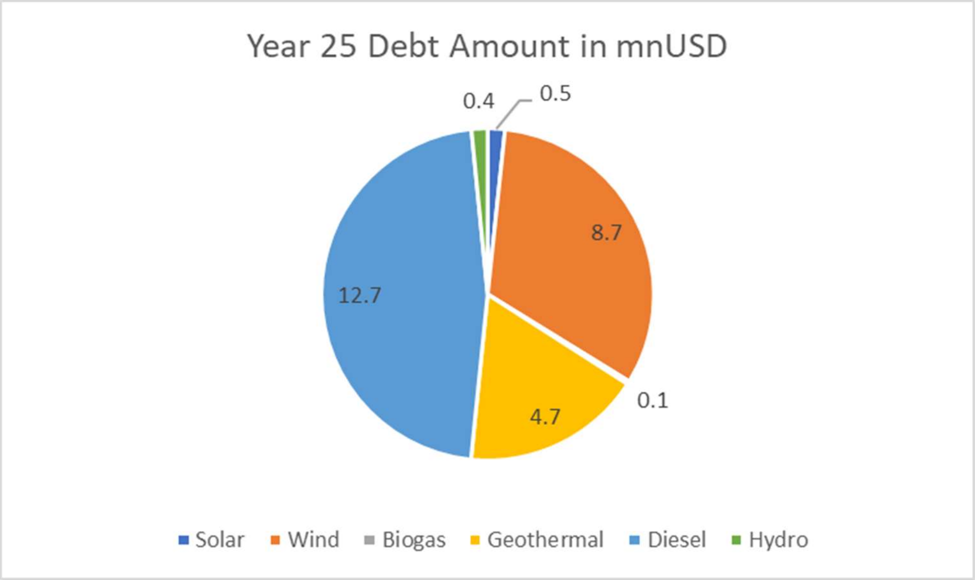


Figure 103 Scenario C year 25 debt

7.2.10.4 R1_9

- Are there any sources of renewable energy that may not be socially acceptable?

Feedback summary	No RE sources should be excluded
Model Inputs	All RE sources (S9 - 4 All in)
Explanation	Wind, solar PV, geothermal, biogas, hydro

Stakeholders have not excluded any forms of RE generation from this scenario. All available forms of generation are therefore used.

7.2.10.5 R1_4,6

- What benefits to the country would you like to see from sustainable energy investments?

Feedback summary	More distributed generation to enable a system which is more resilient
Model Inputs	Long duration storage
Explanation	Use of PHS and chemical storage

In year 25, 33.7 MWp of distributed solar PV is installed and a total of 79.4 MW|1.88 GWh of PHS and 81.6MW|40.9 GWh of chemical energy storage are used as provided in Table 102.

7.2.10.6 R1_2

- What sources of energy for electricity generation should receive priority for development in the electricity sector? Why?

Feedback summary	Use of wind energy
Model Inputs	Maximise utility wind (S2 - 2 Utility wind)
Explanation	Up to maximum wind potential

Wind energy usage in years 20 to 25 was 225.4 MW representing about 84% of total wind energy potential.

7.2.10.7 R2_RE

– The Government of Saint Lucia (GOSL) has set a target of 35% by 2025 and 50% by 2030 for generation of electricity from renewable sources. Are you in agreement with this vision? If not, suggest an alternative.

Feedback summary	Targets should be higher
Model Inputs	Higher targets (S1 - 3 Higher target)
Explanation	Stakeholder targets of 35%/2025; 80%/2030 with addition of 95%/2035; 100%/2040)

The higher energy targets were achieved with zero (0) excess RE production and about 4.3 GWh of residual demand supplied by biodiesel representing less than 1% of total demand in years 20 to 25.

7.2.10.8 R2_GH

– The Government of Saint Lucia (GOSL) has set a target of 7% reduction in GHG emissions in the energy sector relative to 2010, by 2030. Are you in agreement with this vision? If not, suggest an alternative.

Feedback summary	The target should be higher
Model Inputs	Output discussion
Explanation	GHG reductions due to RE calculated and discussed as an output.

Figure 104 provides the $C0_2$ emissions savings over the transition period and a comparison with the 2010 baseline. Emissions savings as a percentage of the 2010 baseline is provided in Table 112.

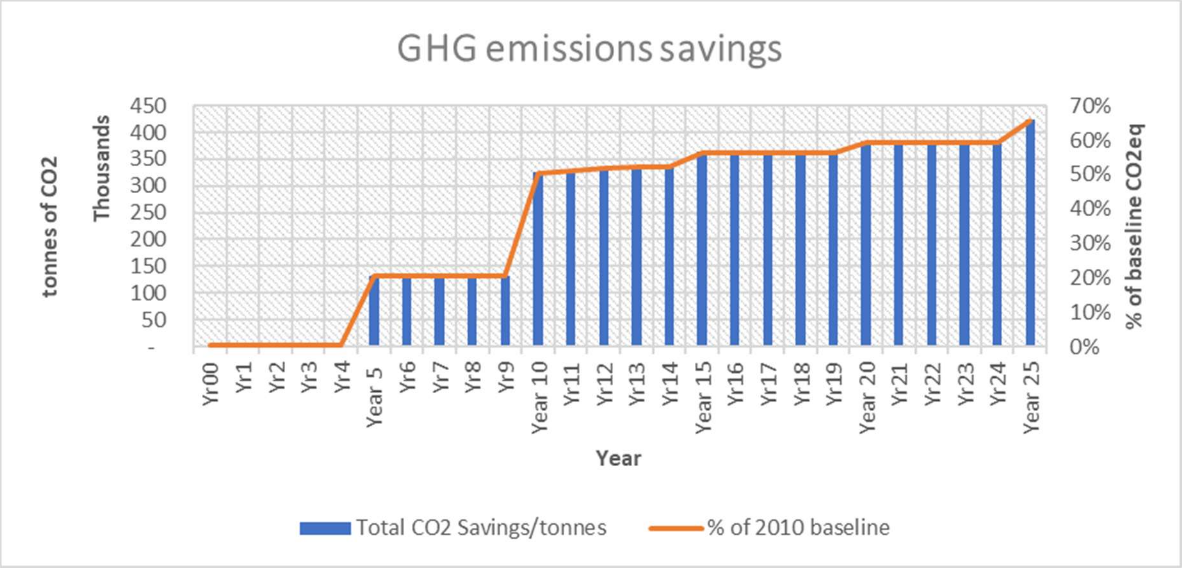


Figure 104 GHG emissions savings

The 7% target is exceeded from year 5 by almost three (3) times at 20.4%. Higher savings are experienced sooner than other scenarios due to the higher RE penetration targets. As with other scenarios, more than 60% of the baseline value in savings is achieved by year 25.

Table 112 Emissions savings as a percentage of the 2010 baseline

	% of 2010 baseline
Year 5	20.4%
Year 10	50.3%
Year 15	56.4%
Year 20	59.1%
Year 25	65.6%

7.2.10.9 R2_EE

- The Government of Saint Lucia (GOSL) has set a target of 20% reduction in energy consumption in the public sector. Are you in agreement with this vision? If not, suggest an alternative.

Feedback summary	Target should be higher
Model Inputs	Higher than target (S12 - 2 More/maximum)
Explanation	23% EE target for domestic, hotel and industrial sectors; 20% EE target for commercial sector

The achieved EE savings in year 25 are displayed for the time period Month 6, days 18 to 20 in Figure 105.

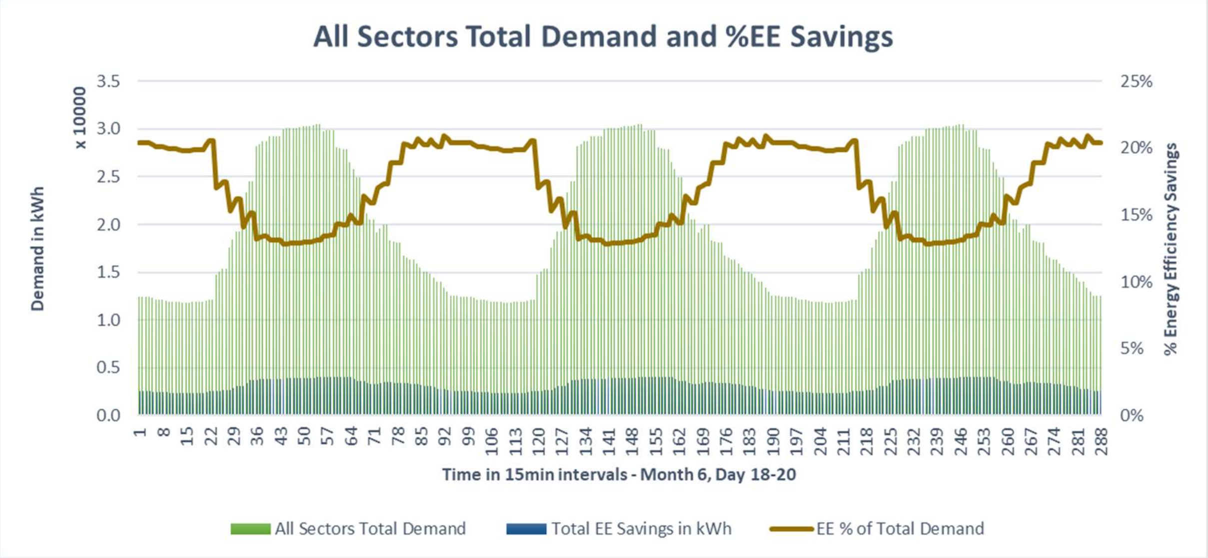


Figure 105 EE savings across all sectors except street lighting

The highest EE savings are observed when EV charging demand is lowest during the nighttime hours. Up to 20% savings are observed meeting the government set target. During the daytime hours when EVs are charging, this reduces to about 13% due to the higher energy consumption. The average annual EE savings in year 25 is about 17% which approaches the government set target. The target should be set based on the transition scenario selected by stakeholders.

7.2.10.10 R2_5,8,12

– What economic sectors should receive priority support for improving efficiency of energy consumption, i.e., achieving the same output with less energy?

Feedback summary	The transport sector should receive priority support
Model Inputs	EV pricing (S5 - 2 EV fleet)
Explanation	Reduction in VAT on investments by 10%; DG solar EV pricing.

The total investment in EV infrastructure has a PV of USD$4.6bn with a 10% reduction to the VAT. This cost would be higher without the reduction. DG direct solar PV consumption energy tariff was an average of USD$0.11 per kWh from year 20 to 25. The DG direct consumption tariff is provided in Figure 106. The tariff keeps decreasing as the fixed O&M costs per kWh decreases with increasing installed capacity.

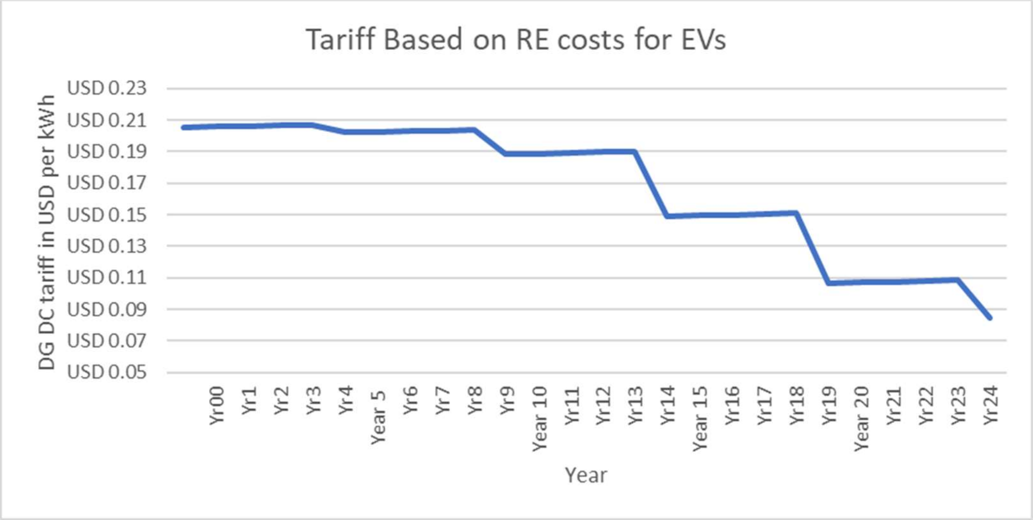


Figure 106 DG direct consumption solar PV tariff for EVs

7.2.10.11 R3_11,14

– What should be the objectives of developing a resilient energy system in Saint Lucia?

Feedback summary	Lower cost and more affordable energy
Model Inputs	Cost driven energy price (S6 - 2 Lifecycle cost plus profit margin; S3 - 2 Based on RE costs for EVs)
Explanation	Energy pricing is based on investment and operations costs of RE plants

This scenario has succeeded in reducing fossil fuel-based energy production by substitution with RE for up to 100% energy consumption. It has also resulted in the lowest tariff of all scenarios starting from year 20 as shown at Figure 107. The tariff was initially higher than all other scenarios in year 10 due to the large capital investments required at that time to achieve the high RE target of 80%. As most of the investment was made early on, the combination of high RE generation and lower cost of debt resulted in a downward trend in the tariff from year 15. In comparison, scenario A does not result in a relatively large tariff in year 10 and follows a similar downward trend from year 20.

The contribution of all sources to the energy tariff in year 25 is provided in Table 113. As seen with other scenarios, biogas electricity has the highest tariff of generation sources. PHS and chemical battery energy storage have the same tariff due to the large installed capacities and amount of energy delivered.

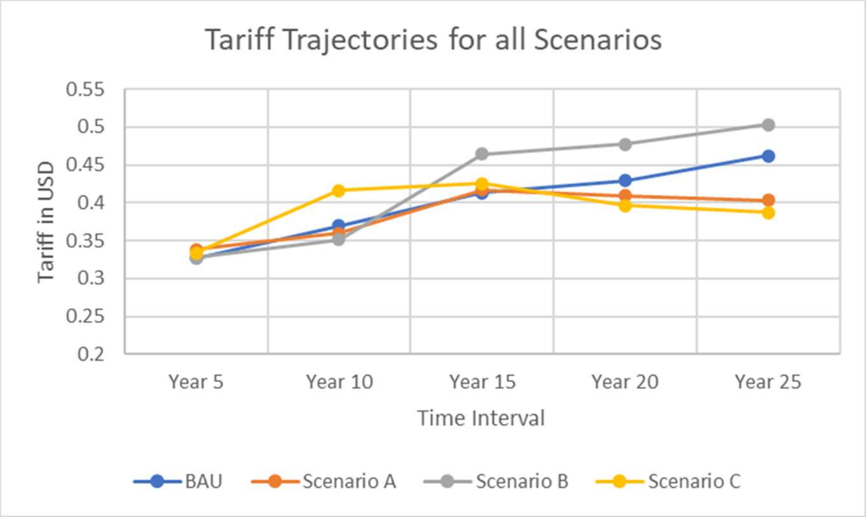


Figure 107 Tariff trajectories for BAU, scenarios A, B and C

Table 113 Energy supplied and associated tariffs in year 25

Energy Source	Energy generated and discharged - GWh	Energy tariff USD$ per kWh	Weighted average tariff (USD$ per kWh)
Solar	85.3	0.192	0.016
Wind	632.4	0.403	0.247
Biogas	2.7	1.845	0.005
Geothermal	159.3	0.273	0.042
Diesel	-	0.461	0.000
Hydro	12.9	0.564	0.007
DSM	0.1	0.311	0.000
V2G	-	0.547	0.000
Ice Storage	4.7	0.463	0.002
Chemical Storage	72.9	0.463	0.033
PHS	59.1	0.586	0.033
Residual Demand Diesel	4.3	0.530	0.002
Total	1,033.7		0.387
		Average Tariff	XCD$1.04
			USD$ 0.39

7.2.10.12 R4_6,14

- What are your objectives for transitioning the energy sector to sustainable energy (RE and energy efficiency)?

Feedback summary	Reduction in greenhouse gas emissions

Model Inputs	Output discussion
Explanation	GHG reductions due to RE calculated and discussed as an output.

Significant GHG reductions can be experienced as indicated in Section R2_GH.

7.2.10.13 R4_1,10

– How should the general public participate in a transition to sustainable energy?

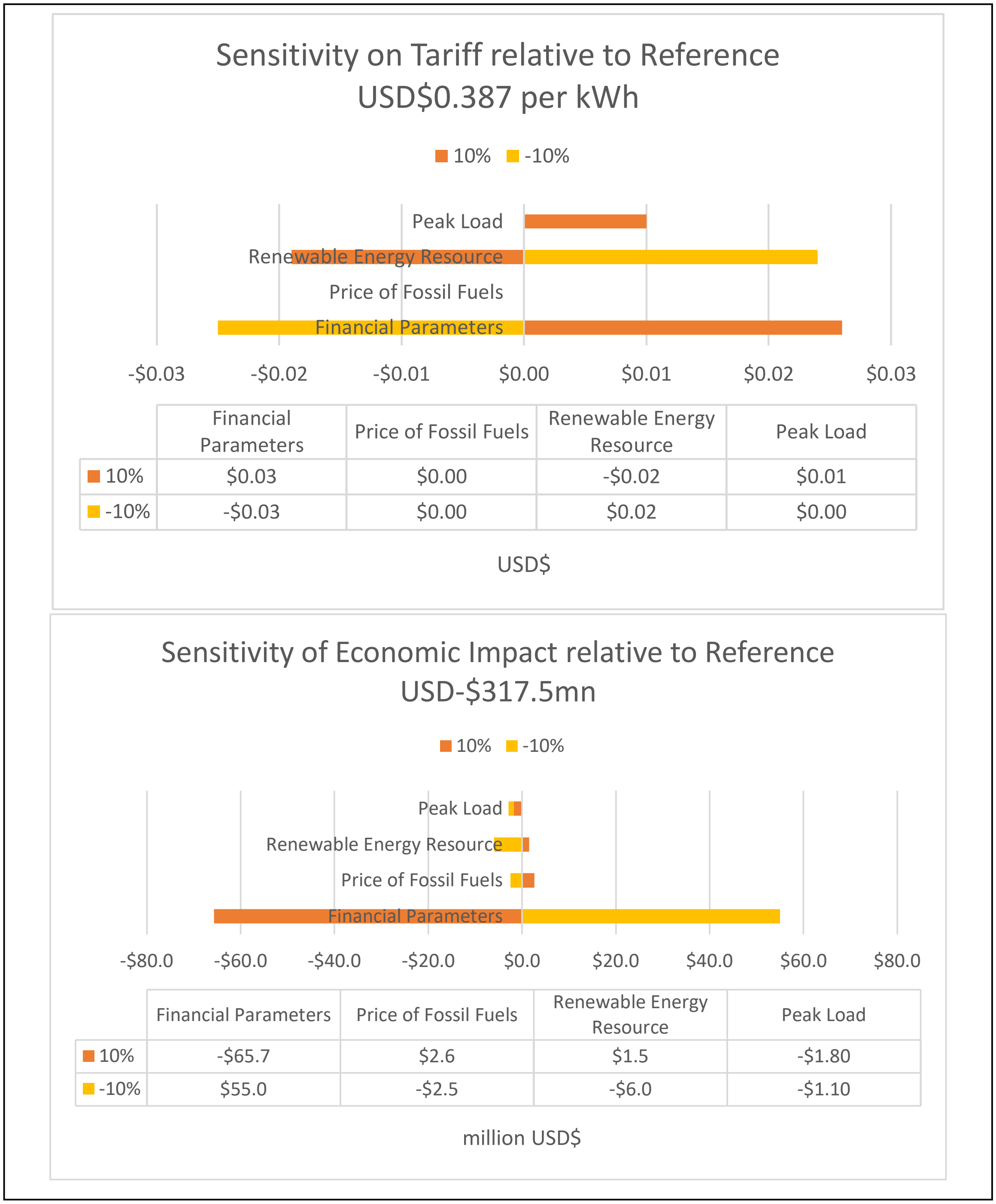
Feedback summary	Emphasis on distributed forms of energy generation
Model Inputs	Use of distributed solar PV
Explanation	Domestic DG solar enabled

Under this scenario, the public will be involved in the installation of 33.7 MWp of distributed solar PV systems by year 25. In addition, as the hydro resource is distributed, the public may also participate in investing in this source of generation. Though the biogas potential is based on municipal solid waste entering the landfill sites, this resource can be diverted to distributed centers for processing into biogas. Wind energy can also be a distributed resource if several sites are developed.

7.2.11 Scenario C Sensitivity Analysis

Results of a sensitivity analysis are provided in Figure 108. The tariff is most sensitive to changes in the financial parameters. A decrease of 10% in financial parameters results in a lowering of the tariff by about USD$0.03 per kWh whereas an increase of 10% results in a tariff increase of about USD$0.03 per kWh. A 10% decrease in the RE resource results in a tariff increase of about USD$0.02 per kWh as less energy is produced for the same investment. A 10% increase in RE resource results in a tariff decrease of about USD$0.02 per kWh. A decrease in peak load does not affect the tariff, however, an increase of 10% results in a USD$0.01 per kWh increase in tariff. The decrease does not affect the tariff because the investments are already made and the fixed part of the energy price is set, regardless of whether it is used or dumped. The increase in peak load results in more biodiesel consumption, hence the increase in tariff. Changes to the price of fossil fuels does not affect the tariff as no fossil fuels are consumed in year 25.

Variations to the financial parameters have the largest effect on the economic impact. An increase of 10% causes a larger impact with a decrease to the economic impact of -USD$65.7mn whereas a decrease of 10% in the financial parameters causes an increase of USD$55mn to the economic impact. The larger impact from an increase in investment cost is due to higher debt payments whereas the lower impact from a reduction in financial parameters is tempered by the variable costs which remain unchanged. A variation in the RE resource results in a lower effect on the economic impact with a decrease of 10% resulting in a lowering of the economic impact by about -USD$6mn. An increase in the resource causes a lower impact of USD$1.5mn additional as excess energy is dumped and does not contribute to the economic impact. Variations to the price of fossil fuels causes an almost symmetric effect on the economic impact with a 10% increase adding USD$2.6mn due to higher taxes on the biodiesel used and a 10% decrease causing a reduction of economic impact by USD$2.5mn. Variations in peak load result in a -USD$1.8mn decrease in economic impact for a 10% increase and a -USD$1.1mn decrease in economic impact for a 10% decrease as an increase in peak load results in more biodiesel consumption and a decrease in peak load causes dumping of excess RE.



Sensitivity on Tariff relative to Reference USD$0.387 per kWh

	Financial Parameters	Price of Fossil Fuels	Renewable Energy Resource	Peak Load
🟧 10%	$0.03	$0.00	-$0.02	$0.01
🟨 -10%	-$0.03	$0.00	$0.02	$0.00

Sensitivity of Economic Impact relative to Reference USD-$317.5mn

	Financial Parameters	Price of Fossil Fuels	Renewable Energy Resource	Peak Load
🟧 10%	-$65.7	$2.6	$1.5	-$1.80
🟨 -10%	$55.0	-$2.5	-$6.0	-$1.10

Figure 108 Scenario C results of sensitivity analysis

7.2.12 Comparison of Scenarios to BAU

A comparison among BAU, scenarios A, B and C is provided in Table 114.

Table 114 Comparison BAU, scenarios A, B and C

	Parameter	Baseline	Scenario A	Scenario B	Scenario C
Year 25	Energy Output - GWh	553.4	894.8	1037.9	898.5
	Demand - GWh	514.5	695.0	749.1	683.5
	Storage Capacity - GWh	0	18.9	79.3	39.3
	Solar IRR	12%	19%	14%	16%
	Wind IRR	NA	29%	23%	30%
	Geothermal IRR	NA	24%	NA	24%
	Hydro IRR	NA	10%	2%	11%
	Biogas IRR	NA	16%	31%	24%
	Total Excess Generation - GWh	NA	0	0	0
	Residual Demand - GWh	NA	3.6	4.9	4.3
	Tariff - USD$ per kWh	0.462	0.403	0.503	0.387
	Dominant RE Source	Solar	Solar	Wind	Wind
	Dominant RE Supply - GWh	4.3	565	748.6	632
	Value of profits remaining in local economy - USD$mn	NA	32.4	46.5	50.5
	Tax revenue - USD$mn	20	113.9	62	39.5
	Average EE Savings	NA	16%	7%	17%
Overall	PV of Tax Revenues (No FF in Scenarios) - USD$mn	195.6	116.4	102.9	146.6
	Economic Impact - USD$mn	-1,252.90	165.4	-135.5	317.5
	PV of Investment Costs - USD$mn	NA	354.9	324.1	396
	RER (without Biodiesel)	1%	100%	100%	100%
	Exclusions	NA	None	Geothermal	V2G
	Year to exceed BAU tax revenues	NA	15	20	10

Demand and energy output of scenario C are similar to scenario A as both scenarios have significantly lower storage capacities than scenario B and no restrictions to sources of generation. Scenario C contains less storage than scenario B, but more than scenario A. All sources of generation in the table have IRR values indicating financial viability. The residual demand for scenario C is between that of scenarios A and B. Scenario C has the lowest tariff among all scenarios in year 25. Though wind is the primary source of RE generation, the installed capacity and generation are less than in scenario B. Scenario C has the highest amount of profits remaining in the local economy despite only part of the profits being kept in the economy. This is because the investments in RE and storage are made sooner and have more time to operate and generate profits compared to the other scenarios. Though the tax revenue at year 25 is the lowest among all the scenarios, at USD$39.5mn, the PV of tax revenues and economic impact are the highest of all scenarios as the majority of investments for the 100% RE transition are made sooner than for all the other scenarios. Consequently, profits were generated earlier and more benefits were generated over the analysed period of twenty-five (25) years. The PV of investments is highest in scenario C because most investments occurred sooner and were subject to lower discounting in calculating the PV. Exclusion of V2G caused a doubling of the amount of chemical battery storage required compared to scenario A. Scenario C took only ten (10) years to exceed BAU tax revenues compared to fifteen (15) years for scenario A and 20 years for scenario B. Scenario C also has the highest energy efficiency savings with an average of 17% in year 25.

A comparison of the annual economic impact trend for all scenarios is provided in Figure 109.

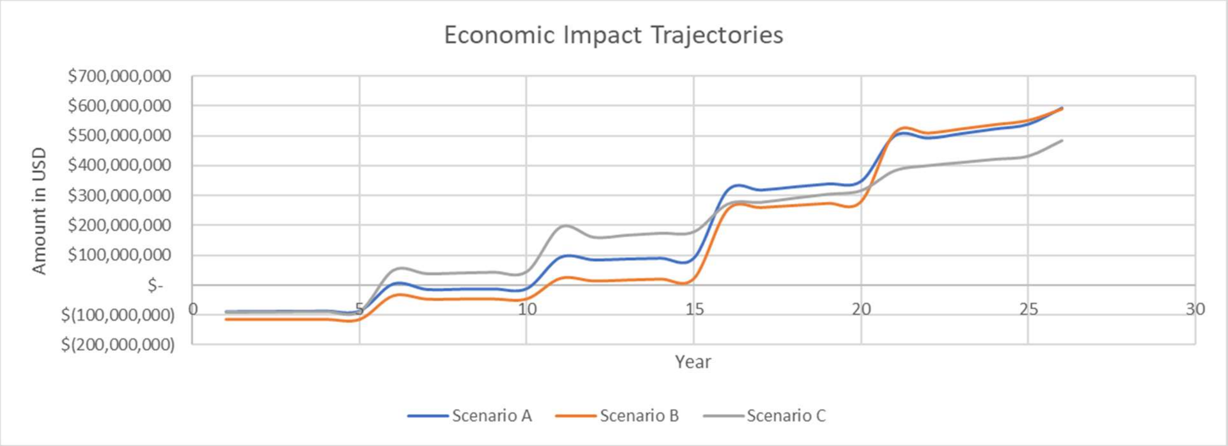


Figure 109 Comparison of annual economic impact for scenarios A, B and C

Scenario C has the highest economic impact from years 5 to 15. The economic impact is between scenarios A and B during the period year 15 to year 20 and beyond year 20, it is lower amounting to just under USD$500mn in year 25. The economic impact becomes positive just after year 5 in scenario C compared to just after year 10 for scenario A and just after year 15 for scenario B.

Average charge power in kW for all scenarios is provided in Figure 110. The average charge power behaviour for scenario C is very similar to scenario A as the energy and storage parameters are also similar.

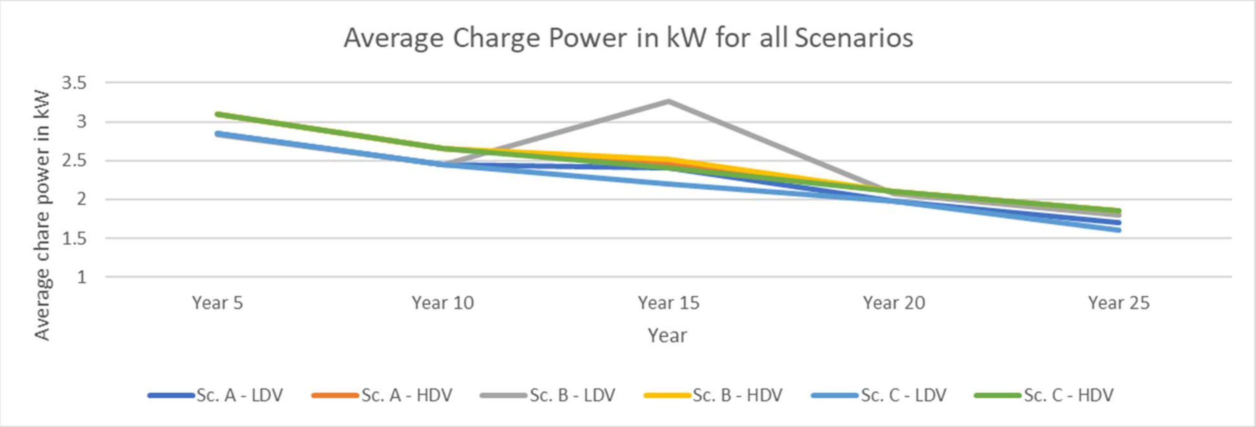


Figure 110 Comparison of average charge power for the EV fleet

7.2.13 Business Case Analysis Results for Baseline and Stakeholder Scenarios

The estimated ROE for investments in diesel fuel generation to meet BAU demand growth is >25%. The PV of fossil fuel taxes over the 25-year period, assuming that the regulatory environment remains unchanged, is USD$ $195.6mn. These results are with a fuel price driven tariff in which fuel costs are passed on to the consumer. The resulting tariff is higher than in scenarios A and C as shown in Table 114. Though this scenario generates the highest taxes, it also has the lowest economic impact at -USD$1,252.9mn. This scenario is attractive from an investor perspective; however, it is not as attractive as the scenarios A, B or C from a country economic perspective.

Utilising suitable financial metrics to measure the performance of the stakeholder scenario investments during the transition period was challenging as investments occurred in any of the 5-year intervals during the 25-year transition period. Consequently, the IRR and ROE are heavily impacted by when investments are made and the total equity fraction of each investment. In many cases, the full benefits during the entire lifetime of each investment, which is taken as 25 years, could not be assessed. Thus, for investments made in year 5, twenty (20) years of the useful life are being considered in the scope of the research, with a reduction in 5-year increments for investments made in each interval period following.

The year 25 IRRs are provided in Table 114 for all RE generation sources. They all meet the 5% threshold for commercial viability except for biogas in scenario B. The PV of tax revenues ranges from 47% lower than BAU for scenario B to 25% lower for scenario C. All scenarios demonstrate an overall economic impact which is a minimum of USD$1.1 billion higher than the BAU over the 25-year analysis period. The scenarios are more attractive both from an investor and a country economic perspective.

7.2.14 Performance of Energy Storage Options

7.2.14.1 Biogas

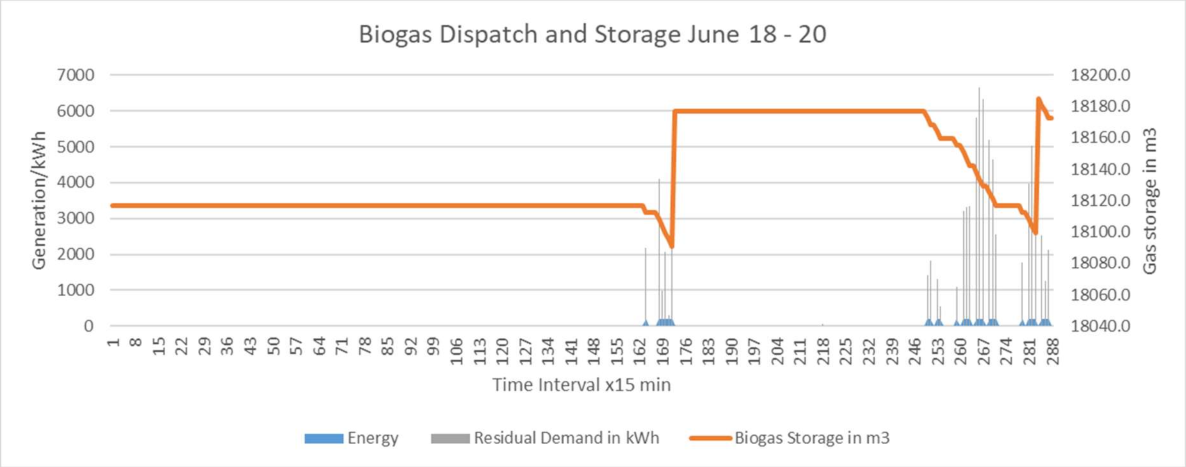


Figure 111 Scenario C biogas storage and energy dispatch

Biogas dispatch, for an indicative period of month 6 days 18 to 20, is provided in Figure 111. Biogas electricity is dispatched in response to residual demand. Gas storage decreases when generation occurs to satisfy demand. In practice, the biogas tariff can be two-tier with a lower tariff when gas storage is full and a higher tariff when storage is low. Such a tiered tariff must result in full cost recovery.

7.2.14.2 PHS

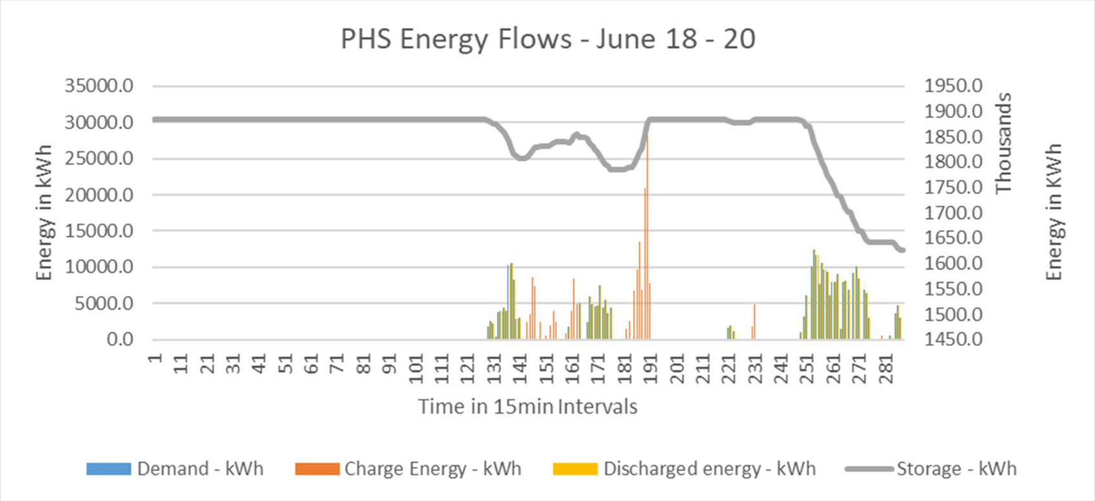


Figure 112 Scenario C PHS energy flows

PHS energy flows are shown for an indicative period in Figure 112. Demand, charging, discharging and total storage are all illustrated. Demand matches discharge energy. Storage decreases as the reservoir discharges.

7.2.14.3 Battery Chemical

Battery chemical storage energy dispatch is illustrated for an indicative period in Figure 113. During the first few days of this period, no discharge is observed and the battery storage is filling up. Towards the end of the period, demand triggers discharge of the battery storage energy. Total energy in storage decreases during discharge. Demand matches discharge.

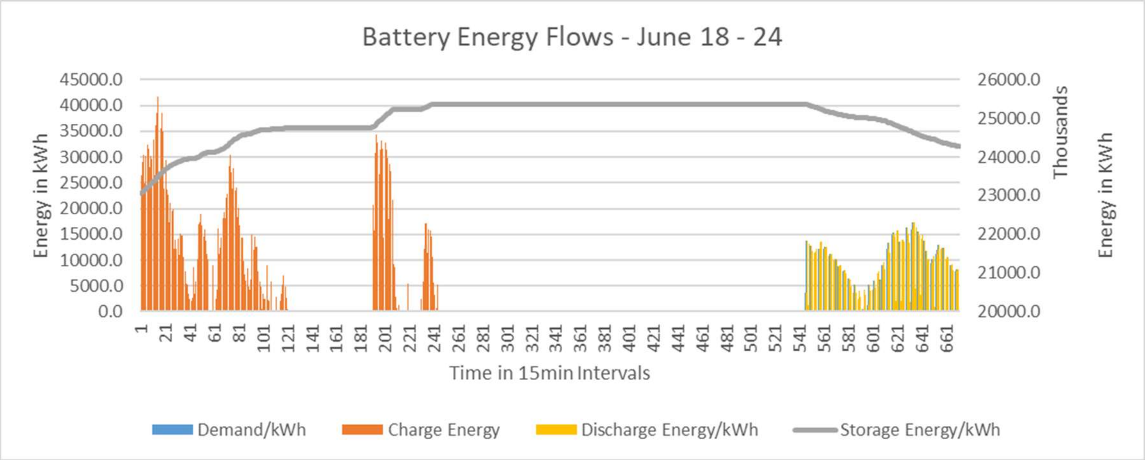


Figure 113 Scenario C battery energy flows

7.2.14.4 DSM

DSM energy shifting is illustrated in Figure 114 and Figure 115. Demand shifting for refrigeration occurs with a reduction in demand followed by an increase in demand after fifteen (15) minutes. For water pumping, pumps are run when excess RE is available. The level of storage can be seen to increase significantly during a short period with high pumping activity and then decrease just as quickly with continuous discharge. The storage is continuously discharged to meet demand. Storage level remains rather constant during the period to the right of the chart in which water pumping and discharge are continuously occurring.

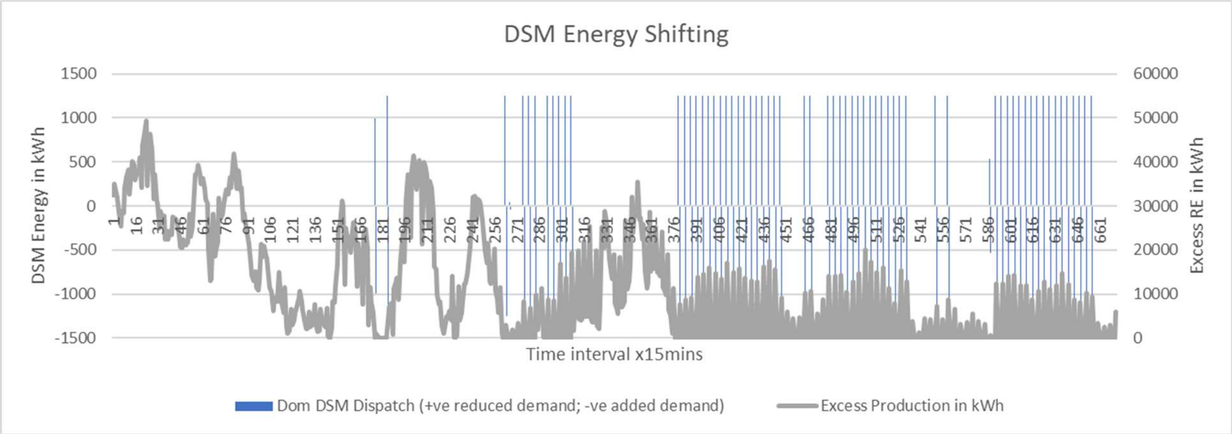


Figure 114 Scenario C DSM energy shifting for refrigeration

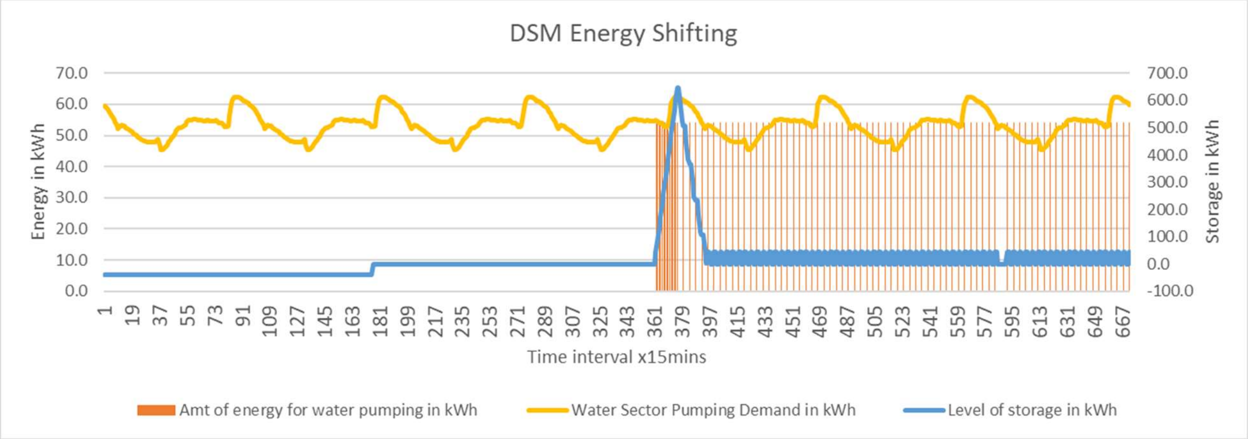


Figure 115 Scenario C DSM energy shifting for water pumping

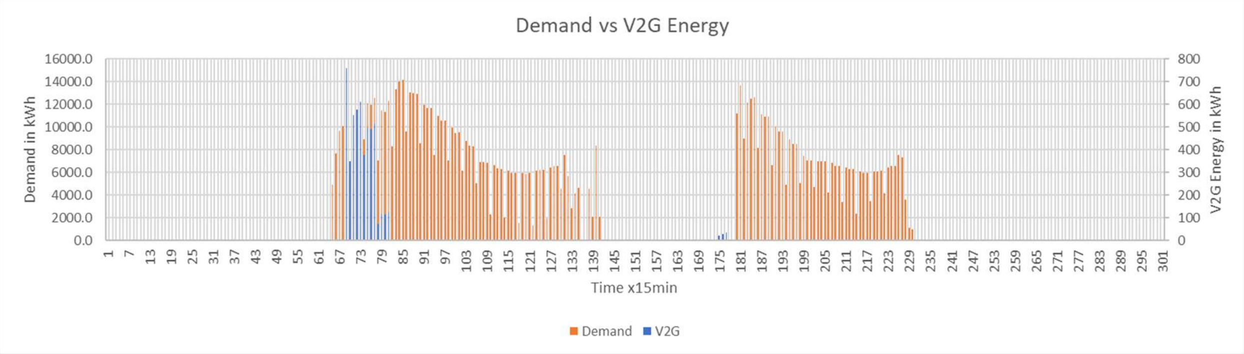


Figure 116 Demand vs V2G

7.2.14.5 V2G

Demand versus V2G for an example period is illustrated in Figure 116. Note that V2G is shown on a separate scale and energy is supplied when there is both demand and sufficient EV battery capacity to satisfy some of that demand.

7.2.15 Comparison of Key Performance Indicators

All scenarios performed equally on the first KPI, i.e., RE ratio, with 100% RE being achieved with a marginal amount of residual demand satisfied using biodiesel. Referencing the data in Table 114 scenario A has the least residual generation demand of 3.6 GWh followed by scenario C at 4.3 GWh and scenario B at 4.9 GWh.

Data for the second KPI, i.e., overall economic impact was also provided in Table 114. Scenario C outperforms all of the other scenarios followed by scenario A and then scenario B.

Data for the last KPI, provided in Figure 107, shows the lowest tariffs were from scenario C followed by scenario A and then scenario B.

Scenario C appears to have the best results based on the selected KPIs. A summary table is provided in Table 115. RE Ratio for baseline is about 1% provided by solar PV.

Table 115 Summary of KPI comparison for scenarios

KPI	Baseline	Scenario A	Scenario B	Scenario C
RE Ratio (Biodiesel GWh)	0	3.6	4.9	4.3
Economic Impact (USD$ mn)	-1253	165.4	-135.5	317.5
Tariff (USD$)	0.462	0.403	0.503	0.387

8 Section 8 Stakeholder Feedback and Preferred Scenario

8.1 Stakeholder selection of preferred scenario

A survey was conducted in which stakeholders were provided with the feedback summary generated from the two (2) rounds of the Delphi survey. A brief description of the inputs derived from the feedback summary used to generate the three (3) scenarios and a summary of outputs from the modelling were also provided. Stakeholders were first required to rate the importance of the Delphi survey questions to them and to use a rating of 2 to identify a question which is considered of 'high importance' and 1 otherwise. Stakeholders were then asked to review the model outputs for each scenario and rank the scenarios based on how well the outputs responded to the stakeholder feedback to the questions. The scenarios were ranked as either 1, 2 or 3 with a score of 3 assigned to the scenario with the best match between the stakeholder feedback and the scenario modelling output. The next best fit between modelling output and scenario is assigned 2 and 1 is assigned to the third rank. A copy of the feedback survey can be found in Appendix A-2 – Feedback Survey.

The survey was sent to twenty-five (25) of the Delphi survey stakeholders (stakeholders who did not participate in the first two (2) survey rounds were excluded) and responses were obtained from eighteen (18) of them, that is a response rate of 72%. To determine the ranking of the scenarios, based on feedback from the stakeholders, each scenario ranking was multiplied by the question rating for each respondent and the results were summed. The results are provided in Table 116. The 'green' cells indicate scores above the average and the 'red' cells indicate scores below the average. The colour shading gets deeper as the value moves away from the average. Most of the highest scores were received for scenario A and most of the lowest scores for scenario C. The highest scoring question was 'sectors for improved EE' (R2_5,8,12) for scenario C with a score of 80 indicating that stakeholders strongly agree that the scenario result matches their expectations for transition of the transport sector to electric mobility. The lowest score went to scenario B, question 'EE target (R2_EE) indicating that the results of a lower EE target would not meet stakeholder expectations.

Table 116 Scoring of scenarios based on stakeholder feedback and question ratings

Question/Scenario	Scenario A	Scenario B	Scenario C
Priorities to improve energy security	73	73	64
Environmental aspects	58	60	62
Government financial support	69	53	58
RE social acceptance	41	43	48
Country benefits	72	56	64
Priority source of RE	65	71	44
RE target	65	58	39
GHG emissions target	48	57	45
EE target	67	38	63
Sectors for improved EE	53	59	80
Resilience objectives	58	73	55
Stakeholder objectives for transition	59	62	47
Public participation	70	55	67

Total	798	758	736

The results of the stakeholder feedback on the outputs indicate that scenario A is the most favoured by the stakeholders with a score of 798. The second ranked scenario is B and the third is C, in the same order of priority of the stakeholder Delphi survey used to generate the scenarios. Scenario A has the highest number of questions with highest scores 7 of which score higher than the average score. Scenarios B and C both have at least five (5) questions scoring higher than the average score.

This is an interesting result and the ranking of the scenarios remains unchanged even when the stakeholder question ratings are all changed to '1' for all questions and stakeholders. This result suggests a robust ranking of the scenarios as shown in Table 117 with scenario A having a total score of 483. This result indicates that though tariff and economics are important to stakeholders, other considerations are important enough to sway their decision away from scenario C to scenario A. Based on the scores in Table 116, these include the 'priorities to improve energy security' modelled by a transition from fossil fuels to RE, 'country benefits' modelled by use of long duration storage and 'public participation' modelled by stakeholder engagement in the transition process. When the question ratings are removed in Table 117, the driving factors are 'RE target' modelled with government set target, 'EE target' modelled with government set target, 'Government financial support' modelled with government supplied equity, commercial debt and part of profits kept in the local economy, 'Country benefits', 'Stakeholder objectives for transition' modelled by cost driven pricing for RE inclusive of the transport sector and 'public participation'. 'Country benefits' and 'Public participation' remain strong drivers in both cases.

In either case, there is very little spread among the scores with a difference of 40 points between scenarios A and B and 62 points between scenarios A and C using the results with question ratings. This indicates that stakeholders do not generally show a strong tendency to select one (1) scenario over another.

Table 117 Scoring of scenarios based on stakeholder feedback and with no question ratings

Question/Scenario	Scenario A	Scenario B	Scenario C
Priorities to improve energy security	37	38	33
Environmental aspects	35	37	36
Government financial support	40	31	37
RE social acceptance	31	36	41
Country benefits	40	32	36
Priority source of RE	39	44	25
RE target	43	37	28
GHG emissions target	33	42	33
EE target	43	28	37
Sectors for improved EE	30	33	45
Resilience objectives	34	42	32
Stakeholder objectives for transition	39	38	31
Public participation	39	31	38
Total	483	469	452

To confirm this, an analysis of the level of agreement of the stakeholders in selecting the most responsive scenario was done using Kendall’s W (coefficient of concordance) which was evaluated for each question. The formula for calculating Kendall’s W is provided in Equation 22 (Franceschini & Maisano, 2021).

Equation 22 Formula for calculation of the coefficient of concordance

$$W^m = \frac{12\left(\sum_{i=1}^{n} R_i^2\right) - 3m^2 n(n+1)^2}{m^2 n(n^2-1) - m\left(\sum_{j=1}^{m} T_j\right)}$$

Where $R_i = \sum_{j=1}^{m} r_{ij}$ is the sum of the rank positions for the i-th object

r_{ij} is the rank position of the object O_i according to the j-th expert

n is the total number of objects

m is the total number of ordinal rankings

$T_J = \sum_{i=1}^{g_j}(t_i^3 - t_i), \forall_j = 1, \dots, m$ where t_j is the number of objects in the i-th group of ties (a group is a set of tied objects)

g_j is the number of groups of ties in the ranking by the j-th expert

There are no ties in the j-th ranking so $T_j = 0$

A coefficient of 1 means complete agreement and a value of 0 means no agreement. Results of the coefficient of concordance analysis for all questions is provided in Table 118.

Table 118 Coefficient of concordance for all questions

Question	W^m
Priorities to improve energy security	0.02
Environmental aspects	0.00
Government financial support	0.06
RE social acceptance	0.08
Country benefits	0.05
Priority source of RE	0.30
RE target	0.18
GHG emissions target	0.08
EE target	0.18
Sectors for improved EE	0.19
Resilience objectives	0.09
Stakeholder objectives for transition	0.06
Public participation	0.06

It should be noted from the table of concordance, on the ranking of the scenarios for each question, that there is almost no agreement among the stakeholders. The highest agreement among all stakeholders for all questions was very low at 0.30 for question the ‘priority source of RE’ to be developed, i.e., R1_2.

Table 119 below provides a comparison between the ranking of the scenarios using the KPIs and the stakeholder feedback.

Table 119 Comparison of scenario rankings

Scenario	KPIs Ranking	Stakeholder Ranking
A	2nd	1st
B	3rd	2nd
C	1st	3rd

The KPIs were not shared with the stakeholders but have been used as a basis for comparison with the stakeholder results. The KPI rankings do not agree with the stakeholder rankings. This highlights the important fact that stakeholder consultation is very important in decision-making on the objectives and expected outcomes of the energy sector transition. The stakeholder feedback and preferred scenario selection would be the basis for any policy changes and plans for transitioning the energy sector.

9 Section 9 Response to Research Question and Policy Framework

9.1 Review of Results versus Research Question

For ease of reference, the research questions are repeated below.

"Can a methodology be developed to design pathways for transitioning to a 100% renewable energy (RE) system in a SIDS country by interconnecting the transport and electricity sectors while providing various benefits through simultaneously meeting multiple stakeholder objectives?"

9.1.1 Research Question 1

What methodology and tools can be used to provide a systematic framework for designing an interconnected electricity and transport system powered by 100% RE?

- What are the economic, environmental, and other sustainability objectives to be satisfied from transitioning to an interconnected transport and electricity energy system powered by RE?
- How will the system operate to control cross sectoral energy flows in order to achieve continuous energy balance?

To address this question, a Delphi survey was conducted for stakeholder inclusion and a purpose-built model was developed using Microsoft Excel to ensure full flexibility to address stakeholder inputs and analyses. The transport sector was integrated into the electricity model by converting projected future fossil fuel consumption into electrical energy demand. Supply of energy to the grid from EV fleet batteries was also incorporated. The demand from EVs was modelled based on known and assumed fleet use habits in the transport sector. V2G was enabled when vehicles were connected to the charging infrastructure, sufficient stored energy was available from the batteries and there was residual system demand.

The economic, environmental and sustainability parameters that could be satisfied by transitioning to 100% RE are provided in Section 7.2. The economic impact trajectories for all scenarios shown in Figure 109 tend to increase over time, that is, growth in energy revenues for both the government and the general public. Any of the stakeholder scenarios will benefit the economy more than the BAU scenario which will continue to have a negative economic impact.

All scenarios will result in the projected CO_2 savings which increase with each 5-year interval as fossil fuel generation is replaced by RE.

In terms of sustainability, all stakeholder scenarios have the same RER target of 100% in year 25 which is achieved in all scenarios. Scenario B is the only one which results in consistently higher energy tariffs than BAU.

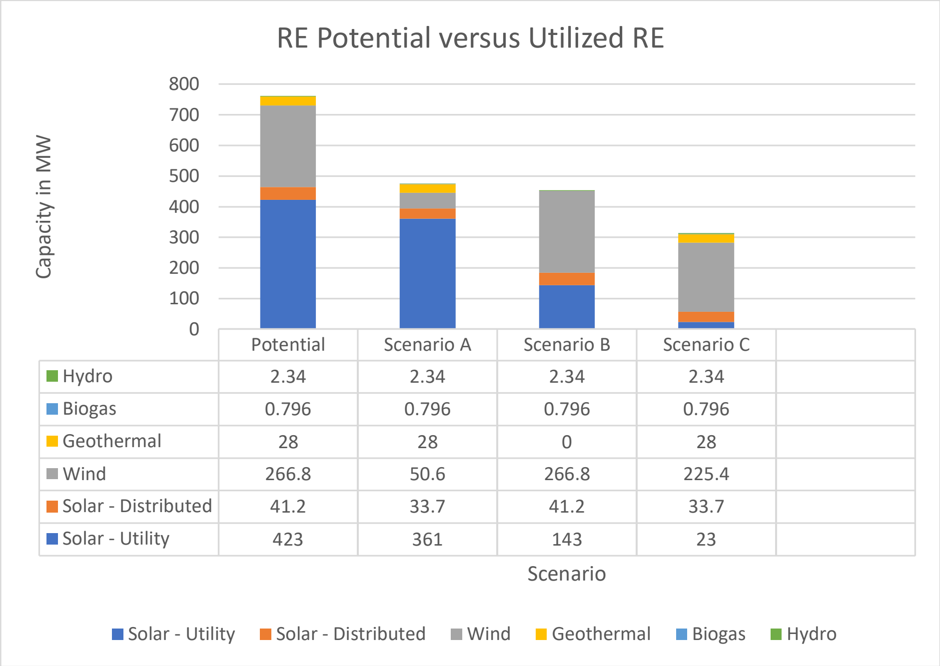
The energy consumption in all sectors was converted to electrical energy demand over a 25-year transition period. Energy flow to and from storage media such as PHS, EV batteries, chemical storage and ice storage was used to achieve continuous supply to demand balance on the system without the need for biodiesel up to year 20 in each scenario. RE was sent into storage and energy moved from storage to satisfy residual demand when sufficient generation was not available. In years 20 and 25, biodiesel is always required to fully balance the system as the additional amount of storage needed to eliminate the flexible generation from biodiesel would not be cost effective.

9.1.2 Research Question 2

What are the 100% RE system configurations that can achieve the energy sector transition objectives?

- What is the time frame during which an energy system transition can be achieved and what are the expected costs and benefits?
- What role can distribute generation play in the energy system transition?
- What are the modalities by which stakeholder objectives are addressed in the proposed transition pathways?

Figure 117 illustrates the estimated RE potential capacity utilised by each of the scenarios compared to the full potential identified.



	Potential	Scenario A	Scenario B	Scenario C
Hydro	2.34	2.34	2.34	2.34
Biogas	0.796	0.796	0.796	0.796
Geothermal	28	28	0	28
Wind	266.8	50.6	266.8	225.4
Solar - Distributed	41.2	33.7	41.2	33.7
Solar - Utility	423	361	143	23

Figure 117 RE utilised capacity versus potential

The energy mix in the three (3) scenarios are only a small sample of the continuum of possibilities for achieving a 100% RE system. The maximum potential of distributed solar PV is higher than estimated in Section 4.5.7 as the potential was estimated based on the current number of domestic customers. By year 25, the number of domestic customers will be larger resulting in a larger total distributed PV potential as provided by the results of the model. Scenario C utilises the lowest amount of RE potential to achieve the 100% RE target, however, it does so by utilising twice the amount of chemical energy storage as compared to scenario A. Though scenario A makes the most use of the available RE potential, it utilises only 63% of the total available capacity. This indicates that there is sufficient terrestrial RE potential to meet the country's energy needs if the land can be made available.

All scenarios must be supplemented with the use of biodiesel or other forms of flexible RE generation that are capable of load following in year 25. Biodiesel has not been discussed as a potential resource, however, if it is to be utilised in years 20 and 25, a supply chain must be established. There exists one (1) small business producing biodiesel from waste oil on the island, however, production volumes are very low and fully consumed by the business. Whether biodiesel, bioethanol or some other form of biofuel is used, a supply chain should be established within the country to ensure energy security.

The largest amount of biodiesel required annually is in scenario B to provide 4.9 GWh annually requiring approximately 1.15 million (1,150,000) litres of fuel assuming a fuel efficiency of 4.28 litres per kWh. Taking crop yield information on palm oil from Indonesia as a reference (*Biofuels: Prospects Risks and Opportunities*, 2008) with production of 4,092 l per ha, a total land space of 281 ha would have to be cultivated to provide the required biodiesel. The amount of arable land in Saint Lucia has shrunk from 5,000 ha in 1978 to 3,000 ha in 2016 (World Bank Group, 2018). There is sufficient arable land in Saint Lucia to provide the required annual volume of biodiesel for all scenarios.

Offshore RE can also be developed to supply the deficit along with additional energy storage. Further possibilities include energy to gas and energy to liquid fuel transition pathways when the technologies become mature.

All transition scenarios have been assumed to occur in a 25-year time frame with investments occurring continuously during that period to meet the interim 5-year interval targets.

Distributed generation is a key requirement for achieving the 100% RE transition scenarios as all scenarios utilise distributed generation. The percentage of distributed generation relative to all other sources of generation in year 25 for all scenarios is provided in Figure 118. The least DG solar is utilised in scenario A at 7.1% of total installed generation capacity. Scenarios B and C utilise 9.1% and 10.8% respectively of DG solar installed capacity relative to all other sources of generation.

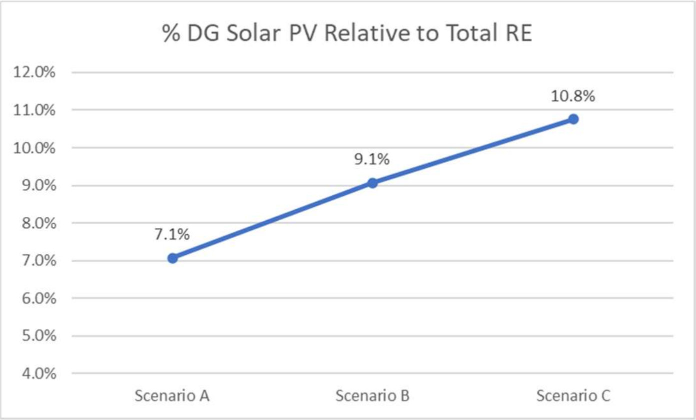


Figure 118 % DG Solar generation capacity in each scenario

Stakeholder objectives have been met by each scenario as presented in Sections 7.2.2, 7.2.6 and 7.2.10. A key point to note is that a portfolio of RE and storage technologies is required to balance demand with supply in every scenario.

9.1.3 Research Question 3

Can interconnection of the transport and electricity sectors result in energy system benefits and synergies?

- What economic and sustainability performance levels can be expected in an interconnected transport and electricity system?

A positive overall economic benefit has been estimated for each stakeholder scenario relative to BAU. If a transition to electrified transport was done in isolation to the rest of the energy sector, the impact on EV tariff to ensure tax revenue parity with BAU fossil fuels is shown in Figure 68 for scenario A. As the transport fleet is transitioned to EVs, fossil fuel tax revenues will gradually decrease. To ensure no overall loss in tax revenues, energy used for charging of EVs will have to be taxed to a tariff of approximately USD$0.30 per kWh in year 25. If all sectors are transitioned in parallel, the overall tax revenues may be transitioned as illustrated in Figure 67 for scenario A.

As the transition is being done in all sectors simultaneously, economies of scale can be expected in investments. Also, the mix of different sources of RE results in the benefit of an overall lower tariff.

9.2 Required Policy Framework

Having decided on the transition pathway to be followed, in this case, scenario A, it will be necessary to ensure that the policies, legal and regulatory frameworks can attract the required investments. As all stakeholders have agreed to the transition pathway, it should be adopted and ratified by the country’s highest decision-making body, which is the Parliament in the case of Saint Lucia. An effective mechanism must also be implemented to procure the required RE and storage capacity. As a minimum, the rules of contracting for supply of energy services must be clear and transparent. A politically neutral organisation should have the mandate of tendering for the required capacity and to repeat the RETraP methodology at regular intervals to ensure alignment of stakeholder objectives with the transition process.

Several options are available for setting the RE tariffs including establishing of feed-in-tariffs (FiTs) determined using a process similar to the analysis done in this study, reverse auctions, net metering, renewable portfolio standards (RPS) and auctions. Armed with information on the tariff levels that would be acceptable to stakeholders, a suitable method can be selected to secure the required generation and storage capacities.

It is important that stakeholders are kept both informed and involved throughout the interval between repeating of the RETraP methodology to capture any changes in objectives. It is also important that the tax transition be monitored closely to ensure tax revenues respond as expected based on the changing taxation policy.

10 Section 10 Risks, Conclusions and Future Work

10.1 Proposed Operational Structure for the Energy System

Sources of DG solar PV to supply transport energy needs should be sized based on the expected charging load. There must be sufficient charge points for the minimum number of EVs to absorb the available solar energy and to provide V2G services. V2G and EV charging must both be centrally controlled by the utility so as to maintain demand-supply balance on the system. All storage sources should also be centrally controlled, either by the utility or as virtual power plants, by third parties so that the utility can provide the signals for charging or discharging to maintain system energy balance.

The system should respond to sources of VRE firstly by consuming the available energy with existing demand and then moving the excess energy into storage, as described in the various storage algorithms. It is unlikely that DSM will play a critical part in the future energy system due to limited options for shifting demand, however, future stakeholders may see this as a priority for reducing system peaks and for taking advantage of time of use tariffs, should these be implemented to encourage desired demand behaviours. As biogas is the most expensive form of generation, the future system should operate to utilise this source from gas storage reserves to keep the costs as low as possible.

The model balances supply and demand in each 15-minute interval. Apart from DSM, the model does not forecast demand to dispatch supply to match it. It merely uses the available supply at each time step and applies it against demand. When the supplies are exhausted, storage options are used. In real world operations, it will be necessary to forecast the supply of VRE at least twenty-four (24) hours ahead to ensure sufficient storage and demand are always available on the system. With this operational methodology, it is anticipated that minimum requirements for smart grid infrastructure, e.g., bidirectional energy flow, real time supply controls and storage sources, communication with and V2G EVs on and off grid, will be required.

There will also be effects on the T&D system that cannot be evaluated with the energy model. Thus, a load flow model of the proposed system changes should be undertaken to evaluate factors such as line loadings, short circuit currents, operation of protection systems, et cetera. An evaluation has been performed of the maximum power expected to flow through transformers at each substation for scenario A with results provided in Figure 119. The maximum transformer power flow requirements are compared to the current installed capacity at each substation at 0.9 power factor. In all cases, except Soufriere, the substations have sufficient transformer capacity for the growth in load expected over the 25-year transition period.

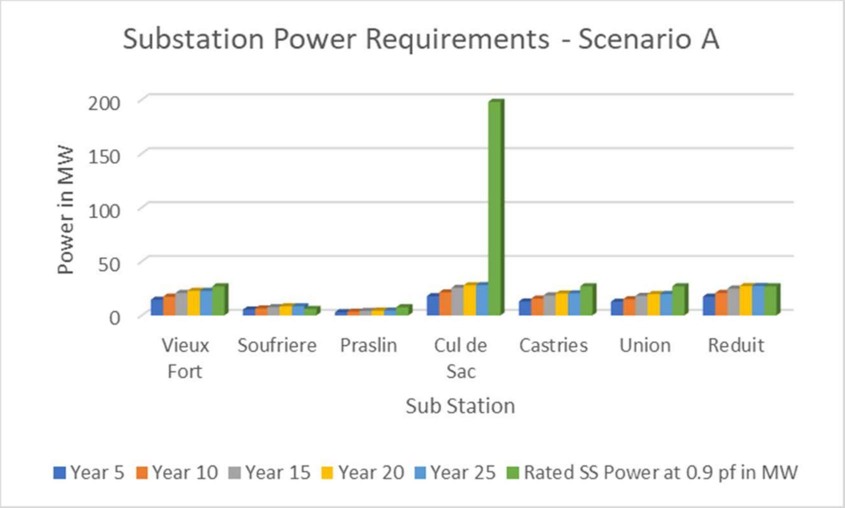


Figure 119 Substation maximum power flow requirements for scenario A

10.2 Risk Assessment and Mitigation

There are some identifiable risks to making a decision for conversion of the country's entire energy system to sustainable sources. Some of these have been identified in Table 120 with some potential mitigations.

Table 120 List of Risks and Mitigation Measures

Risk	Mitigation
Lack of political will	Political will can be influenced by civil society and public advocacy groups. As stakeholders, such organized groups must be integrally involved in the RE transition process.
Unattractive investment environment	The legal and regulatory system must be reformed to facilitate investments in the energy sector. Resources must be dedicated to identifying and resolving any barriers in this area. The ease of doing business must be improved and the contracting process must be transparent and supported by a reliable legal system.
Availability of indigenous fossil fuel reserves	Some countries classified as SIDS have found large fossil fuel reserves and have decided to exploit those resources, despite having large RE potential. This is a political and economic decision which can be influenced by stakeholders but which ultimately is determined by the expected economic benefits. Organised civil society groups should take a lead role in garnering public support for investments in sustainable sources of energy.
Land use conflicts for installation of solar and wind	The preceding analysis identified large areas of land that can be committed to solar PV and wind farms. In the island situation, priority for land use tends to be for hotel or residential development. In the case of wind energy, offshore development can be an alternative put forward by future stakeholders. In the case of solar PV, options for shared uses of solar PV land should be considered, e.g., farming of certain crops on solar farm land. This can open the availability of agricultural land for use as solar farms. As options for integrating solar PV

	into the built environment are developed, these should be included in future transition scenarios.
Lack of stakeholder support for a transition	To lead the transition process, strong champions for change will be needed. These leaders, whether civil society or government agencies, must engage with, lobby and maintain the support of key stakeholders to ensure a sustained commitment to the transition process. As the transition is suggested to take place in 5-year increments, this gives sufficient time to provide proof that the planned solutions work and provide the expected economic and sustainability benefits.
Decision made to invest in more fossil fuel generation in the short-term	In some SIDS, the decision is being made to invest in fossil fuel generation as a so-called ‘bridge’ strategy until more investments in RE are made. This continues the BAU unsustainable patterns and locks the country into another 25-year fossil fuel investment. Such decisions tend to be made at critical junctures when existing plant and equipment are no longer economical to run. As an alternative, a solid plan of investment can be prepared through involvement of key stakeholders and by using the RETraP methodology. An investment plan can be generated to be immediately implemented even before existing fossil fuel generation plant and equipment becomes obsolete or uneconomical to run.
Decision made not to invest in PHS	PHS is a key form of storage for the transition scenarios. It also serves a second function as a source of freshwater storage. If a decision is made not to invest in this form of storage, then alternatives will have to be selected. Alternatives are currently more expensive, however, as their prices decrease, they should be considered through future iterations of the RETraP process. Additionally, other sustainable forms of load following generation should be considered as they become more mature and viable.
No supply chain for biodiesel set up	Biodiesel has been suggested as an option for balancing the energy system in years 20 to 25 for all stakeholder scenarios. As no supply chain currently exists in Saint Lucia or the Caribbean Region for biodiesel, other options can be considered for providing system balancing services. One (1) option is the use of biomass energy crops such as King grass, which is currently being considered for trials in Barbados. Other energy crops for biofuels or biogas can also be evaluated. These should be considered as they become options in future iterations of the RETraP process. Offshore RE combined with power to gas or power to liquid fuels can also be considered.
Oil prices trend downwards	As long as RER remains the primary reason for making a transition to sustainable energy, a downward trend in the price of fossil fuels should have minimal impact on the will to continue transitioning. In addition, the economic impact is likely to continue being more favourable with RE as compared to fossil fuels. The transition scenario will be adjusted in future iterations of the RETraP process if the primary objectives of the stakeholders evolve.
Solar PV systems are destroyed by catastrophic (Category 5) hurricanes	As a result of the Caribbean Region’s experience with Category 5 hurricanes in 2017 and 2019, PV system suppliers are now designing their systems to withstand higher sustained wind speed and wind gust conditions. It is expected that systems will become more resilient to climate change impacts as design changes are implemented and tested in practice.

Reliability of wind and solar energy forecasts	Short-term sub-hourly weather forecasting is not currently done; however, meteorological stations are available around the island and in neighboring islands to make short-term forecasting possible. This will require some additional investment but is necessary for both wind and solar PV investments to facilitate dispatching.

10.3 Comparison with Similar Published Works

(Taibi & Fernandez, 2017) found that the lowest cost of energy production occurs when V2G services are provided and charging takes place during the day resulting in the integration of larger shares of VRE into the grid. The authors also found that storage investments can be avoided if daytime charging is used for EVs. Uncontrolled charging was found to increase energy not served and, therefore, the need for storage. These results are consistent with the findings of this research work which has gone a step further to evaluate the impact of V2G as a source of energy storage for the case of Saint Lucia.

(Matthew, 2017) used a systems dynamics approach to investigate the impact of policies on RE and EV integration into a small isolated energy grid system. The work suggested that the learning by doing opportunity of small islands may not be significant, thereby supporting the use of mature technologies in island energy systems. The author investigated the potential impact of policies based on socio-economic factors and endogenous pressures in moving towards sustainable electricity generation on an island system. The systems approach utilised looked at the causes, effects and feedback loops within the island system to get an understanding of how policies can influence change to sustainable energy over time. The author also investigated how the selected policies can result in a stabilization of the generation capacity mix. The work focused on a system in which energy pricing is externally set and does not represent the situation in a SIDS country, however, it is a method that also guides policy decision-making within the island energy system. Like this research work, the author factors in a lag time for investments to take place. The author also shows that there are limitations to the policy goals that can be achieved within a defined timeframe. The author suggests that a carefully paced approach to achieving RE targets should be set and the results of system dynamics modelling can show limitations due to investment costs and capacity of the energy system to absorb changes quickly. An understanding of these limitations helps policymakers set achievable targets. An understanding of this in the Saint Lucia context can improve the quality of the information put forward for policy decision-making based on this research and provide insights to an effective time interval for repeating the RETraP process.

10.4 Conclusions and Recommendations

Scenario A incorporates all the highest priority requirements of the stakeholders and it was also selected as the scenario that best responded to the stakeholder requirements. It was selected by the stakeholders as the best scenario for transitioning the energy system in Saint Lucia.

There is a continuum of scenarios that can meet the stakeholder objectives and these scenarios will change depending on the requirements of the stakeholders involved in the RETraP process. It is very important to define the stakeholders to ensure that the key ones are consulted and contribute to setting the transition objectives.

The RETraP methodology makes it possible to alter the transition trajectory to suit changing stakeholder requirements through a regular iterative process. In addition, the methodology makes it possible to find solutions to multi-criteria stakeholder objectives.

The RETraP methodology can, therefore, be used as an input to creating an Integrated and Resilient Resource Plan (IRRP) as it involves stakeholder inputs into steering the energy transition scenario and it also includes growth from all sectors, particularly transport. Additionally, the RETraP strengthens the IRRP process by allowing a holistic view of the entire energy system to understand interactions and define areas where the utility may want to consider new business models, e.g., with distributed generation for transport. It also expands the IRRP process by considering the conversion of all forms of energy in all sectors to electrical energy. The RETraP methodology focuses on transitioning to 100% RE in all sectors over a defined and finite time period, which in this research, was set to twenty-five (25) years.

Individual tariffs, for some sources of generation and storage, are much higher than the average for the scenarios evaluated, however, when included in the energy mix, the average tariff can be acceptable to the stakeholders. This indicates the overall tariff and outputs from a scenario should be used for decision-making and not the tariffs from individual investments in generation and storage.

The RETraP methodology has been developed and demonstrated to be effective in creating 100% RE transition scenarios that meet the defined multi-criteria stakeholder objectives. The methodology allows transition pathways to be adapted as stakeholder requirements change through an iterative process. It also allows the interconnection of all energy sectors to achieve a 100% RE system.

10.5 Key Contributions

The key contributions of this research work to the body of knowledge in the field of transitioning island energy systems to 100% RE systems are summarised below:

1. An evaluation was made of a suitable EV charging connection profile to be used in the SIDS island of Saint Lucia with the result of a solar follow charging connection profile being selected. This was the best evaluated connection profile suited to minimising additional system storage and residual demand to be satisfied by biodiesel in years 20 and 25 of the transition.
2. A heterogenous group of stakeholders provided responses to a Delphi survey that contributed to the development of the transition scenarios. This process revealed the thinking of stakeholders in Saint Lucia concerning their requirements for a 100% RE state. It also resulted in an innovative use of the Delphi survey to guide inputs and outputs for the various scenarios generated through direct integration of survey results into the energy model.
3. An evaluation was made of the potential of DSM, ice storage and V2G for increasing penetration of RE in a SIDS case. The results obtained were limited by the algorithms used and provide insights into one (1) possible way of combining these resources for each scenario.
4. The research resulted in the elaboration of a flexible methodology for building transition scenarios that integrates all energy consumption sectors and fulfils multi-criteria stakeholder objectives. The methodology was applied to the island state of Saint Lucia, but it can be applied to any SIDS.
5. An evaluation was made of the economic impact from transitioning to sustainable energy including impacts on revenues from the existing fossil fuel taxation system compared to revenues

from taxation of RE sources. It was shown in all scenarios that a transition to a 100% RE system results in economic benefits superior to the BAU situation.

6. It was shown that it is possible to leverage investments in RE and supporting infrastructure to provide a positive economic impact in the case of Saint Lucia, that is, the economic benefit to the country is greater than 0. In the BAU case, the economic impact is negative. For scenario A, the economic impact is about 47% of the total investment over the transition period. The ratio is 80% for scenario C.

10.6 Future Work

Some of the areas identified for further work are summarised below:

1. Further research should be done to identify and evaluate the suggested and other potential PHS sites in the country. Feasibility studies should be done on the most promising sites;
2. Further research is needed to determine how much EV battery capacity can be secured for V2G and what is the best incentive to get customers to provide the battery capacity. Other smart strategies for deploying V2G should also be explored;
3. An analysis of charging infrastructure needs should be undertaken to ensure an optimal distribution of charging stations so that sufficient connections are always possible to facilitate demand-supply balance for smooth operation of the grid via V2G services;
4. An evaluation of time of use and place of use tariffs (for DG consumption of the transport fleet) should be undertaken to determine how effective these tariffs may be at modifying behaviour of EV owners;
5. It would be useful to test the policy direction suggested by this research using a systems dynamics approach to get a better understanding of how effective the policies may be during implementation and how the entire system would change, inclusive of behaviour of stakeholders, over the suggested transition timeframe;
6. The requirements for information communication systems and smart grid infrastructure to manage the demand and supply energy flows to and from the various sources of supply and demand should be investigated;
7. Additional work will be required to determine what level of capacity margin should be kept on the system to maintain system reliability parameters. It will also be necessary to perform a power flow analysis of the system for the suggested transition scenario to determine the upgrades that will be required and when; and
8. The impact of mature offshore and marine RE technologies should be evaluated to reduce the land use requirement for RE in future iterations of the scenarios.

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https://doi.org/10.1016/j.rser.2016.10.036

Section 12 Appendix

Appendix A – Delphi Survey Questionnaire

Registration Information

Name: [ ]

Age: [ ]

Gender: [Male]/[Female]/[Prefer not to say]

Occupation: [ ]

Level of Education [A 'Levels]/[Bachelor's]/[Master's]

Background

Most small island developing states (SIDS) in the world have set targets for reducing energy generation from fossil fuels (particularly diesel and heavy fuel oils) and reducing greenhouse gas (GHG, includes carbon dioxide, methane, et cetera) emissions with the intention of achieving a future state in which energy consumption does not result in GHG emissions.

The research project associated with this survey will develop a methodology to be used as a tool for small island developing states to plan and evaluate the impacts of transitioning from fossil fuel-based energy to RE and energy efficiency, together referred to as sustainable energy. The research will investigate the interactions of all sectors that utilise energy in the country. The primary sectors in Saint Lucia related to energy include electricity generation, transportation, domestic, commercial, hotel and industrial. To this end, this survey will gather stakeholder information to inform the development of scenarios for defining transition pathways. A stakeholder refers to anyone who uses energy for whatever purpose and is therefore affected by the environmental, social, economic impacts of energy generation, transmission, distribution and consumption.

A review of the literature indicates that though some island countries are making progress in transitioning their energy systems to sustainable sources of energy to achieve a future with little or no GHG emissions, there is no established methodology to guide SIDS in this process. Most of the islands that have achieved 100% or close to 100% RE in their electricity supply are connected to a mainland grid via a sub-sea cable for energy export and import. No small island developing state has transitioned both their electricity and transport sectors to 100% RE.

The survey seeks to identify the major factors that will strongly influence the adoption of sustainable energy, in all sectors that use energy in Saint Lucia. There is a mix of technical and social questions. The researcher encourages respondents to be as liberal as possible in providing reasonable responses to the questions.

Research Purpose

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To develop a methodology for investigating how a rapid transition to sustainable energy of the energy sector on the island of Saint Lucia can be achieved within a stakeholder agreed timeframe and to meet stakeholder requirements.

The research will investigate what technical, policy and implementation steps should be taken to transition the energy system to 100% sustainable energy in all economic sectors including ground-based transportation and how such a transition will impact the economy.

Purpose of the Delphi Survey

The Delphi survey method seeks to reach consensus from respondents to the responses for the questions asked. The survey will investigate what are the most important factors influencing adoption of sustainable energy and the prioritization of these factors to build scenarios for research purposes.

The results from this research will be analysed and will contribute to a Doctor of Economics (Dr. rer. pol) thesis with the Europa-Universität Flensburg in Germany. The thesis title is:

Methodology for design of 100% renewable energy transition pathways to meet Small Island Developing States (SIDS) transport and electricity objectives.

Ethical and Communication Requirements

As the island of Saint Lucia is small, it is possible that survey respondents will become aware of each other. Should this occur, it is a requirement of participation that respondents do not communicate or collude with each other in answering the questions at any point during the survey.

Respondents will be required to fill the basic registration information at the beginning of this document and return via email to complete the registration process. Both survey rounds will be administered via email. Respondents will be alerted by telephone or text message when the questionnaire is emailed. Please respond to the email with the **completed registration information**. In the first round, respondents will be required to respond using **voice notes (VN) on WhatsApp or by email to kenaldonza@gmail.com**. A separate VN is to be submitted for each question. Each VN should begin with a statement of the respondent’s name and the question number. The number for responding by VN is **1-758-384-4111**.

Required Time

Both survey rounds will be completed in about 2-3 weeks. Respondents are strongly encouraged to do further research if necessary to fully understand the issues before responding. There are 13 questions. The first round will take between 20-60min depending on familiarity with the subject matter. The second round is a prioritisation of responses received in the first round and will take between 10-30 minutes.

This research is for academic purposes. The respondent is requested to be as open minded as possible and to use public sources of information for further background to guide their responses. The identity of respondents will be kept confidential.

Feedback

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The survey responses will be used to build scenarios that generate pathways to achieving the stakeholder objectives identified in the survey. In a final engagement, the scenario results will be shared with all respondents and your feedback requested to determine how well the presented scenario results respond to your objectives identified through the survey. This last step will take place a few months after the second round.

Clarification of terms used:

Energy Intensity - a measure of the amount of energy needed to produce one unit of output.

Energy Sector – refers to all areas of the economy that consume energy in all forms such as electrical, liquid and gaseous fuels, solar, biomass, etc.

Energy Security – this refers to having local control over energy supplies and the ability to have enough energy whenever needed from various sources at an acceptable cost.

Instrument – an economic tool used to encourage a targeted behaviour by the population.

Legislative/Regulatory – refers to an issue defined by law.

Mechanism – refers to a process, procedure and/or system for performing an activity.

Policy – refers to a statement of political will.

Resilience - 'the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions through adaptable and holistic planning and technical solutions'. (E. Hotchkiss, "Bonus Module : Using Solar for Resilience," in *City and County Solar PV Training Program*, 2016.)

Sustainable Energy – renewable energy and energy efficiency.

Questions

R1_7: What should be the national priorities for improving energy security in the energy sector (electricity, transport, cooking, etc)?

Response:

R1_8,11: What environmental aspects should be considered when making decisions on investments in the energy sector?

Response:

R1_3,10,13: Should government continue to provide financial support for investments in the energy sector or should all energy investments be financially viable on their own?

Response:

R1_9: Are there any sources of renewable energy that may not be socially acceptable? Please list.

Response:

R1_4,6: What benefits to the country would you like to see from sustainable energy investments?

Response:

R1_2: What sources of energy for electricity generation should receive priority for development in the electricity sector? Why?

Response:

R2_RE: The St. Lucia Government (GOSL) has set a target of 35% by 2025 and 50% by 2030 for generation of electricity from renewable sources. Are you in agreement with this vision? If not, suggest an alternative.

Response:

R2_GH: The St. Lucia Government (GOSL) has set a target of 7% reduction in GHG emissions in the energy sector relative to 2010, by 2030. Are you in agreement with this vision? If not, suggest an alternative.

Response:

R2_EE: The St. Lucia Government (GOSL) has set a target of 20% reduction in energy consumption in the public sector. Are you in agreement with this vision? If not, suggest an alternative.

Response:

R2_5,8,12: What economic sectors should receive priority support for improving efficiency of energy consumption i.e. achieving the same output with less energy?

Response:

R3_11,14: What should be the objectives of developing a resilient energy system in St. Lucia?

Response:

R4_6,14: What are your objectives for transitioning the energy sector to sustainable energy (renewable energy and energy efficiency)?

Response:

R4_1,10: How should the general public participate in a transition to sustainable energy?

Response:

Appendix A-1 – Delphi Survey Round 2

Registration Information

Name: [ ]

Second Round

The second round is a prioritisation of responses received in the first round and will take between 10-30 minutes. I have grouped related responses as much as possible into numbered bins.

You are required to enter the bin number of your highest priority response in the empty cell below the title 1st Priority. Your second priority response number should be entered in the empty cell below the title 2nd Priority. Likewise, please do the same for 3rd and 4th priority responses.

As an example, if a question had 5 responses, and my first priority response is no 4, second priority is no 1, third priority is no 3 and fourth priority is no 5, the completed table will look like this:

1st Priority	2nd Priority	3rd Priority	4th Priority
4	1	3	5

If you wish to add an additional response which is not available, you are free to do so as a new numbered bin (or item).

Feedback

The survey responses will be used to build scenarios that generate pathways to achieving the stakeholder objectives identified in the survey. In a final engagement, the scenario results will be shared with all respondents and your feedback requested to determine how well the presented scenario results respond to your objectives identified through the survey. This last step will take place a few months after the second round.

Clarification of terms used:

Energy Intensity - a measure of the amount of energy needed to produce one unit of output.

Energy Sector – refers to all areas of the economy that consume energy in all forms such as electrical, liquid and gaseous fuels, solar, biomass, et cetera.

Energy Security – this refers to having local control over energy supplies and the ability to have enough energy whenever needed from various sources at an acceptable cost.

Instrument – an economic tool used to encourage a targeted behaviour by the population.

Legislative/Regulatory – refers to an issue defined by law.

Mechanism – refers to a process, procedure and/or system for performing an activity.

Policy – refers to a statement of political will.

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Resilience - ‘the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions through adaptable and holistic planning and technical solutions’. (E. Hotchkiss, “Bonus Module : Using Solar for Resilience,” in *City and County Solar PV Training Program*, 2016.)

Sustainable Energy – renewable energy and energy efficiency.

Questions

R1_7: What should be the national priorities for improving energy security in the energy sector (electricity, transport, cooking, et cetera)?

1st Priority	2nd Priority	3rd Priority	4th Priority

1) We need to start with **the legislation**, currently we have restrictions on the size of the solar units one can place on their business and homes, this needs to change. **Energy governance** (who assumes control of the entire operations/system: government or private entity?) Enabling legislation, fiscal incentives for investments, **energy policy and implementation plan** that is responsive to energy landscape. Incentivise transition to renewable energy. Development of supportive **regulatory frameworks**.
2) We need to **invest more in non-oil sources of energy generation,** e.g., wind, solar, hydro, geo-thermal. There needs to be diversity driven by a national policy. Increased generation of electricity must continue with **renewables** and the market for generation and sale should not be a monopoly held by LUCELEC. Use of alternative energy sources: solar, wind and wave energy. Renewable clean energy. Other national priorities would be diversification (not relying on one source, but exploring geothermal, solar, wind, hydro, biomass energy in areas where these sources are plentiful on the island), and decentralization of energy systems. In other words, in the context of St Lucia can we adopt a hybrid energy system? Increased access to renewable energy. **Electricity** is a widely used form of energy in Saint Lucia and access and cost of electricity has a major impact on quality of life, productivity and growth. As such electricity for service delivery and economic activity should be prioritised. Expansion of **renewable forms of energy** for electricity generation – focus on solar, wind and geothermal. Develop a more diverse energy mix by investing significantly in the development of renewable energies in particular geothermal, wind, solar and biogas. This would reduce the dependence and intake on fossil fuels and energy imports. Once sustainable electricity is provided it can be used for both Cooking and Transportation. Electricity (household green energy). Using renewable energy **for heating and drying applications**.
3) **Access to financing**, for homes, small-medium size businesses, this will allow persons to be able to implement renewable energy projects which can improve efficiency and reduce our carbon footprint at the same time. Addressing the issue of high costs and **lack of suitable financing** for RE technologies.
4) The public sector in particular can swiftly adopt the sole use **of electric or hybrid transportation**. Electrifying the transportation sector using electricity generated from renewable energy resources.
5) Being able to purchase **fuel** at **a cost** which is **affordable**. Keep energy cost low. I would consider fundamental are energy availability and affordability given the meagre resources we have to rely on. **Lower cost** of electricity. For **economic gain and sustainability**.
6) Access by **vulnerable** groups; very easily **accessible**. Areas that threaten human development particularly among the most vulnerable such as, cooking must be prioritised.
7) Restructuring of transportation network to introduce **mass transit passenger vehicles** between hubs (e.g., Castries / Gros Islet), while reassigning shorter routes to smaller passenger vehicles.

Given that many members of the public are reliant on **public transportation** this sector should not be excluded. Energy for transport is also important and increasingly the transportation sector is becoming a growing sector hence it is also a priority. **Alternative modes of transport** – including reliable forms of mass transport. The national priorities should be the Electricity and the Transport Sectors as they have the greatest impact.

8) Reduce energy demand by implementing **energy efficiency programmes** and policies in the energy sector, e.g., retrofitting of homes, building code reform, importation of **fuel efficient** and electric vehicles and equipment. Buildings, hospitality.
9) Reduce **carbon footprint**.
10) Improving **information and awareness** of RE technologies among the general populace.
11) Development of **technical capacity** for working with new sources of energy including renewables.

R1_8,11: What environmental aspects should be considered when making decisions on investments in the energy sector?

1st Priority	2nd Priority	3rd Priority	4th Priority

1) There must be very little or no impact to **surface or ground water** supplies and **quality of air**. Therefore, these two must be at the forefront of any decision to alter the sector. Impact on **water quality** and consumption where water is used for cooling as in the case for geothermal energy. Impact on air quality, water resources, MEA compliance. Climate Change, Emissions, Pollution in whatever form air, water, land, noise. No negative impact on environment. I firmly believe that the environment as a whole must be considered. That being said energy production must consider **land, air and water pollution** and their adverse effects. Increasingly, it can be noted that issues such as greenhouse emissions, climate change (change in weather and climate patterns), contaminated water and ground; and also reduced air quality.
2) **Carbon emissions** from particular investment. **GHG emissions level** is low but has shown a slight increase over the 2010 baseline. Therefore, selective investments should be significant enough to reduce level. GHG emissions, pollutants, other impacts on flora and fauna. **Energy emission costs** and applicable legislation in that regard. Impact on the environment in terms of **CO2** or productive use e.g., agriculture, tourism et cetera. **Reduced carbon footprint**. Contributions to carbon sequestration. Availability of the renewable resource. Energy generation that produces no or little **greenhouse gases.**
3) **Geographic constraints** for equipment set up- landscaping and logistical impacts. Population density, **space occupation** for energy system and impact on community (social and economic impact, for example, whether **agricultural land** will be taken away, would public access to certain areas be restricted once the energy systems are installed?) The impact on existing and future land uses including potential conflicts, opportunities for co-existence and making optimal **use of land resources**. Monitoring of environmental impacts is also important, particularly impact on health. The amount of land required and opportunity cost. Compatibility of energy equipment with **wildlife, building codes** for the community, et cetera. The **impact on ecosystems** such as mangroves and rivers should be factored in. **Impact on wildlife and habitat**. **Land** disturbance

how would it affect farmers, land owners. Health impact on animal life, impact on the natural environment. **Noise impact**. Impact on the immediate ecosystem. Legislative constraints that may impede use of certain areas, such as **protected sites** (those that should not be tampered with based on historical or cultural value yet have immense potential for the type of "green" energy to be extracted. Impact of investment on land and marine ecosystems. Would energy equipment and **infrastructure affect other existing structures**, such as communications infrastructure? Would these need to be modified to integrate in the drive towards the "green energy transformation?" Whether the manufacturing plant location will be viable in the long run – will the location be more conducive to other developmental innovations? The **waste from the process** (there is still some) how will it affect the environment? The level of consumption and the rate at which it can be renewed – does it harm the environment?

4) The opinions and point of view of local residents on energy infrastructure and renewable energy equipment which must be set up in their area (and perhaps alter **the landscape or aesthetics** of the environment, for example, acceptance of residents of photovoltaic systems on homes/buildings which may not appear stunning on roof tops). Aesthetics, limiting the populace enjoyment of the environment either their access or visual appreciation. **Visual impacts**.

R1_3,10,13: Should government continue to provide financial support for investments in the energy sector or should all energy investments be financially viable on their own?

1st Priority	2nd Priority	3rd Priority	4th Priority

3) With the current rises in fuel, transportation, other raw materials, I believe that the government **should continue** to provide support. The absence of that may mean that persons who fall in the low-income bracket may not be able to afford electricity. Energy investment has always enjoyed government subsidies particularly when starting operations. I therefore believe that as we push to energy diversity particularly in renewable financial **support from government must continue**. It is known that some of these technologies are constantly changing through research and development and this makes the initial investment pricey. Tax **incentives** among other support measures are surely needed for budding energy companies. I believe government **should provide assistance** to investments within the energy sector. Additionally, because of the high start-up costs, limited resources and the importance of moving towards a greener energy space globally I believe that government has as an **obligation to provide support** (both technical and financial) to viable investments within the sector. It can also be noted that the overall benefits of such projects to small island states can be invaluable and help us to significantly reduce our energy and import (fossil fuel) bill. Government must definitely continue to **provide financial support** as majority of persons with the ideas do not have the financial means in SIDS. Financial institutions are not always willing to invest in such ventures especially when the outcome is not certain. Government needs **to keep providing financial support** at least until they are financially viable on their own. Direct involvement by government is paramount. It fosters a united approach in the green energy transformation. **Government subsidisation** may reduce the cost of energy to consumers. The cost effectiveness can encourage companies to switch quicker. Also, government funding can help accelerate the development of renewable energy technologies. Governmental involvement

encourages the development of policies to promote and support renewable energy. With this comes perks, such as tax exemptions, rebates and other fiscal incentives that companies may want to take advantage of. The legal and economic regime created by the gov't can either enable or impede the development of renewable technologies, and attract or repel potential investors. Government financial support for research and development would encourage efficient renewable energy generation. We have observed that the privatization of utility systems in St Lucia has brought on more financial stability, management discipline and economic gains to the electricity, water and tele-communications businesses. However, the shift to absolute privatization of renewable energy generation may hinder the development of new renewable energy generation projects and affect the possible expansion capacity of energy generation to favour short-term projects driven by revenue flow. Privatization supports the idea of profit-driven businesses. There is a tendency of private sector entities to focus on short-term markets for maximum cash flow. The concern is that, short-term markets for wholesale electricity may hamper development of new renewable energy generation projects which will demand exorbitant capital costs. **Gov't may have to support financially** to encourage the development of renewable energy projects that deliver long-term benefits. Within the context of Saint Lucia and other SIDS, **governments should continue** to provide some financial support even if it is indirect support as these have proven to be a major catalyst for increased energy investments. For the short-term this support may be necessary to meet the national energy goals. There may be a need for financial support or incentives especially if cost is a barrier, to counter externalities not considered with the current situation unless a carbon tax is imposed on the use of fossil fuels. In the short-term Government should continue to provide some financial support especially in the startup stages however the aim should be enabling financial viability. Government should be facilitatory and can provide some tax incentives. Many investments are financially viable on their own without financial support from the government. The government can however **provide financial support to** attain specific policy objectives where the cost and benefits of the support can be quantified and the benefits outweigh the costs.

4) The energy company needs to diversify in other sources of energy that can be cheaper for consumers, good for the environment and **profitable enough to be viable** on their own. **No direct financing** from Govt. Ultimately the aim should be to have a financially viable energy sector especially as there is the thrust towards low-carbon economy. However, government should **create the enabling environment** towards this together with relevant players. Critically though, the role of government should be to create the necessary enabling environment to facilitate investments and innovation by the private sector. Government ought to create an enabling environment for investments including policy and legislative frameworks. Additionally, governments ought to incentivise investors and incrementally transition to private sector. In so doing the energy sector will become **financially sustainable**. Energy investments should be viable on their own.
5) There should be **a mixed approach**. In the case of fledgling local enterprises that may lack the financial wherewithal but have sustainable plans partnerships should take place. Incentives for renewable energy developments too can spurn the interests of private investors regionally and internationally. Government support is needed to ensure a proper functioning society as the energy sector can face market failures for which regulations are necessary. Support from the government is needed, however, it should be equitable available. Support should be provided in

startup, with a specific set target to be attained by the business. At which point the government investment / support should stop. The business should then become viable, sustainable and ongoing without aid and or assistance. Government should **create the fiscal space** for private investors. Through concessions. These concessions will allow all energy investments to be financially **viable on their own**.

R1_9: Are there any sources of renewable energy that may not be socially acceptable? Please list.

1st Priority	2nd Priority	3rd Priority	4th Priority

1) While **solar energy** is one of the renewable sources that we can take the most advantage of in Saint Lucia, due to the fact that these projects would require **vast masses of land**. I can see this becoming an issue for our forest and famers.
2) **Hydroelectricity**. This would require a dam at a strong river. The island has its limits in term of **arable land** and this would surely impact on hundreds of acres of land. The island has a large farming sector with many operating within the floodplains of rivers. There would be significant displacement of farm and destruction of land.
3) A source of energy which may not be socially acceptable is that of **geothermal energy** for fear of eruptions. In St Lucia Geothermal Energy might be the only source of renewable energy which will not be socially acceptable as the drive-in volcano, which is a tourist attraction, will have to be repurposed to harness the energy. I do not think that locals are in favour of interfering with the Sulphur Springs to generate electricity. I have sat in many town hall discussions on this. The majority of people in Soufriere who were invited to these forums spoke passionately against interfering with the volcano. They believe this will have more catastrophic consequences than the geothermal energy exploitation mission sought after. Geothermal in Belplaine Soufriere is not viewed favourably by the residents of the potential drilling area. Perhaps geothermal because of the association with earthquakes. There may be some misgivings about geothermal energy because of the perception that it can trigger volcanic activity.
4) To my knowledge there are **none** which have garnered any social discontent. No issues with any of the renewable sources being contemplated.
5) **Biogas** from human waste. **Biomass** (organic matter used as a fuel).
6) **Ocean technologies** though still not fully commercial will need some planning to make efficient use of the marine space. **Tidal power**.
7) **Wind power:** Most likely would be installed in rural and/or agricultural areas hence could threaten the livelihood of farmers and potentially reduce property value. There also may be some public health concerns in regard to the sound of the blades/turbine. Community dialogue may be necessary to establish trust and by-in. In some cases, consideration for **wind** turbine placement is necessary. Wind may have a significant environmental impact in a small island state.
8) **Nuclear sources.**

R1_4,6**:** What benefits to the country would you like to see from sustainable energy investments?

1st Priority	2nd Priority	3rd Priority	4th Priority

1) Reduced tariffs, reduced rates. **Reduction in energy cost** to consumers. Ultimately a lower cost of living and greater stability w.r.t. cost of input materials or sources (e.g., fossil fuels vs solar). Reduce energy cost to consumers. Reducing the cost of energy, productive use of sustainable energy investments in manufacturing and other sectors which directly impact the country. **Reduced energy tariffs** to allow improved economic growth. Reduction in oil-based energy production, savings from the **reduction of importation of fuel**. Reduction in energy costs, reduction in fuel importation bill. Stable and possible lower energy prices, environmental integrity and **local ownership**. Cost containment. **Reduced currency outflows**. Energy Security and financial protection from the volatility of fuel pricing. Being **energy independent**. Reduced reliance on foreign sources of energy. Less reliant on imported fuel / energy hence better able to mitigate the associated risks in regards to shortages and price. Sustainable futures, improve efficiencies, reduced production costs. Improved quality of life. Reduced volatility of electricity prices in response to oil price shocks.
2) Introduction and **increase in sustainable energy jobs**. Opportunities for young entrepreneurs and local innovators. Creation **of 'green' jobs** in manufacturing, installation et cetera. **Employment** opportunities. Increased local employment and **job opportunities** with job creation. Increase in technical skills related to renewable energy technologies.
3) **Improved air quality** in the urbans areas. Energy which is environmentally friendly. My hope is that sustainable energy investments lead to **a cleaner environment**, more affordable energy in the long-term, and greater linkages so that **waste can be converted into energy**. Repurpose use of waste. Better healthcare and health of population. **Reduce carbon footprint** in SIDS. Less greenhouse gases. Smaller carbon footprint, improved air and water quality. Dependence on and expansion of renewable energy generation can change the trajectory on climate change. Sustainable energy investments will help shift to a **low-carbon economy**, any benefits in terms of savings on fuel cost should be considered for re-investment in the social sectors for better living quality for the less fortunate. Reduction in carbon emissions. Attainment **of NDC targets.**
4) More **efficient power supply**, with very few outages or fluctuations. Greater resilience in post hurricane recovery through **more distributed generation. Modernization of** outdated **infrastructure** to support Smart initiatives. Encouragement and support for innovation and development in **new technologies** in general. Better consumer choices / options. Attraction of **grant funding**.
5) **Energy security**, economic growth, enhanced **reliability and resiliency** particularly from natural disasters. Increased resilience of the energy system to external shocks.

R1_2: What sources of energy for electricity generation should receive priority for development in the electricity sector? Why?

1st Priority	2nd Priority	3rd Priority	4th Priority

1) **Solar and wind.** The natural abundance of supply on island. The fact that they complement each other with solar peak production during the day and wind sustaining generation throughout the night. I believe they are easier to install and maintain. Also, I believe they are environmentally friendly, most persons have some knowledge of the two and it may be more socially acceptable in the short-term; because the technology involved are well established. Solar and Wind because of the potential that exists for these forms and also because they are becoming competitive with conventional generation particularly with falling battery prices that can help address the issue of intermittency and stability. These sources should receive priority for development because (i) of the island's favourable resource potential, (ii) they are proven technologies that can be procured at reasonable cost (and costs are rapidly declining), and (iii) they were identified in the most recent National Energy Transition Strategy.
2) **Geothermal** should be considered because it is dispatchable. If feasible may be able to cover base load without having a negative impact on rates, et cetera.
3) For SIDS we are big on **Solar, Wind, and Tidal power**. We are small Islands surrounded by massive waves so we can focus on Tidal Power. We have sunlight almost 12 hours a day so perfect for harnessing solar power. Being close to the sea we have abundance of wind. So, focus should definitely be in those 3 areas.
4) **Solar -** We are in the tropical zone. There is an abundance of sun all year round, and in every part of the island. We have evidence from solar water heaters, solar powered businesses and homes that this can be yoked and is efficacious. Solar because of its simplicity, (ease of conversion, mature technology), Opportunity for quick rollout. I believe solar energy should be prioritised given that some inroads have already been made by electricity company LUCELEC, and entities such as Solar Dynamics with solar hot water systems. Expansion might be easier for this source given our prevailing climatic conditions as well. Low hanging fruit, assessment show potential for generating significant power and land space is available especially for crown lands. Country has rich solar resources which should be further exploited in respect of DG and utility scale projects. The prices have dropped over the years (not taking into account the recent supply chain struggles) and battery storage technologies are improving with more anticipated price drops. Solar as the technology has evolved over the years and perhaps grants can be received to expand this industry. Relatively light environmental Impact. Easy installation and relatively cheap maintenance. Can be installed on rooftops minimising land use. Ideal for small island states and small economies. In Saint Lucia, some work has been done in the development of solar energy for electricity generation and hence it would be easy to build on what's there already as compared to other sources like geothermal. Solar due to abundance and consistency of supply. The solar energy is readily available, though, creating a form of saving the energy for dispensation over lengthened periods, will have to be investigated.
5) **Wind** due to its availability and consistency.
6) **Wind, geothermal, solar**. These are tried and proven technologies which should be lower risk investments. Geothermal may have the greatest sustainability potential provided a viable source can be tapped.
7) **Solar energy** is the most likely option for St Lucia, with the possibility of exploring **geothermal** from the sulphur springs.

R2_RE: The Government of Saint Lucia (GOSL) has set a target of 35% by 2025 and 50% by 2030 for generation of electricity from renewable sources. Are you in agreement with this vision? If not, suggest an alternative.

1st Priority	2nd Priority	3rd Priority	4th Priority

1) Yes, I am **in agreement**, we have already seen strides with implementation of LUCELEC's 3MW the solar farm in La Tourney Vieux Fort. In agreement, but should be noted that at the time targets were set, the landscape seemed more poised towards achieving through wind and solar. Much work is required through geothermal given the stage at which development process is at, so 2030 target may need adjustment or steady and significant investment in solar is needed together with supporting legislation especially on existing maximum cap allowed. Generally, "yes", although higher benchmarks would always be better. I agree with this vision, but it is highly unattainable, (due to) current world events, COVID, war in Ukraine. Additionally, the platform (regulations guidelines, concessions) for achieving this has not been established. The transformation (In a SIDS Context) will be private sector lead, this has not been fully established. I am in agreement once there is a plan that can show how it will be achieved and if it can lead to a lower cost of electricity. The vision is ambitious based on the fact the little progress has been made over the years. In order to achieve these targets, which are modest, in comparison to some other SIDS, the planned legislative reforms, et cetera, must be quickly put in place to attract investments in RE. The vision is ok but not enough has been done to facilitate its actual attainment. We have noticed the various solar energy plants initiated by the energy supplier in St Lucia. A more widespread use of this method, due to our high level of solar energy can assist in attaining this goal; however, the paused initiatives need to be resumed. This is a very ambitious target without the supporting legal and regulatory framework in place. I **am in support** of this vision. More effort should be spent on developing and implementing strategy to achieve ambitious yet realistic targets.
2) (**Lower**). I **do not** believe we have the political will to execute and realize this goal. I believe that the vision can manifest to an extent. I would **therefore suggest** 20% by 2025 and 40% by 2030. I find this timeline impossible to meet. We are presently experiencing the worst economic downturn and financial recession in the history of world economies catalysed by the Covid-19 pandemic. It may take us years to ricochet from this blow. Government will need to expedite their plans with the commensurate financial resources to enable progress in order to achieve this target. In the absence of these, it is surely a tall mandate. I would extend 35% to 2035 and 50% to 2040. The timelines are way too short and targets are too ambitious considering where we're currently at. The timelines should be over a thirty-year time frame. I think the targets may serve as motivation but given the current pace of development they do not seem achievable. I don't think these goals will be achieved given the political landscape in St Lucia. There needs to be an apolitical approach with a commitment by all political organisations jointly to prioritize these goals. Considering it's already 2022, these targets are unrealistic. Given our current status a more realistic target would be 35% by 2030 and 50% by 2035. I was unaware of this; perhaps better methods of communicating these aspects and its benefits to the country should be explored. I would want to know whether this is achievable by 2025, if not a more realistic goal should be put in place, say 25%.

3) (**Higher**). 2030 should be **revised to** 80%. I think by the year 2030 we should be close to 100%. Our energy usage is very small compared to developed countries so it is very easy to implement renewable sources of energy.

R2_GH: The Government of Saint Lucia (GOSL) has set a target of 7% reduction in GHG emissions in the energy sector relative to 2010, by 2030. Are you in agreement with this vision? If not, suggest an alternative.

1st Priority	2nd Priority	3rd Priority	4th Priority

1) **No -** (**Lower**) historically we have not been able to achieve a 5% reduction, there has been not consistent decline, I would suggest a target of at least 3%. I agree with this vision, but in the current environment I believe 3.5% is more practical why? Opportunities for high impacts visible reductions are limited, hotels and the small manufacturing sector should be purposely targeted.
2) **Yes** - I believe that we can reduce our emissions by 7% considering that our emissions are already significantly low. This seems attainable if we adopt an aggressive approach to fulfilling the mandate of renewable energy cultivation. We can accomplish a lot in 8 years with adequate funding and intellectual power. Yes, attainable especially with thrust to increase **EV use.** 7% reduction is a bit low but is a fair target as majority of GHG are from vehicles in SIDS. It means that majority of **vehicles** will have to **shift to electric** for GHG to be reduced significantly. Generally, “yes”, although higher benchmarks would always be better. Yes, but once the necessary adjustments to facilitate greater RE penetration are done. If the target was developed in a scientific way , then yes. LUCELEC’s 3 MW of solar farm reduced the consumption of diesel by 2-3%. With energy efficiency and more solar this be achieved quite easily. If Geothermal is found to be feasible, then this will be exceeded significantly. I’m in agreement with the target but more effort is required. It’s a good vision to have, however we are in 2022 and steps have not initialised – this may need revision.
3) **No – (Higher);** it should be close to 50%. Such a target seems very mediocre. Perhaps reduction should match that of renewable energy targets and at the very least 25%.

R2_EE: The Government of Saint Lucia (GOSL) has set a target of 20% reduction in energy consumption in the public sector. Are you in agreement with this vision? If not, suggest an alternative.

1st Priority	2nd Priority	3rd Priority	4th Priority

1) **NO (Lower)** - I do not see that happening. The GOSL continues to rent property in various districts/constituencies around the island in other to achieve that target they would have to build their own facilities that will be built with the mind set of achieving that target. The target was set with no clear strategy for achieving it. It is past 2020 and while a few EE interventions have taken place there is need for more investments.

2) **Agree** - Should more consideration be given to the use of resources within the public sector I am sure we can reduce consumption by 20% or even more. 20% reduction is fair. Generally, "yes", although higher benchmarks would always be better. I am, but it depends on the time frame. I would like to know how this vision would be achieved. Yes, can be achieved through further retrofitting (and M&E) and good practices. There is a lot that the Government can do to meet this target in the public sector. It is very achievable. This is a reasonable target. One of the areas where significant strides can be made is in the design of public buildings to reduce use of CFCs. I think that this is a good target but the investments in equipment, measures and people are necessary. **Yes.** This is achievable by retrofitting GOSL offices, e.g., replacement of aged AC systems with newer technology. This target is achievable. I am in agreement. This can be achieved quite easily by retrofitting lighting with LEDs and utilizing more efficient AC systems and by the use of an energy management system. I agree. If this can be achieved the practices will be emulated in private (at home) even if it's only due to its potential to increase disposable income. Yes, I am in agreement with vision (however I believe this may be elusive).
3) **No (Higher),** it can be closer to 50%. Should aim higher.

R2_5,8,12: What economic sectors should receive priority support for improving efficiency of energy consumption, i.e., achieving the same output with less energy?

1st Priority	2nd Priority	3rd Priority	4th Priority

1) **Tourism** because collectively, it's the largest single commercial utiliser, impact of cost of energy receives greater attention hence there is a basis for collective strategies to be formulated. Tourism related services. Hotel sector.
2) The **manufacturing** sector, though there are not many, should receive priority. Private business (manufacturers), **Commercial, Industrial, Construction**
3) **Agriculture, fisheries and** food.
4) The **public transportation** sector and the government fleet of vehicles. These all-use fossil fuels the foremost source of pollution and GHG. **Transportation sector**, Public transport – minibuses can be mandated to be replaced with hybrids or vehicles with an agreed fuel economy. Suggested lower import duties and road tax on these. The **transportation** and commercial sectors should receive support. Especially bus, taxi and government transportation.
5) **Water distribution** (including banning the importation and sale of filtered water).
6) **Electricity**
7) **Residential** sector, **domestic** / households – (due to the time spent at home).
8) **Government Services** public offices (gov't departments), Port services, Healthcare Services.

R3_11,14**:** What should be the objectives of developing a resilient energy system in Saint Lucia?

1st Priority	2nd Priority	3rd Priority	4th Priority

1) **Cost reduction**, cheaper energy. Reduce the financial cost of energy for businesses; Reduced cost of living (after the initial setup is factored). Opportunities to supply better services for the people since a major expense for the country is the importation of fuels. More stable cost of energy.
2) Maintaining a **balance** between supply and demand at all times. Reduce energy demand and improve demand response capabilities of energy infrastructure. Improve **flexibility** of the energy system.
3) Making **renewable energy** the primary source. 0% dependency on fossil fuels and 100% use of "safe and easily maintained" renewable energy. **Independent** energy. Abundance and diversification of renewable energy generation, self-sufficiency, reduced dependence on foreign sources of energy; secure energy sources. Reduce reliance on imported fuel to guard against external shocks to the economy. **Diversify energy sources** and reduce dependency on energy imports. A chance to focus on our food industry as we provide our own energy to sustain our agricultural sector – again leading less foreign debt (reduced food importation) which leads to an improved chance of new innovations.
4) **Improve the reliability** of the system to **climate change** and the yearly occurrences of adverse weather systems. Reliability and low environmental impact. Deliver reliable energy services, which is little affected by weather conditions (after a storm, heavy rains, lightning strikes). Limiting the impact of exogenous shocks in that sector, resilience to natural or manmade disasters. To limit the impact on the infrastructure from various events such as weather and cyber-attacks as well as having the means of restoring systems as quickly as possible. Micro grids will help in this regard, particularly if there is extensive damage to transmission and distribution networks. Establish an energy system that addresses the challenges and impact of climate change as well as Natural hazards, e.g., Hurricanes. Ensuring **energy security**, efficiency and reliability. Decrease vulnerability of the energy system. Developing a system that can speedily recover from shocks. **Reducing vulnerability** to natural hazards. Decreasing the length of disruption in services following natural hazards. Decreasing time of restoration of services to critical infrastructure and services.
5) **Sustainable**, affordable and **environmentally friendly** energy systems should be our objectives. Cleaner energy. Enactment of policies to ensure that energy infrastructure is maintained and developed to continue to support energy system resilience. Our aims should be to operate in the most environmentally (friendly) ways, to reduce waste and emissions and to bring in more affordable energy sources. Overcome key risks and vulnerabilities (climate and otherwise) of the island's energy systems by enhancing resilience of entire energy value chain (infrastructure and processes). Reduced carbon emissions, healthier country. Less reliance on foreign assistance – leads to reduced debts.
6) A resilient energy system depends not merely on fiscal support, but also public education that is sustained **and partnerships** that create a resilient energy movement. Involvement of all players especially power company, regulators and private sector as significant investment will be required and regulations and policy will determine extent of benefits. Improved quality of life. To support resilience in its broadest sense across all sectors as energy resilience is key to overall resilience. **Stakeholder engagement** that ensures by-in, data sharing and implementation of action plans. Education from preschool to enable a cultural change within our population (survival of

renewable energy). **Possibility of earning income** as these systems and their implementation can lead to the sale of innovative ideas to other countries.

R4_6,14: What are your objectives for transitioning the energy sector to sustainable energy (renewable energy and energy efficiency)?

1st Priority	2nd Priority	3rd Priority	4th Priority

1) Ability to produce and therefore **determine cost of energy**. **Reduce price volatility**. Price containment in terms of the tariff. Introduce dividend programmes, incentives and subsidies for renewable energy use, and carbon taxes**, loss of subsidies** for less desirable forms of energy. **Cheaper energy**. Reduced energy cost and associated economic benefits to be derived. Economic benefits at the personal level. More useable income in the wallet. **Energy security**, limiting the impact on climate change as well as **lowering cost** to increase the country's competitiveness and standard of living. Reduce Energy costs. To benefit from the lower cost of energy generation from renewable energy. Achieve savings in fuel cost, redeployment of savings to other sectors, economic resilience building.
2) **Creation of new jobs** and technologies.
3) **Reliability** and low environmental impact. Achieving energy security, affordability while maintaining very reliable services.
4) Alignment of **energy-efficient strategies** with broad renewable energy goals. This should be transparent in energy planning and industrial development strategies. Encouraging my workplace and business to think and go green. Purchasing **energy-efficient** appliances, lights. Use of solar water heaters. Greater economic efficiency. Investment in innovation in energy sources and efficiency. My objectives are to invest in items that are energy efficient (transportation) and my own awareness of how I consume energy and the ways in which I utilise to amend harmful personal practices. Sustainable development benefits at the national level. Ensure that as far as is practical the most efficient and sustainable processes are embraced and implemented. Efficient manufacturing.
5) Upgrade existing or **modernize the grids** so that they can supply **from variable output sources**, such as solar and geothermal. Start **harvesting renewable energy** on a small scale, such as install the technology on buildings and homes using existing distribution networks if possible and applying appropriate controls to voltage, et cetera. Gradually expand to a larger scale. **Installing solar** panels on current and future homes. Improve sustainability of the energy sector. Independent energy. **Self-generation Renewable** energy (solar). To reduce dependence on imported fossil fuels. Revise building codes/laws to ensure use of renewable energy on new structures. Adopting a levelled-playing field for **renewable energy options** and efficiency.
6) **Reduce greenhouse gas** emissions by 50% and improve air pollution. As time goes by our quality of life is hindered by our use of fossil fuels for energy; more children are born annually with allergies and sensitivities with developmental issues. With a polluted environment, development and growth are stunted. With renewable energy and its efficient use, we will have **less pollutants** transmitted in the air we breathe, absorbed by the foods we eat, and carried in the water we

drink. To reduce carbon dioxide emissions and attain Saint Lucia’s NDC targets. **Environmentally friendly,** cleaner energy. Cleaner environment. Environmental protection and emissions reductions. Institute a cap on carbon emission.

7) **Electrify inland transportation**

R4_1,10: How should the general public participate in a transition to sustainable energy?

1st Priority	2nd Priority	3rd Priority	4th Priority

1) Think Green and getting into the habit of building houses that run **on solar**. Allowing them to **generate their own energy**. Persons who can afford should move to solar energy to run their homes and small businesses. Promoting **self-generation** and alternatives to fossil energy use. Provide opportunities for **green business based on sustainable energy**. Provide opportunities for accessing sustainable energy products. The ability to convert waste, for example, wastewater for use in other purposes and reviewing their energy consumption patterns.

2) Purchasing **energy-efficient** appliances. Implement RE, energy conservation and **energy efficiency** measures that are affordable and cost effective, et cetera. This should be done through investments in **energy-efficient vehicles like electric cars** and buses. Adopting best practices and measures in the **conservation of energy** at their homes and businesses.

3) The public should benefit and participate by gainful **employment** where possible in these new sources of energy as they are introduced.

4) There can also be opportunity for **shareholding** in these industries and companies. I believe the general public will participate in advocating and **making investments** for personal transition. Keep an open mind and stay updated with trends in and **availability of technology** for sustainable energy, so that informed decisions can be made every step of the way. **Ownership through investments.** By the greater use of energy-efficient technologies and as **prosumers**. Once motivated, citizens can participate by **investing in renewable energy generation** and ownership for their residences and businesses. By **providing land resources** required for utility scale investments.

5) **Greater awareness** for buy-in to shift to use **of RE as users** and practitioners, accessibility to incentives. Town hall meetings, call in programmes, radio and television talk shows, Target schools and hold **discussions** with students. Target workplaces, particularly those in the industrial/manufacturing sector which are significant contributors to carbon emission. Actively engage in **consultative processes** to shape policy. **Advocacy** with a view to motivating the late adopters and laggards, Testimonials. Provide opportunities and information for feedback on national energy plans and activities. For any country the success of transitioning to sustainable energy is dependent **on acceptance and participation** of the General Public. The public must be engaged and be made aware of the benefits associated with sustainable energy so that they can participate. Governments should promote initiatives, policies, programmes and projects to foster public participation in the transition. Taking part in the development of transition policies especially in regards to impact on the environment and the communities. By embracing cultural adaptations which contribute to sustainable development of the society. The general public should be actively involved **via education**, and household solar panels at little or no cost. The students just beginning school can be sensitised from early to begin thinking and doing small tasks which lead efficient uses of sustainable energy. Be open to undertaken **open dialogue** with all parties (LUCELEC and Government) involved in the energy transition.

6) Participation should be incentivised by via a system similar to the LEED **standards** used in the US. Currently there is little incentive besides moral suasion. Within our culture most practises begin

with an initiative from the government. With a drive from a focused group on the matter (then Senator Jimmy fletcher begun a few for climate change) specific or targeted groups can begin **community based small projects** which link to a nationwide goal.

Appendix A-2 – Feedback Survey

Delphi Survey – Feedback Round

Registration Information

Name:

Feedback Round Instructions

In the second round of the Delphi survey, you prioritized the responses provided by all respondents to the questions. A summary of the overall prioritized responses can be found at Appendix A. Table 121 provides a summary of:

1. The survey questions;
2. A brief 'feedback summary' of the first three prioritized responses. The first priority response to each question was used to build scenario A (2nd column), the second priority response scenario B (3rd column) and the third priority response, scenario C (4th column);
3. A brief description of the 'model inputs' representing the respondent responses;
4. A brief 'explanation' of how the model input is applied in the modeling tool;
5. A brief summary of the 'model outputs' generated from the modelled scenario in response to the input;
6. A description of the ratings to be applied to the importance of the question to the respondent and a description of the rankings to be applied. Only one ranking may be applied per scenario and the rankings may not be repeated for the same question;
7. An empty row in which the rating is entered in the first column, the ranking for scenario A in the second column, the ranking for scenario B in the third column and the ranking for scenario C in the fourth column. This is repeated for each question.

Each question receives an importance rating of either 1 or 2. Each scenario receives a ranking of 1, 2 or 3. Every scenario must be ranked. Please do not repeat rankings in the same question e.g., both scenarios A and B ranked no.2. Ties in ratings must be avoided.

Three scenarios were generated in 5-year intervals up to 25 years. All scenarios achieved 100% RE generation in year 20, though at different transition rates over the 20 years. A summary comparison of all scenarios is provided in Table 126 for more information.

Your input is required only in Table 121. Please enter responses (only numerical digits) in the 'blue' rows.

Feedback Table

Table 121 Summary of Delphi survey feedback, model inputs and outputs and empty rows for ratings and rankings

Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R1_7	What should be the national priorities for improving energy security in the energy sector (electricity, transport, cooking, et cetera)?		
Feedback summary	Legislation and improved regulatory framework	Increased generation from renewable energy options available to Saint Lucia	High costs, improving efficiency and reducing carbon footprint
Model Inputs	Mandated transition of all fossil fuel consumption to RE	All RE sources used except geothermal	EV infrastructure pricing. Mandated transition of all fossil fuel consumption to RE. Conversion of transport fleet to EVs
Explanation	% of projected fossil fuel demand in domestic, industrial, hotel and commercial sectors converted to electricity demand over 25 years	Solar PV, wind, biogas and hydro	Reduction in VAT on investments in EVs. Projected fossil fuel demand in domestic, industrial, hotel and commercial sectors converted to electricity demand. % of transport fleet to be converted from fossil fuel to electric vehicles
Model Outputs	100% fossil fuel consumption in all sectors converted to electrical energy demand. Peak load grew by 82%.	See Table 122; Figure 120, Figure 121, Figure 122	Total investment in EV infrastructure over 25 years is USD$4.6bn compared to USD$5.0bn in scenarios A and B.
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R1_8,11	What environmental aspects should be considered when making decisions on investments in the energy sector?		
Feedback summary	Pollution to land, air and water supplies should be minimised	Reduction of greenhouse gas emissions.	Minimise land use conflicts and negative impacts.
Model Inputs	Ban on internal combustion engine transport imports	All RE sources used except geothermal	Maximise utility wind usage.
Explanation	% of transport fleet to be converted from fossil fuel to electric vehicles	Solar PV, wind, biogas and hydro	Add the maximum amount of wind energy to achieve RE targets

Model Outputs	100% of transport fleet converted to EVs by year 25	See Figure 123, Figure 124, Figure 125	Land requirement for wind farms approximately 383,000 m^2 compared to 2,400,000 m^2 for solar in scenario A (including roof tops and car parks)
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R1_3,10,13	Should government continue to provide financial support for investments in the energy sector or should all energy investments be financially viable on their own?		
Feedback summary	Mixed financing approach	Government provides financial support	Energy investments must be viable on their own
Model Inputs	Blended financing	Government financed	Commercial financed
Explanation	70% debt at 8% for 10 years and 30% equity return of 5%	70% debt at 4.5% for 15 years and 30% equity return of 5%	70% debt at 8% for 10 years and 30% equity return of 13%
Model Outputs	See Box 1	See Box 2	See Box 3
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R1_9	Are there any sources of renewable energy that may not be socially acceptable?		
Feedback summary	Exclusion of nuclear energy	Exclude geothermal energy	No renewable energy sources should be excluded
Model Inputs	All RE sources used	No geothermal	All RE sources used
Explanation	Wind, solar PV, geothermal, biogas, hydro	Wind, solar PV, biogas, hydro	Wind, solar PV, geothermal, biogas, hydro
Model Outputs	See Table 122	See Table 122	See Table 122
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R1_4,6	What benefits to the country would you like to see from sustainable energy investments?		

Feedback summary	Improved energy security, reliability and resiliency	Reduction in energy tariffs and fossil fuel-based energy production	More distributed generation to enable a system which is more resilient
Model Inputs	Long duration storage	Cost driven energy price	Long duration storage
Explanation	Use of pumped hydro and chemical storage	Energy pricing is based on investment and operations costs of renewable energy plants	Use of pumped hydro and chemical storage
Model Outputs	See Table 123	See Figure 126 and Figure 127	*See* Table 125
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R1_2	What sources of energy for electricity generation should receive priority for development in the electricity sector? Why?		
Feedback summary	Solar PV as a source of renewable energy to be given priority	Use of solar PV and wind energy	Use of wind energy
Model Inputs	Maximise utility PV	Maximise wind and distributed PV	Maximise utility wind
Explanation	Maximise utility solar PV use	Up to maximum wind potential plus distributed and utility solar PV (increase solar PV to 2.5 kWp per domestic customer)	Up to maximum wind potential
Model Outputs	85% of total estimated utility solar PV capacity used, i.e., 360.9 MWp.	41.2 MWp of distributed solar PV and maximum estimated wind capacity of 266.8 MW used in year 25.	84% of total estimated wind capacity, i.e., 225.4 MW used in year 25.
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R2_RE	The Government of Saint Lucia (GOSL) has set a target of 35% by 2025 and 50% by 2030 for generation of electricity from renewable sources. Are you in agreement with this vision? If not, suggest an alternative.		

Feedback summary	Agree with the existing government target	Target for renewable energy penetration should be lower	Targets should be higher
Model Inputs	Government targets agreed	Lower targets	Higher targets
Explanation	Government targets of 35%/2025; 50%/2030 with addition of 75%/2035; 100%/2040)	Stakeholder targets of 20%/2025; 35%/2030 with addition of 50%/2035; 100%/2040)	Stakeholder targets of 35%/2025; 80%/2030 with addition of 95%/2035; 100%/2040)
Model Outputs	Targets achievable with energy and storage mix at – Table 123 and Figure 127	Targets achievable with energy and storage mix at - Table 124 and Figure 127	*Targets achievable with energy and storage mix at -* Table 125 and Figure 127
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R2_GH	The Government of Saint Lucia (GOSL) has set a target of 7% reduction in GHG emissions in the energy sector relative to 2010, by 2030. Are you in agreement with this vision? If not, suggest an alternative.		
Feedback summary	The target should be lower	The target is adequate	The target should be higher
Model Inputs	Output discussion	Output discussion	Output discussion
Explanation	GHG reductions due to RE calculated and discussed as an output.	GHG reductions due to RE calculated and discussed as an output.	GHG reductions due to RE calculated and discussed as an output.
Model Outputs	See Figure 123	See Figure 124	See Figure 125
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R2_EE	The Government of Saint Lucia (GOSL) has set a target of 20% reduction in energy consumption in the public sector. Are you in agreement with this vision? If not, suggest an alternative.		
Feedback summary	Target is acceptable	Target should be lower	Target should be higher
Model Inputs	Government target	Lower than target	Higher than target
Explanation	20% EE target for domestic, hotel, industrial and commercial sectors	10% EE target for domestic, hotel, industrial and commercial sectors	23% EE target for domestic, hotel and industrial sectors; 20% EE target for commercial sector

Model Outputs	Average EE reduction in year 25 is 16%.	Average EE reduction in year 25 is 7%.	Average EE reduction in year 25 is 17%.
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R2_5,8,12	What economic sectors should receive priority support for improving efficiency of energy consumption, i.e., achieving the same output with less energy?		
Feedback summary	The hotel sector should receive priority support	The commercial sector should receive priority support	The transport sector should receive priority support
Model Inputs	Ice storage pricing for cooling in hotel sector	Ice storage pricing for cooling in commercial sector	EV pricing
Explanation	Reduction in VAT on investments by 10%	Reduction in VAT on investments by 10%	Reduction in VAT on investments by 10%; Distributed generation solar PV pricing for charging of EVs
Model Outputs	Total investment in ice storage cooling was USD$9.4mn. 4.3 GWh was stored and 3.2 GWh was discharged in year 25.	Total investment in ice storage cooling was USD$8.6mn. 5.8 GWh was stored and 3.0 GWh was discharged in year 25.	Total investment in EV infrastructure was USD$4.6bn. Distributed generation solar PV direct energy consumption average tariff was USD$0.11 per kWh between year 20 to 25.
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R3_11,14	What should be the objectives of developing a resilient energy system in Saint Lucia?		
Feedback summary	A more reliable energy system which is resilient to climate change	Cleaner, sustainable and more affordable sources of energy with reduced carbon emissions	Lower cost and more affordable energy
Model Inputs	Long duration storage	Maximise wind and distributed PV	Cost driven energy price
Explanation	Use of pumped hydro and chemical storage	Up to maximum wind potential plus distributed and utility solar PV	Energy pricing is based on investment and operations costs of renewable energy plants

Model Outputs	75 MW|1.88 GWh of pumped hydro storage; 63.7 MW|17.9 GWh of battery storage in year 25 – see Table 123	Maximum wind potential of 266.8 MW used; 143 MWp utility solar PV; 41.2 MWp distributed solar PV – see Table 124	See tariff trajectory for scenario C at Figure 126
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R4_6,14	What are your objectives for transitioning the energy sector to sustainable energy (renewable energy and energy efficiency)?		
Feedback summary	More control of and to reduce the cost of energy	More reliable energy system with higher energy security	Reduction in greenhouse gas emissions
Model Inputs	Cost driven energy price	Long duration storage	Output discussion
Explanation	Energy pricing is based on investment and operations costs of renewable energy plants	Use of pumped hydro and chemical storage	GHG reductions due to RE calculated and discussed as an output.
Model Outputs	See tariff trajectory for scenario A at Figure 126	97 MW|1.88 GWh of pumped hydro storage in years 20 to 25; 104.7 MW|77.4 GWh of battery storage in year 25 – see Table 124	See Figure 125
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest
Question	1st Priority/Scenario A	2nd Priority/Scenario B	3rd Priority/Scenario C
R4_1,10	How should the general public participate in a transition to sustainable energy?		
Feedback summary	Public consultation, education and awareness building	Higher energy efficiency	Emphasis on distributed forms of energy generation
Model Inputs	Stakeholder engagement	Mandated transition of fossil fuel consumption to RE	Use of distributed solar PV
Explanation	Discussion of inputs/outputs	% of projected fossil fuel demand in domestic, industrial, hotel and commercial sectors converted to electricity demand/% of transport	Domestic distributed solar generation

		fleet to be converted from fossil fuel to electric vehicles	
Model Outputs	Outputs provided here for stakeholder feedback.	Average EE reduction in year 25 is 7%. 100% of transport fleet converted to EVs and supplied by RE.	33.7 MWp of distributed solar PV in year 25
Importance: 1- normal or 2- high	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest	*Ranking*: 1 – lowest; or 2 – medium; or 3 - highest

Following are tables and figures providing data in response to the scenario questions.

Table 122 Installed capacities by source in year 25 for each scenario

	Scenario A	Scenario B	Scenario C
Maximum Energy or Capacity by Source	Year 25	Year 25	Year 25
Solar – Utility (MWp)	361	143	23
Solar - Distributed (MWp)	34	41	34
Wind (MW)	51	267	225
Biogas (MW)	1	1	1
Geothermal (MW)	28	-	28
Hydro (MW)	2	2	2
Diesel (MW)	-	-	-
DSM (MW)	5	5	5
DSM Energy (MWh)	1	1	1
V2G - LDV (MW)	4	9	-
LDV V2G Energy (kWh)	929	2,122	-
Ice Storage - Commercial (MW)	2	2	2
Ice Storage - Commercial (kWh)	363	363	363
Ice Storage - Hotel (MW)	1	1	1

Ice Storage - Hotel (kWh)	300	300	300
Chemical Storage (MW)	64	105	82
Chemical Storage (MWh)	17,904	77,421	40,898
PHS (MW)	75	97	79
PHS (MWh)	1,885	1,885	1,885
Peak Residual Demand Diesel (MW)	75	74	76

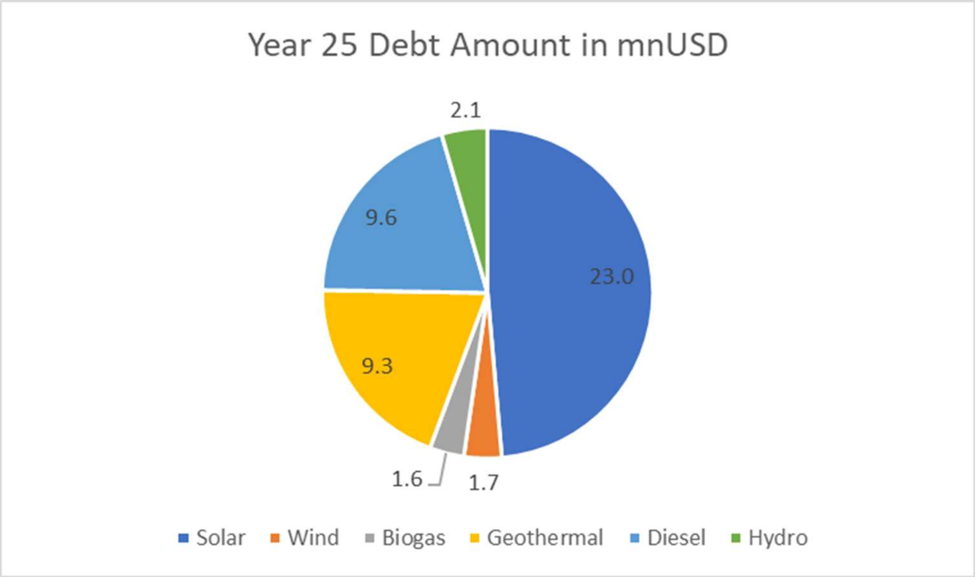


Figure 120 Year 25 debt for scenario A

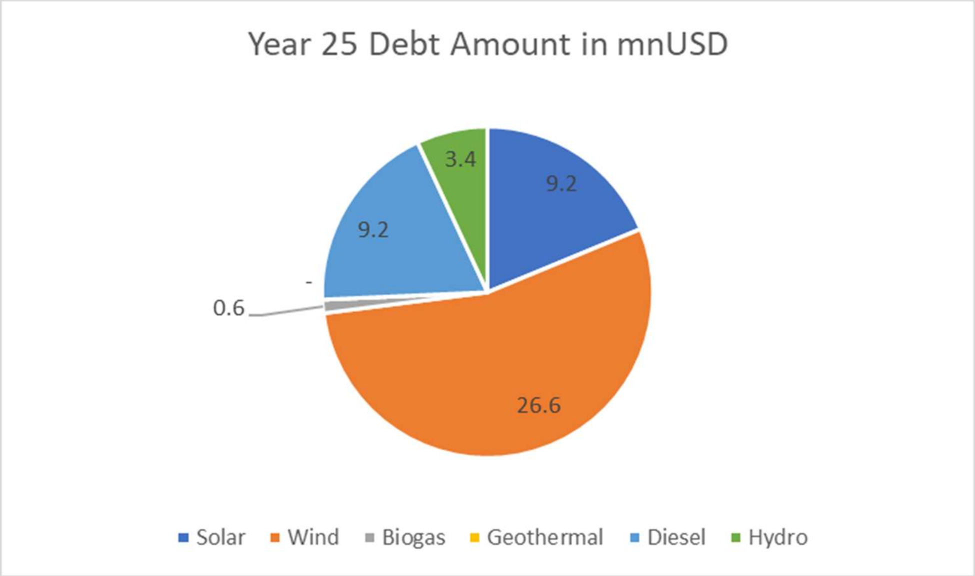


Figure 121 Year 25 debt for scenario B

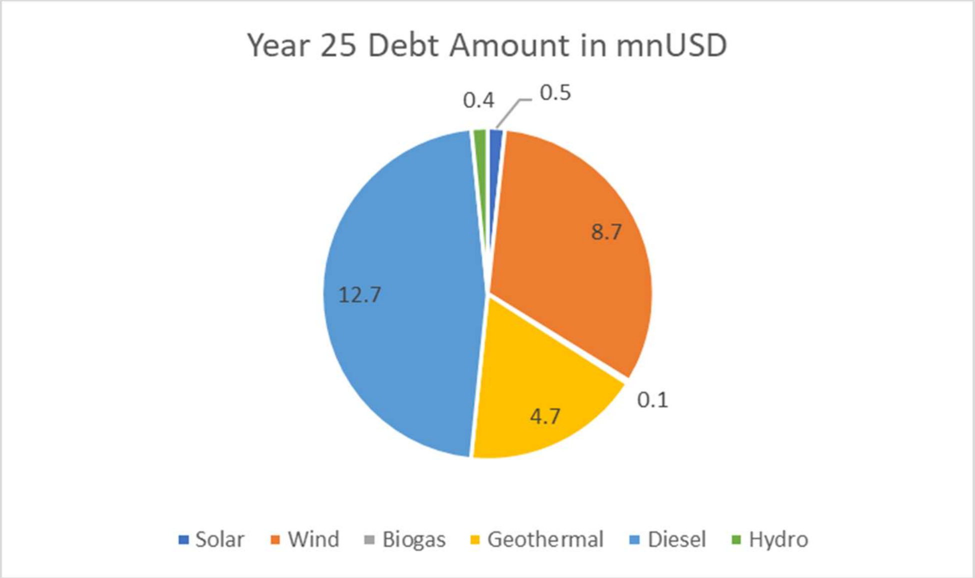


Figure 122 Year 25 debt burden for scenario C

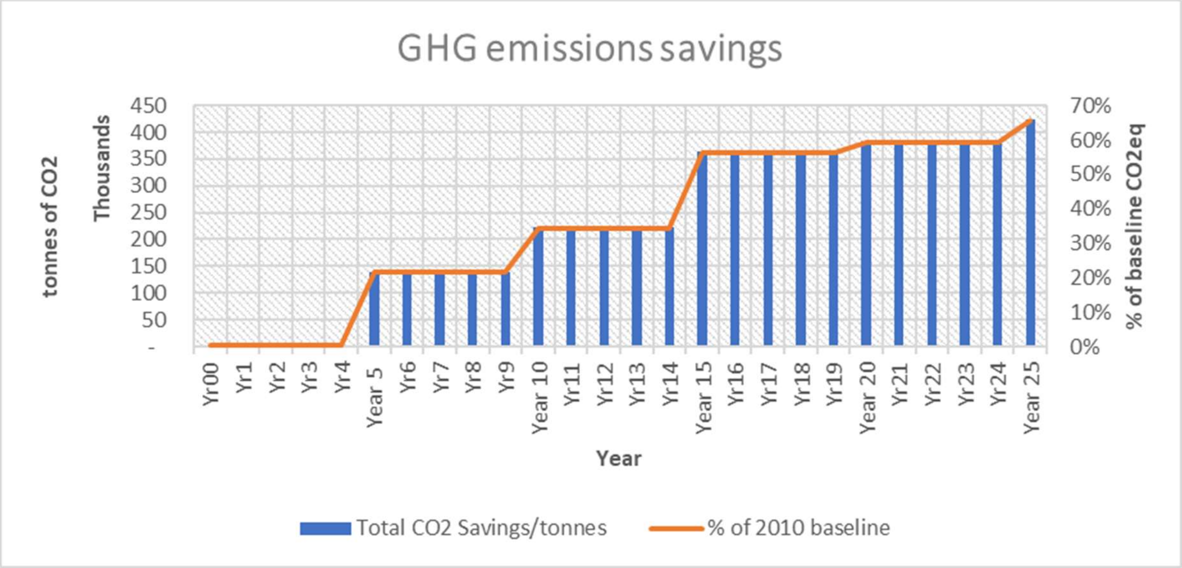


Figure 123 Scenario A GHG emissions savings compared to 2010 baseline

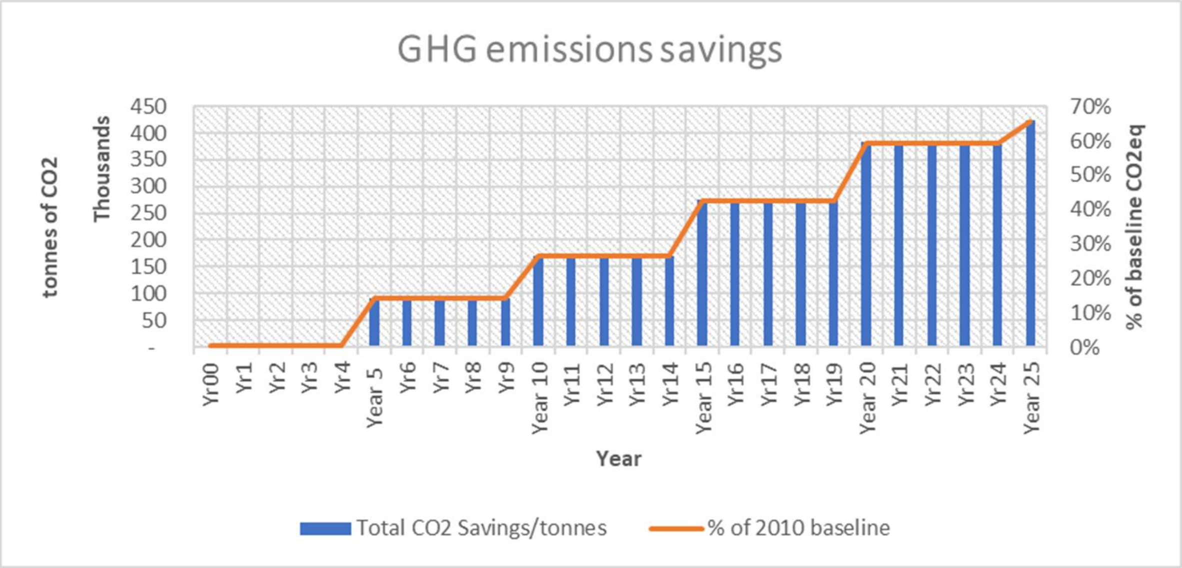


Figure 124 Scenario B GHG emissions savings compared to 2010 baseline

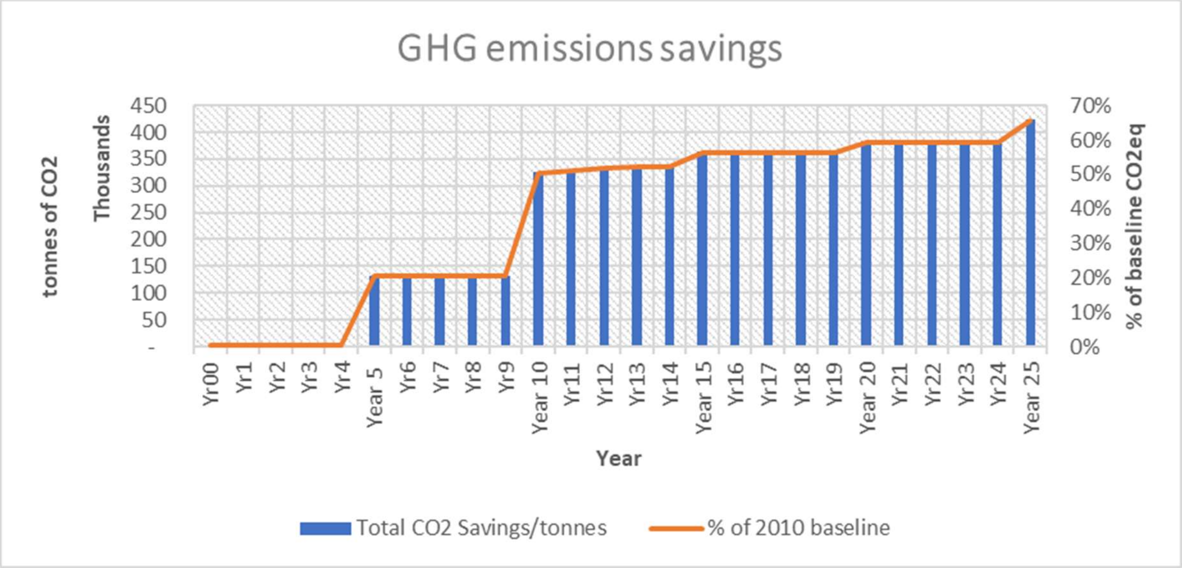


Figure 125 Scenario C GHG emissions savings compared to 2010 baseline

Box 1 - Scenario A Financial Results

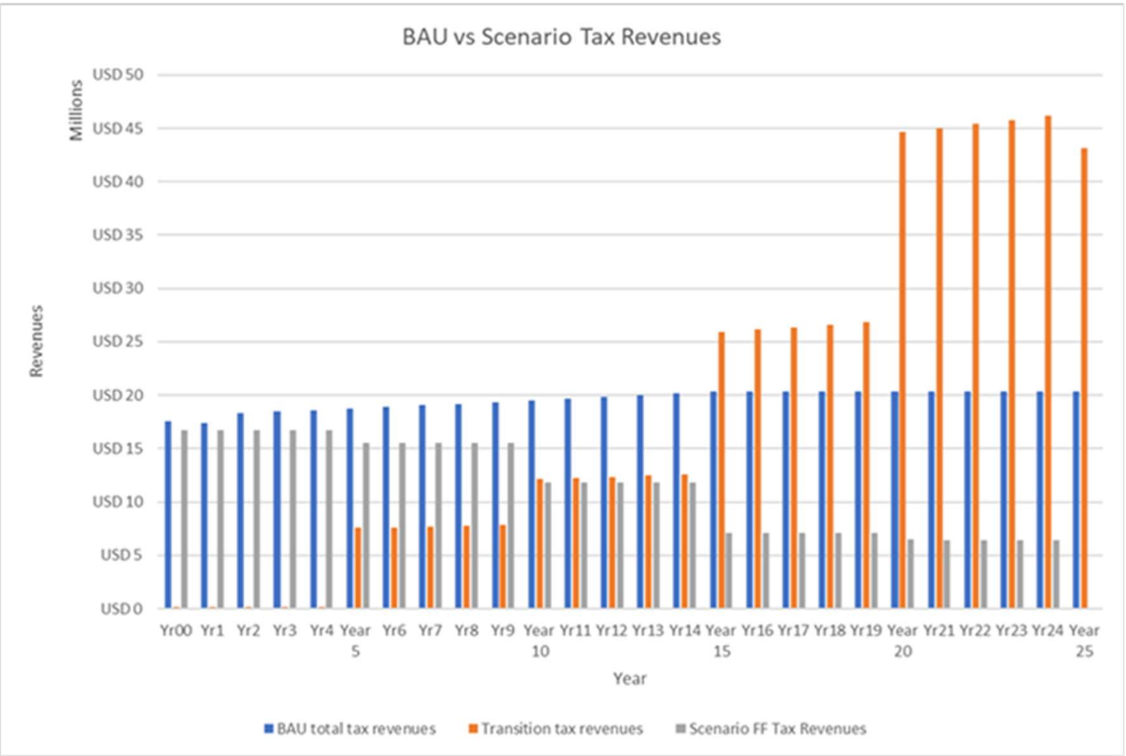
Financial Results

RE and Storage Sources	Average ROE	Year 25 ROE	25 Year IRR	NPV in USD
Solar	8%	13%	19%	$23,946,816
Wind	23%	43%	29%	$30,144,940
Biogas	6%	27%	16%	$92,855
Geothermal	11%	7%	24%	$10,160,048
PHS	2%	6%	15%	$597,975
DSM	-10%	-73%	NA	($54,412)
Battery Chemical	-1%	12%	16%	$2,476,527
V2G	-9%	-21%	2%	($3,238,921)
Ice Storage	-5%	-15%	13%	$202,530
Hydro	-12%	-17%	10%	($900,870)
Energy Efficiency	26%	5%	4%	($26,093,052)

Profits remaining in the economy

RE Source	% of Gross Profits	Amount in $USD
Solar	19%	15,904,294
Wind	41%	11,424,455
Biogas	10%	447,344
Geothermal	14%	4,672,755
Hydro	0%	-
Total		32,448,848

Tax Transition



Present value of all investments

RE and Storage Resource	Present Value of Investment in USD
Wind	$42,125,173
Solar	$97,466,292
Geothermal	$31,821,786
Diesel	$29,605,173
Biogas	$1,399,190
Hydro	$11,507,632
Ice Storage	$9,364,506
PHS	$15,252,872
V2G	$14,753,626
Battery Chemical	$19,435,536
Energy	$82,069,845

Box 2 – Scenario B Financial Results

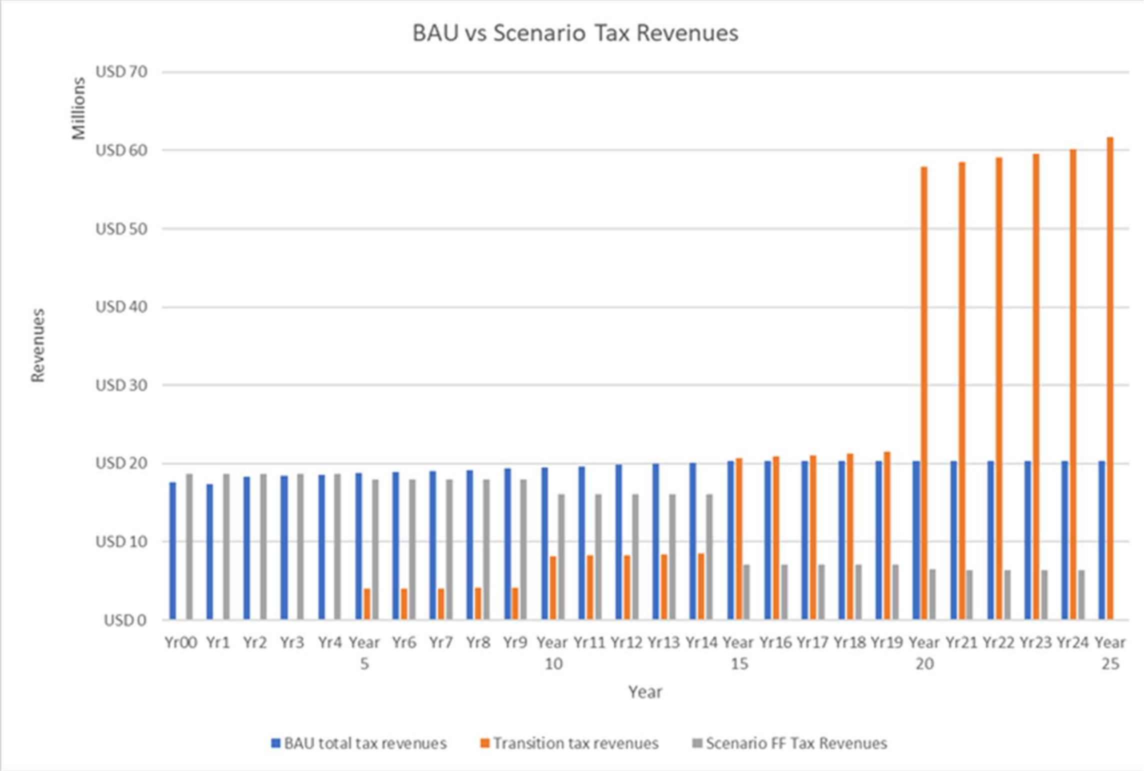
Financial Results

RE and Storage Sources	Average ROE	Year 25 ROE	25 Year IRR	NPV in USD
Solar	8%	13%	14%	$2,571,542
Wind	16%	25%	23%	$23,721,137
Biogas	26%	34%	31%	$2,237,915
Geothermal	0%	0%	NA	$0
PHS	2%	7%	4%	($3,186,367)
DSM	725%	322%	102%	$3,450,951
Battery Chemical	24%	123%	29%	$7,864,525
V2G	-9%	-20%	-11%	($6,075,721)
Ice Storage	-6%	-12%	1%	($2,556,064)
Hydro	-12%	-10%	2%	($4,655,748)
Energy Efficiency	41%	31%	17%	$22,937,425

Profits remaining in the economy

RE Source	% of Gross Profits	Amount USD
Solar	24%	8,724,456
Wind	24%	36,240,934
Biogas	36%	1,526,599
Hydro	0%	-
Total		46,491,989

Tax Transition



Present value of all investments

RE and Storage Resource	Present Value of Investment in USD
Wind	$74,621,569
Solar	$52,851,664
Geothermal	$0
Diesel	$38,023,344
Biogas	$3,320,954
Hydro	$16,619,914
Ice Storage	$8,586,774
PHS	$19,750,692
V2G	$14,753,626
Battery Chemical	$8,087,859
Energy Efficiency	$87,284,858
Demand Side Management	$178,516
Total	$324,079,769

Box 3 – Scenario C Financial Results

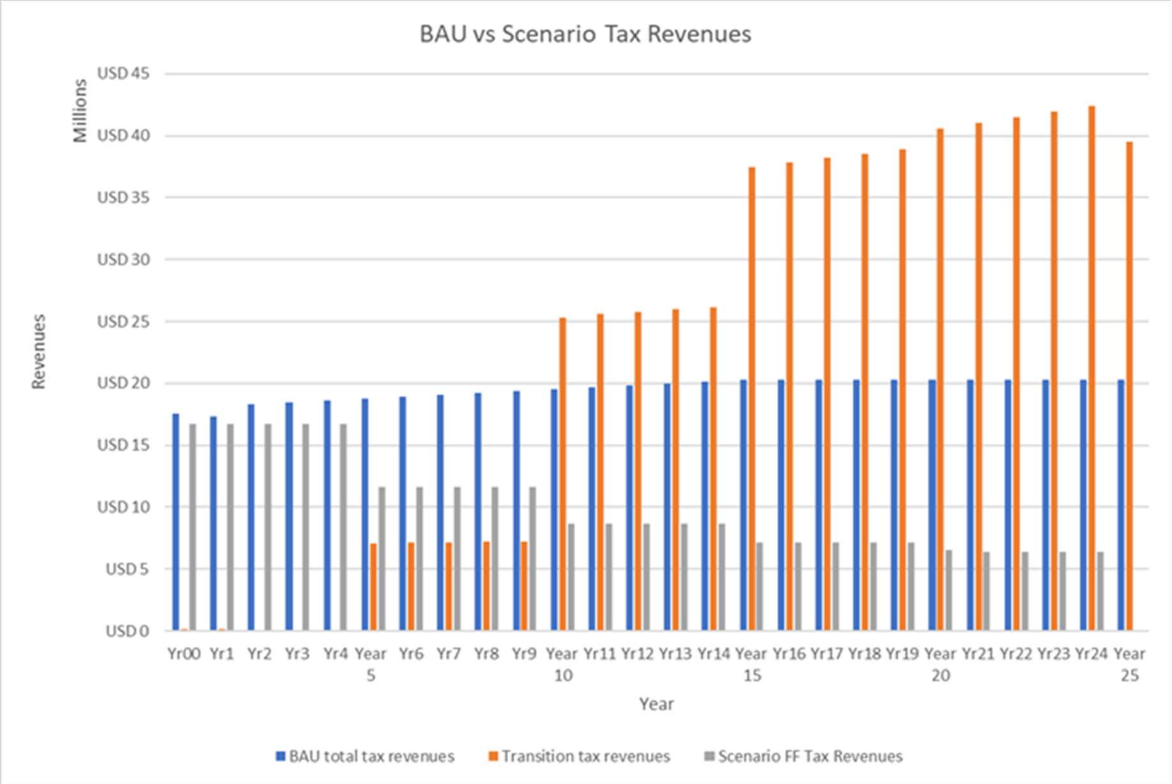
Financial Results

RE and Storage Sources	Average ROE	Year 25 ROE	25 Year IRR	NPV in USD
Solar	5%	12%	16%	$4,298,275
Wind	17%	32%	30%	$60,309,931
Biogas	27%	45%	24%	$2,357,467
Geothermal	23%	21%	24%	$28,637,997
PHS	6%	14%	23%	$12,498,412
DSM	132%	-26%	NA	($3,929,142)
Battery Chemical	29%	85%	15%	$1,420,087
V2G	0%	0%	NA	$0
Ice Storage	-10%	1%	11%	($1,662,240)
Hydro	-8%	1%	11%	($1,322,563)
Energy Efficiency	35%	16%	6%	($24,266,898)

Profits remaining in the economy

RE Source	% of Gross Profits	Amount USD
Solar	33%	2,745,072
Wind	31%	37,940,851
Biogas	13%	547,719
Geothermal	30%	9,098,408
Hydro (*due to depreciation expense)	6%	176,777
Total		50,508,827

Tax Transition



Present value of all investments

RE and Storage Resource	Present Value of Investment in USD
Wind	$91,486,531
Solar	$30,276,567
Geothermal	$66,836,825
Diesel	$24,712,705
Biogas	$5,210,910
Hydro	$25,638,336
Ice Storage	$17,229,240
PHS	$34,539,200
V2G	$0
Battery	$17,769,680

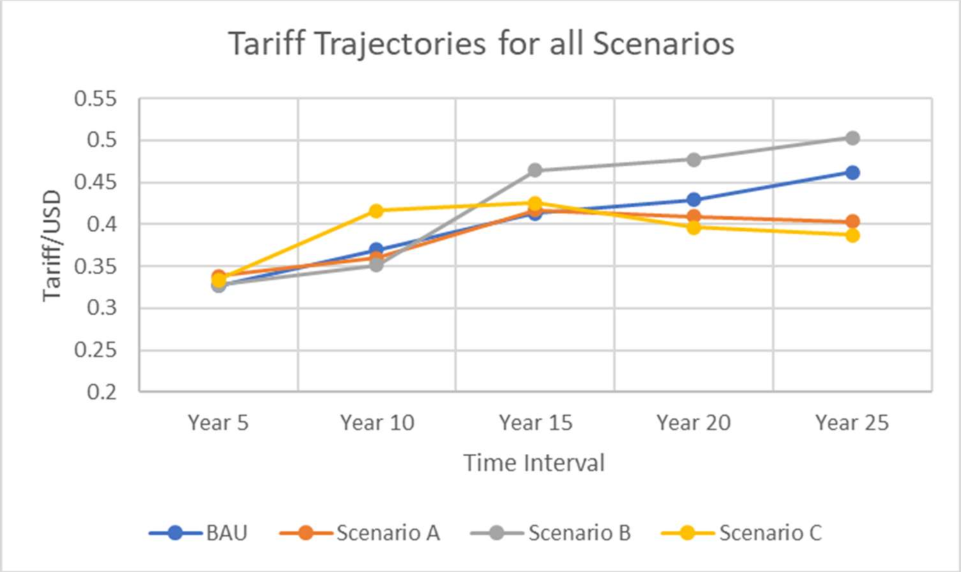


Figure 126 Tariffs in 5-year intervals for each scenario

BAU is business as usual continuing with consumption of fossil fuels.

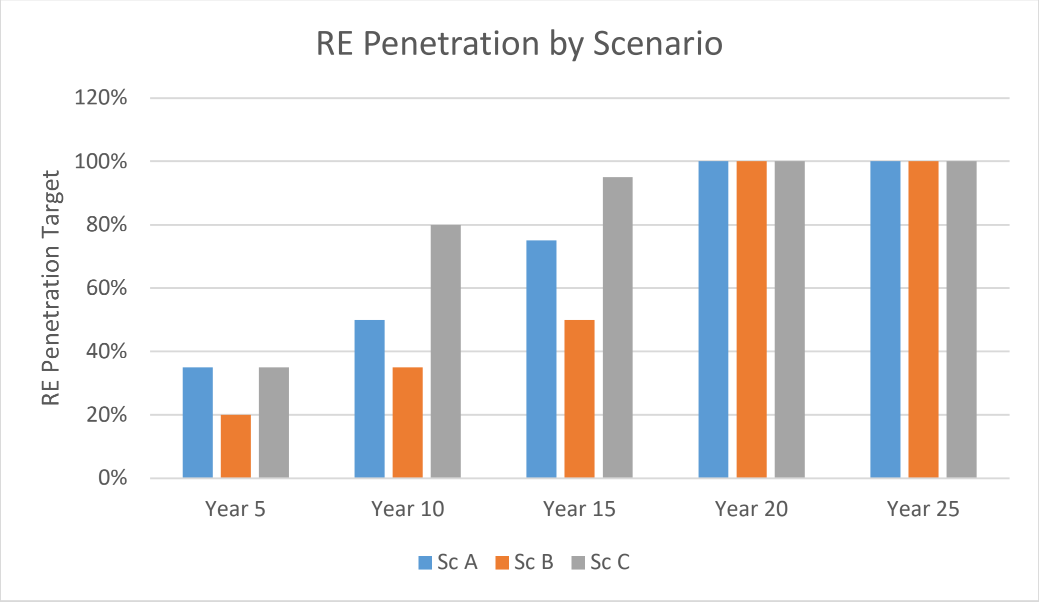


Figure 127 RE penetration by scenario

Energy Transition Pathways

In Table 123, Table 124 and

Table 125, DSM means demand side management, V2G means energy transfer from electric vehicle to the electricity grid, PHS is pumped hydro storage and Peak Residual Demand Diesel is supplied by regular diesel fuel in years 5, 10 and 15. It is supplied by biodiesel in years 20 and 25.

Table 123 Scenario A energy transition pathway

Maximum Energy or Capacity by Source	Year 5	Year 10	Year 15	Year 20	Year 25
Solar – Utility (MWp)	37.1	70.7	177.5	357.5	360.9
Solar - Distributed (MWp)	11.3	16.3	24.7	33.3	33.7
Wind (MW)	41.4	46.0	41.4	50.6	50.6
Biogas (MW)	-	-	-	0.8	0.8
Geothermal (MW)	-	7.0	21.0	28.0	28.0
Hydro (MW)	-	-	1.8	2.3	2.3
Diesel (MW)	38.2	29.4	12.9	-	-
DSM (MW)	-	-	-	5.0	5.2
DSM Energy (MWh)	-	-	-	1.2	1.2
V2G - HDV (MW)	-	-	-	-	-
HDV V2G Energy (kWh)	-	-	-	-	-
V2G - LDV (MW)	-	-	6.5	4.4	3.7
LDV V2G Energy (kWh)	-	-	1,631.6	1,097.3	928.8
Ice Storage - Commercial (MW)	-	-	1.1	1.5	1.5
Ice Storage - Commercial (kWh)	-	-	274.7	363.2	363.2
Ice Storage - Hotel (MW)	-	-	0.9	1.2	1.2

Ice Storage - Hotel (kWh)	-	-	224.1	299.7	299.7
Chemical Storage (MW)	7.4	25.0	47.6	63.6	63.7
Chemical Storage (MWh)	6.4	133.4	577.1	15,627.2	17,903.8
PHS (MW)	-	-	-	75.0	75.2
PHS (MWh)	-	-	-	1,884.7	1,884.7
Peak Residual Demand Diesel (MW)	32.8	47.5	64.7	74.8	75.0

Table 124 Scenario B energy transition pathway

Maximum Energy or Capacity by Source	Year 5	Year 10	Year 15	Year 20	Year 25
Solar – Utility (MWp)	19.0	52.0	67.0	138.0	143.0
Solar - Distributed (MWp)	7.7	13.7	20.0	40.5	41.2
Wind (MW)	23.0	41.4	82.8	266.8	266.8
Biogas (MW)	0.2	0.3	0.4	0.8	0.8
Geothermal (MW)	-	-	-	-	-
Hydro (MW)	0.5	0.8	1.2	2.3	2.3
Diesel (MW)	40.0	32.5	17.1	-	-
DSM (MW)	0.9	1.6	2.4	5.0	5.2
DSM Energy (MWh)	-	0.4	0.6	1.2	1.2
V2G - HDV (MW)	-	-	-	-	-
HDV V2G Energy (kWh)	-	-	-	-	-

V2G - LDV (MW)	-	-	10.3	10.3	8.5
LDV V2G Energy (kWh)	-	-	2,581.2	2,568.4	2,121.9
Ice Storage - Commercial (MW)	-	-	0.7	1.5	1.5
Ice Storage - Commercial (kWh)	-	-	183.9	363.2	363.2
Ice Storage - Hotel (MW)	-	-	0.6	1.2	1.2
Ice Storage - Hotel (kWh)	-	-	154.2	299.7	299.7
Chemical Storage (MW)	-	1.6	47.9	104.3	104.7
Chemical Storage (MWh)	-	0.4	402.3	70,381.9	77,421.0
PHS (MW)	-	-	-	97.2	97.3
PHS (MWh)	-	-	-	1,884.7	1,884.7
Peak Residual Demand Diesel (MW)	34.2	53.9	89.0	75.1	74.3

Table 125 Scenario C energy transition pathway

Maximum Energy or Capacity by Source	Year 5	Year 10	Year 15	Year 20	Year 25
Solar – Utility (MWp)	7.9	14.6	22.0	23.0	23.0

Solar - Distributed (MWp)	11.3	26.0	31.3	33.3	33.7
Wind (MW)	18.4	96.6	179.4	225.4	225.4
Biogas (MW)	0.3	0.6	0.8	0.8	0.8
Geothermal (MW)	14.0	28.0	28.0	28.0	28.0
Hydro (MW)	0.8	1.9	2.2	2.3	2.3
Diesel (MW)	35.0	20.9	11.0	-	-
DSM (MW)	1.6	3.8	4.6	5.0	5.2
DSM Energy (MWh)	-	0.9	1.1	1.2	1.2
V2G - HDV (MW)	-	-	-	-	-
HDV V2G Energy (kWh)	-	-	-	-	-
V2G - LDV (MW)	-	-	-	-	-
LDV V2G Energy (kWh)	-	-	-	-	-
Ice Storage - Commercial (MW)	-	1.1	1.4	1.5	1.5
Ice Storage - Commercial (kWh)	-	272.4	351.5	363.2	363.2
Ice Storage - Hotel (MW)	-	0.9	1.2	1.2	1.2
Ice Storage - Hotel (kWh)	-	224.1	288.1	299.7	299.7
Chemical Storage (MW)	-	36.7	60.9	81.9	81.6
Chemical Storage (MWh)	-	1,624.0	26,119.4	38,233.4	40,897.6

PHS (MW)	-	38.2	59.3	79.7	79.4
PHS (MWh)	-	1,884.7	1,884.7	1,884.7	1,884.7
Peak Residual Demand Diesel (MW)	30.9	39.5	55.1	75.8	75.6

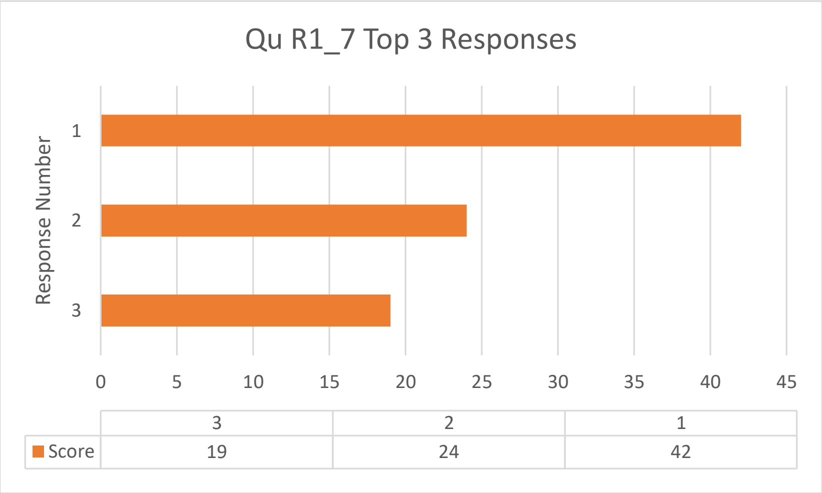
Comparison of results from all scenarios

Table 126 Summary comparison of Baseline, scenarios A, B and C

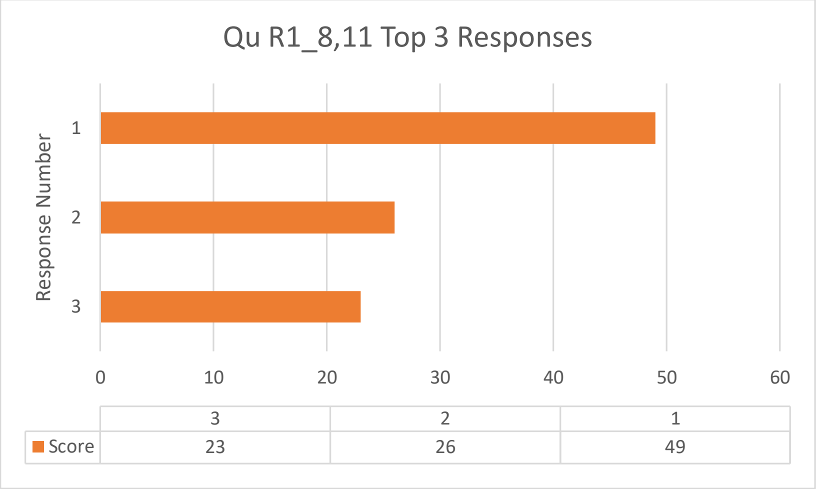
	Parameter	Baseline	Scenario A	Scenario B	Scenario C
Year 25	Energy Output - GWh	553.4	894.8	1037.9	898.5
	Demand - GWh	514.5	695.0	749.1	683.5
	Storage Capacity - GWh	0	18.9	79.3	39.3
	Solar IRR	12%	19%	14%	16%
	Wind IRR	NA	29%	23%	30%
	Geothermal IRR	NA	24%	NA	24%
	Hydro IRR	NA	10%	2%	11%
	Biogas IRR	NA	16%	31%	24%
	Total Excess Generation - GWh	NA	0	0	0
	Residual Demand - GWh	NA	3.6	4.9	4.3
	Tariff - USD$ per kWh	0.462	0.403	0.503	0.387
	Dominant RE Source	Solar	Solar	Wind	Wind
	Dominant RE Supply - GWh	4.3	565	748.6	632
	Value of profits remaining in local economy -USD$mn	NA	32.4	46.5	50.5
	Tax revenue - USD$mn	20	113.9	62	39.5
	Average EE Savings	NA	16%	7%	17%
Overall	PV of Tax Revenues (No FF in Scenarios) - USD$mn	NA	116.4	102.9	146.6
	Economic Impact - USD$mn	(1,252.90)	165.4	-135.5	317.5
	PV of Investment Costs - USD$mn	NA	354.9	324.1	396
	RER (without Biodiesel)	1%	100%	100%	100%
	Exclusions	NA	None	Geothermal	V2G
	Year to exceed BAU tax revenues	NA	15	20	10

Appendix A-2 Feedback RND2

Prioritised feedback to Delphi survey.

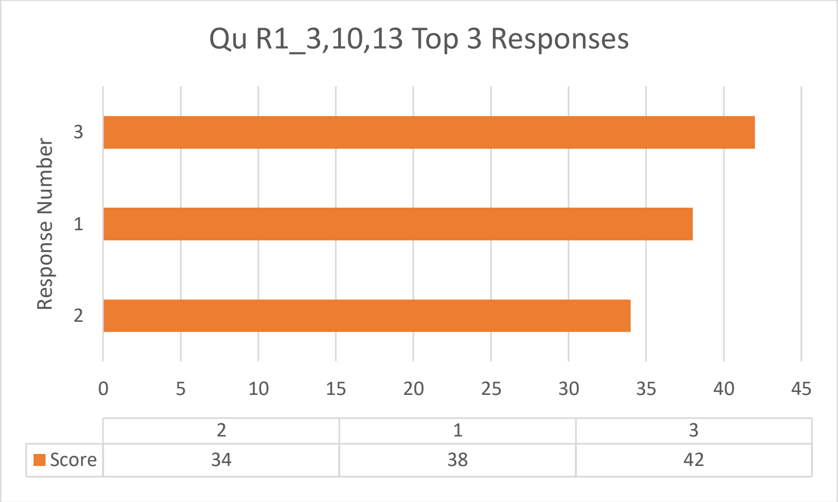


4) We need to start with the legislation, currently we have restrictions on the size of the solar units one can place on their business and homes, this needs to change. Energy governance, enabling legislation, fiscal incentives for investments, energy policy and implementation plan that is responsive to energy landscape. Incentivise transition to renewable energy. Development of supportive regulatory frameworks.
5) We need to invest more in non-oil sources of energy generation, e.g., wind, solar, hydro, geo-thermal. There needs to be diversity driven by a national policy. Increased generation of electricity must continue with renewables and the market for generation and sale should not be a monopoly held by LUCELEC. Use of alternative energy sources: solar, wind and wave energy. Renewable clean energy. Other national priorities would be diversification (not relying on one source, but exploring geothermal, solar, wind, hydro, biomass energy in areas where these sources are plentiful on the island), and decentralization of energy systems. In other words, in the context of St Lucia can we adopt a hybrid energy system? Increased access to renewable energy. Electricity is a widely used form of energy in Saint Lucia and access and cost of electricity has a major impact on quality of life, productivity and growth. As such electricity for service delivery and economic activity should be prioritised. Expansion of renewable forms of energy for electricity generation – focus on solar, wind and geothermal. Develop a more diverse energy mix by investing significantly in the development of renewable energies in particular geothermal, wind, solar and biogas. This would reduce the dependence and intake on fossil fuels and energy imports. Once sustainable electricity is provided it can be used for both Cooking and Transportation. Electricity (household green energy). Using renewable energy for heating and drying applications.
6) Access to financing, for homes, small-medium size businesses, this will allow persons to be able to implement renewable energy projects which can improve efficiency and reduce our carbon footprint at the same time. Addressing the issue of high costs and lack of suitable financing for RE technologies.



4) There must be very little or no impact to surface or ground water supplies and quality of air. Therefore, these two must be at the forefront of any decision to alter the sector. Impact on water quality and consumption where water is used for cooling as in the case for geothermal energy. Impact on air quality, water resources, MEA compliance. Climate change, emissions, pollution in whatever form air, water, land, noise. No negative impact on environment. I firmly believe that the environment as a whole must be considered. That being said energy production must consider land, air and water pollution and their adverse effects. Increasingly, it can be noted that issues such as greenhouse emissions, climate change (change in weather and climate patterns), contaminated water and ground; and also reduced air quality.
5) Carbon emissions from particular investment. GHG emissions level is low but has shown a slight increase over the 2010 baseline. Therefore, selective investments should be significant enough to reduce level. GHG emissions, pollutants, other impacts on flora and fauna. Energy emission costs and applicable legislation in that regard. Impact on the environment in terms of CO2 or productive use e.g., agriculture, tourism et cetera. Reduced carbon footprint. Contributions to carbon sequestration. Availability of the renewable resource. Energy generation that produces no or little greenhouse gases.
6) Geographic constraints for equipment set up- landscaping and logistical impacts. Population density, space occupation for energy system and impact on community (social and economic impact, for example, whether agricultural land will be taken away, would public access to certain areas be restricted once the energy systems are installed?) The impact on existing and future land uses including potential conflicts, opportunities for co-existence and making optimal use of land resources. Monitoring of environmental impacts is also important, particularly impact on health. The amount of land required and opportunity cost. Compatibility of energy equipment with wildlife, building codes for the community et cetera. The impact on ecosystems such as mangroves and rivers should be factored in. Impact on wildlife and habitat. Land disturbance how would it affect farmers, land owners. Health impact on animal life, impact on the natural environment. Noise impact. Impact on the immediate ecosystem. Legislative constraints that may impede use of certain areas, such as protected sites (those that should not be tampered with based on historical or cultural value yet have immense potential for the type of “green” energy to be extracted).

Impact of investment on land and marine ecosystems. Would energy equipment and infrastructure affect other existing structures, such as communications infrastructure? Would these need to be modified to integrate in the drive towards the “green energy transformation?” Whether the manufacturing plant location will be viable in the long run – will the location be more conducive to other developmental innovations? The waste from the process (there is still some) how will it affect the environment? The level of consumption and the rate at which it can be renewed – does it harm the environment?

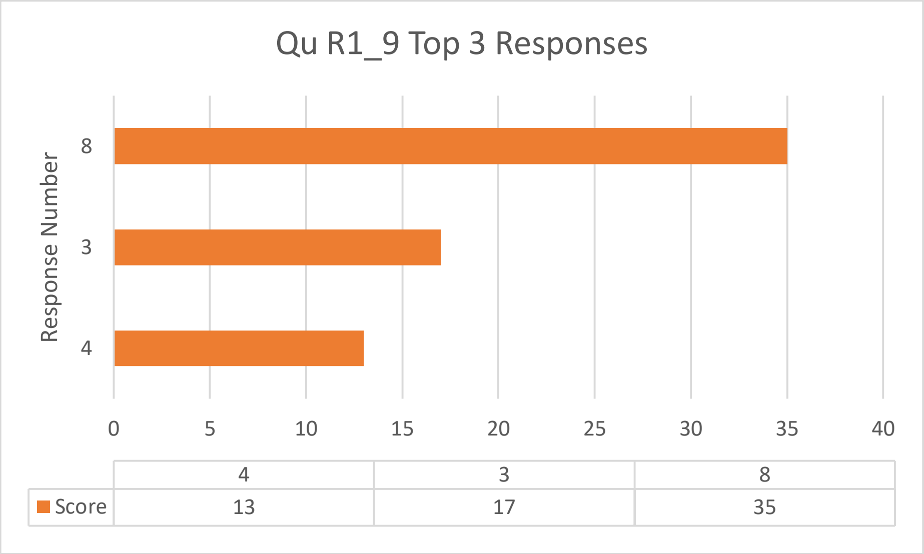


	2	1	3
Score	34	38	42

4) There should be a mixed approach. In the case of fledgling local enterprises that may lack the financial wherewithal but have sustainable plans partnerships should take place. Incentives for renewable energy developments too can spurn the interests of private investors regionally and internationally. Government support is needed to ensure a proper functioning society as the energy sector can face market failures for which regulations are necessary. Support from the government is needed, however, it should be equitably available. Support should be provided at start up, with a specific set target to be attained by the business. At which point the government investment / support should stop. The business should then become viable, sustainable and ongoing without aid and or assistance. Government should create the fiscal space for private investors. Through concessions. These concessions will allow all energy investments to be financially viable on their own.

2) With the current rises in fuel, transportation, other raw materials, I believe that the government should continue to provide support. The absence of that may mean that persons who fall in the low-income bracket may not be able to afford electricity. Energy investment has always enjoyed government subsidies particularly when starting operations. I therefore believe that as we push to energy diversity particularly in renewable financial support from government must continue. …. Tax incentives among other support measures are surely needed for budding energy companies. I believe government should provide assistance to investments within the energy sector. Additionally, because of the high start-up costs, limited resources and the importance of moving towards a greener energy space globally I believe that government has as an obligation to provide support (both technical and financial) to viable investments within the sector. It can also be noted that the overall benefits of such projects to small island states can be invaluable and help us to significantly reduce our energy and import (fossil fuel) bill. Government must definitely continue to provide financial support as majority of persons with the ideas do not have the financial means in SIDS…Gov't may have to support financially to encourage the development of renewable energy projects that deliver long-term benefits. Within the context of Saint Lucia and other SIDS, governments should continue to provide some financial support even if it is indirect support as these have proven to be a major catalyst for increased energy investments.

2)	The energy company needs to diversify in other sources of energy that can be cheaper for consumers, good for the environment and profitable enough to be viable on their own. No direct financing from Govt. Ultimately the aim should be to have a financially viable energy sector especially as there is the thrust towards low-carbon economy. However, government should create the enabling environment towards this together with relevant players. Critically though, the role of government should be to create the necessary enabling environment to facilitate investments and innovation by the private sector. Government ought to create an enabling environment for investments including policy and legislative frameworks. Additionally, governments ought to incentivise investors and incrementally transition to private sector. In so doing the energy sector will become financially sustainable. Energy investments should be viable on their own.

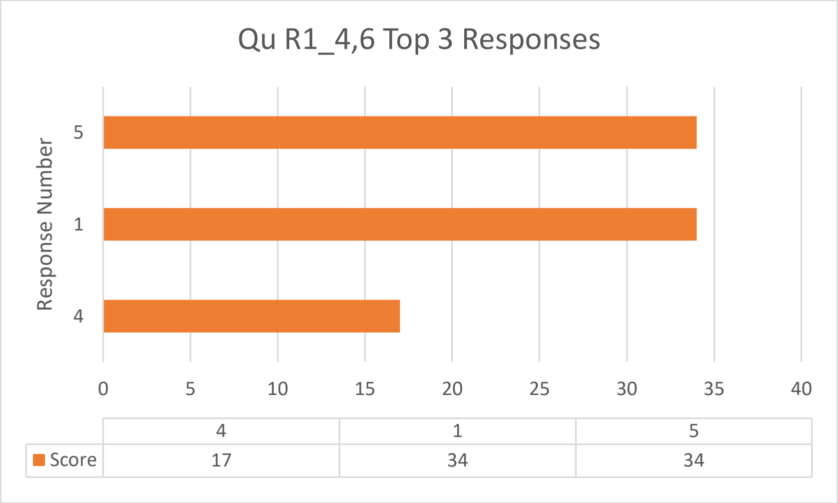


	4	3	8
■ Score	13	17	35

8) Nuclear sources.

3) A source of energy which may not be socially acceptable is that of geothermal energy for fear of eruptions. In St Lucia Geothermal Energy might be the only source of renewable energy which will not be socially acceptable as the drive-in volcano, which is a tourist attraction, will have to be repurposed to harness the energy. I do not think that locals are in favour of interfering with the Sulphur Springs to generate electricity. I have sat in many town hall discussions on this. The majority of people in Soufriere who were invited to these forums spoke passionately against interfering with the volcano. They believe this will have more catastrophic consequences than the geothermal energy exploitation mission sought after. Geothermal in Belplaine Soufriere is not viewed favourably by the residents of the potential drilling area. Perhaps geothermal because of the association with earthquakes. There may be some misgivings about geothermal energy because of the perception that it can trigger volcanic activity.

4) To my knowledge there are none which have garnered any social discontent. No issues with any of the renewable sources being contemplated.

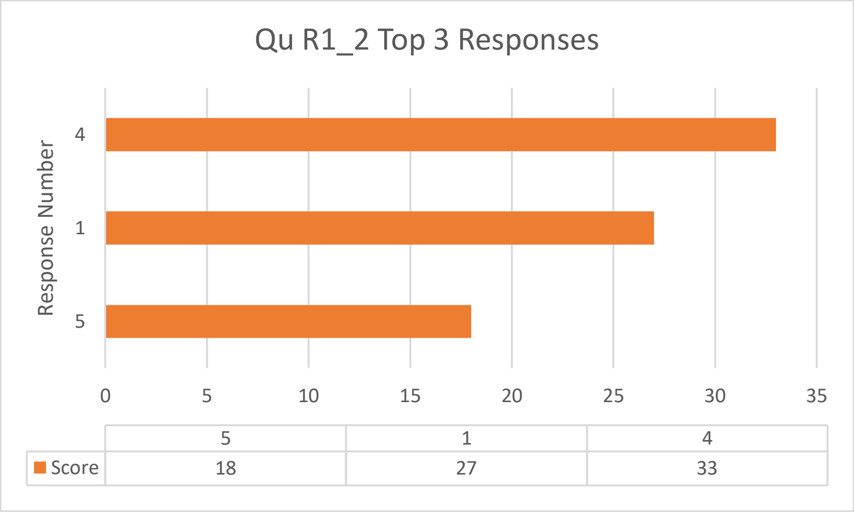


	4	1	5
Score	17	34	34

5) Energy security, economic growth, enhanced reliability and resiliency particularly from natural disasters. Increased resilience of the energy system to external shocks.

1) Reduced tariffs, reduced rates. Reduction in energy cost to consumers. Ultimately a lower cost of living and greater stability w.r.t. cost of input materials or sources (e.g., fossil fuels vs solar). Reduce energy cost to consumers. Reducing the cost of energy, productive use of sustainable energy investments in manufacturing and other sectors which directly impact the country. Reduced energy tariffs to allow improved economic growth. Reduction in oil-based energy production, savings from the reduction of importation of fuel. Reduction in energy costs, reduction in fuel importation bill. Stable and possible lower energy prices, environmental integrity and local ownership. Cost containment. Reduced currency outflows. Energy Security and financial protection from the volatility of fuel pricing. Being energy independent. Reduced reliance on foreign sources of energy. Less reliant on imported fuel / energy hence better able to mitigate the associated risks in regards to shortages and price. Sustainable futures, improve efficiencies, reduced production costs. Improved quality of life. Reduced volatility of electricity prices in response to oil price shocks.

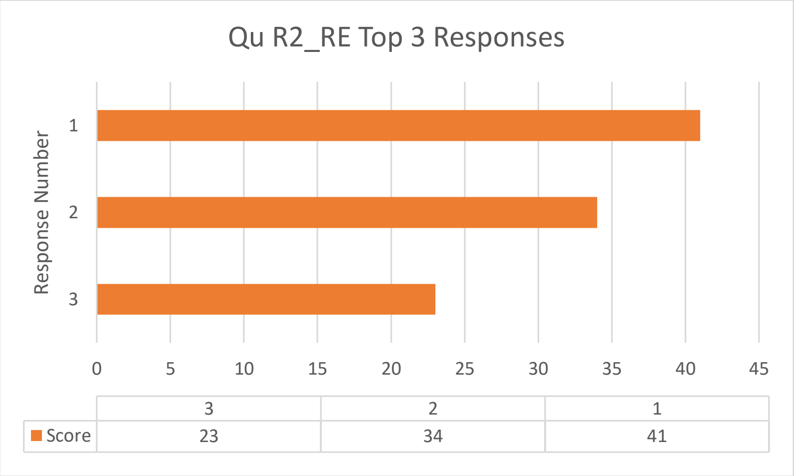
4) More efficient power supply, with very few outages or fluctuations. Greater resilience in post hurricane recovery through more distributed generation. Modernization of outdated infrastructure to support Smart initiatives. Encouragement and support for innovation and development in new technologies in general. Better consumer choices / options. Attraction of grant funding.



4) Solar - We are in the tropical zone. There is an abundance of sun all year round, and in every part of the island. We have evidence from solar water heaters, solar powered businesses and homes that this can be yoked and is efficacious. Solar because of its simplicity, (ease of conversion, mature technology), Opportunity for quick rollout. I believe solar energy should be prioritised given that some inroads have already been made by electricity company LUCELEC, and entities such as Solar Dynamics with solar hot water systems. Expansion might be easier for this source given our prevailing climatic conditions as well. Low hanging fruit, assessment show potential for generating significant power and land space is available especially for crown lands. Country has rich solar resources which should be further exploited in respect of DG and utility scale projects…

2) Solar and wind. The natural abundance of supply on island. The fact that they complement each other with solar peak production during the day and wind sustaining generation throughout the night. I believe they are easier to install and maintain. Also, I believe they are environmentally friendly, most persons have some knowledge of the two and it may be more socially acceptable in the short-term; because the technology involved are well established. Solar and Wind because of the potential that exists for these forms and also because they are becoming competitive with conventional generation particularly with falling battery prices that can help address the issue of intermittency and stability. These sources should receive priority for development because (i) of the island's favourable resource potential (ii) they are proven technologies that can be procured at reasonable cost (and costs are rapidly declining) (iii) they were identified in the most recent National Energy Transition Strategy.

5) Wind due to its availability and consistency.



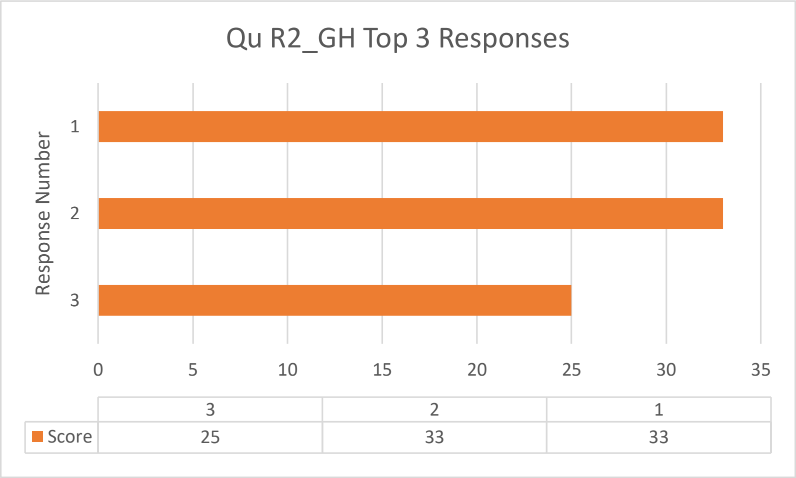
	3	2	1
■ Score	23	34	41

3) Yes, I am in agreement, we have already seen strides with implementation of LUCELEC's 3MW the solar farm in La Tourney Vieux Fort. In agreement but should be noted that at the time targets were set, the landscape seemed more poised towards achieving through wind and solar. Much work is required through geothermal given the stage at which development process is at, so 2030 target may need adjustment or steady and significant investment in solar is needed together with supporting legislation especially on existing maximum cap allowed. Generally, "yes", although higher benchmarks would always be better…

4) (Lower). I do not believe we have the political will to execute and realize this goal. I believe that the vision can manifest to an extent. I would therefore suggest 20% by 2025 and 40% by 2030. I find this timeline impossible to meet. We are presently experiencing the worst economic downturn and financial recession in the history of world economies catalysed by the Covid-19 pandemic. It may take us years to ricochet from this blow. Government will need to expedite their plans with the commensurate financial resources to enable progress in order to achieve this target.

In the absence of these, it is surely a tall mandate. I would extend 35% to 2035 and 50% to 2040. The timelines are way too short and targets are too ambitious considering where we're currently at. The timelines should be over a thirty-year time frame. I think the targets may serve as motivation but given the current pace of development they do not seem achievable. I don't think these goals will be achieved given the political landscape in St Lucia. There needs to be an apolitical approach with a commitment by all political organisations jointly to prioritize these goals. Considering it's already 2022, these targets are unrealistic. Given our current status a more realistic target would be 35% by 2030 and 50% by 2035. I was unaware of this; perhaps better methods of communicating these aspects and its benefits to the country should be explored. I would want to know whether this is achievable by 2025, if not a more realistic goal should be put in place, say 25%.

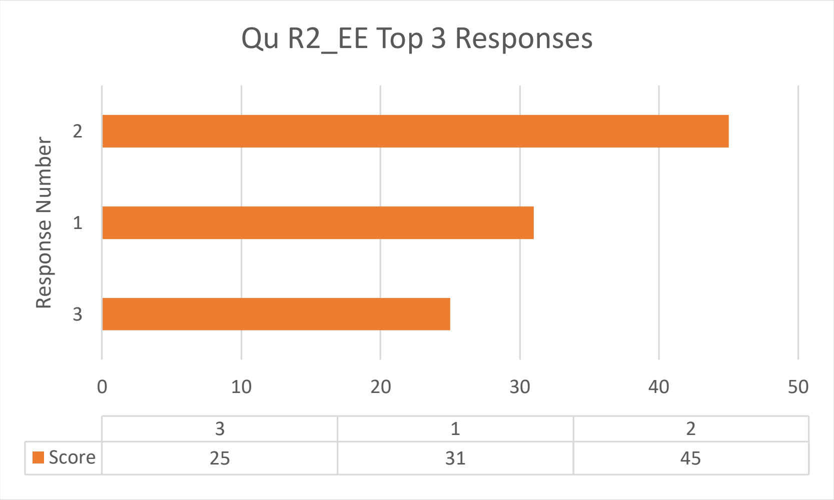
3) (Higher). 2030 should be revised to 80%. I think by the year 2030 we should be close to 100%. Our energy usage is very small compared to developed countries so it is very easy to implement renewable sources of energy.



1) No - (Lower) historically we have not been able to achieve a 5% reduction, there has been not consistent decline, I would suggest a target of at least 3%. I agree with this vision, but in the current environment I believe 3.5% is more practical why? Opportunities for high impacts visible reductions are limited, hotels and the small manufacturing sector should be purposely targeted.

2) Yes - I believe that we can reduce our emissions by 7% considering that our emissions are already significantly low. This seems attainable if we adopt an aggressive approach to fulfilling the mandate of renewable energy cultivation. We can accomplish a lot in 8 years with adequate funding and intellectual power. Yes, attainable especially with thrust to increase EV use. 7% reduction is a bit low but is a fair target as majority of GHG are from vehicles in SIDS. It means that majority of vehicles will have to shift to electric for GHG to be reduced significantly…

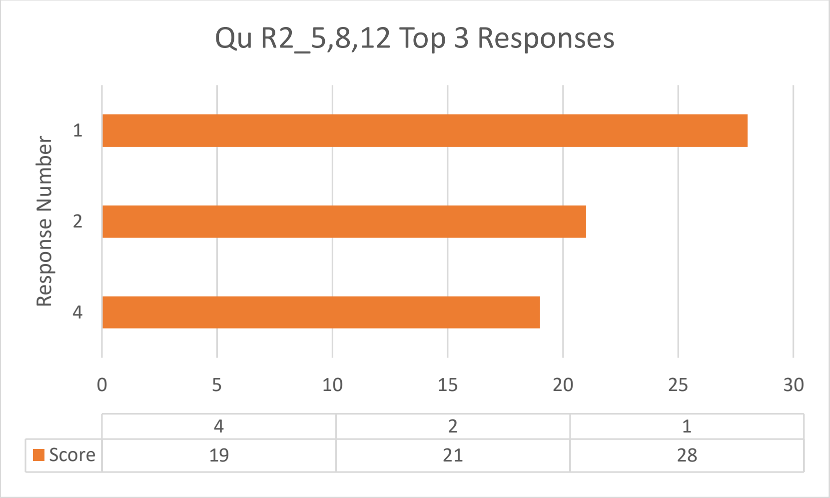
3) No – (Higher); it should be close to 50%. Such a target seems very mediocre. Perhaps reduction should match that of renewable energy targets and at the very least 25%.



2) Agree - Should more consideration be given to the use of resources within the public sector I am sure we can reduce consumption by 20% or even more. 20% reduction is fair. Generally, “yes”, although higher benchmarks would always be better. I am, but it depends on the time frame. I would like to know how this vision would be achieved. Yes, can be achieved through further retrofitting (and M&E) and good practices. There is a lot that the Government can do to meet this target in the public sector. It is very achievable. This is a reasonable target…

1) No (Lower) - I do not see that happening. The GOSL continues to rent property in various districts/constituencies around the island in order to achieve that target they would have to build their own facilities that will be built with the mind set of achieving that target. The target was set with no clear strategy for achieving it. It is past 2020 and while a few EE interventions have taken place there is need for more investments.

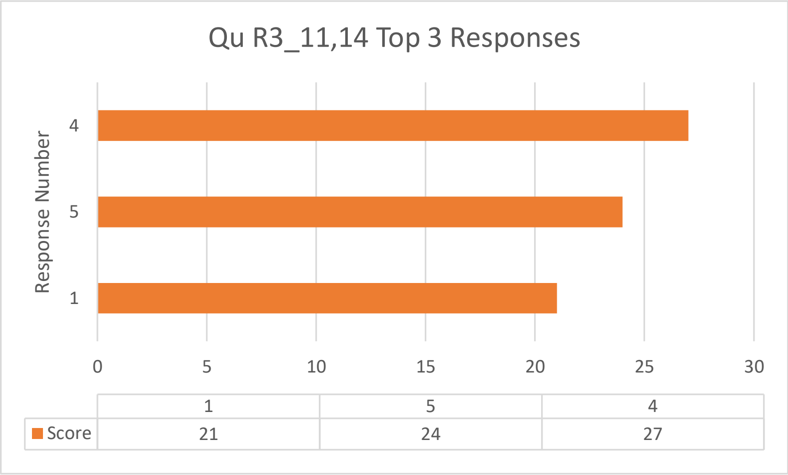
3) No (Higher), it can be closer to 50%. Should aim higher.



3) Tourism because collectively, it's the largest single commercial utiliser, impact of cost of energy receives greater attention hence there is a basis for collective strategies to be formulated. Tourism related services. Hotel sector.

4) The manufacturing sector, though there are not many, should receive priority. Private business (manufacturers), Commercial, Industrial, Construction.

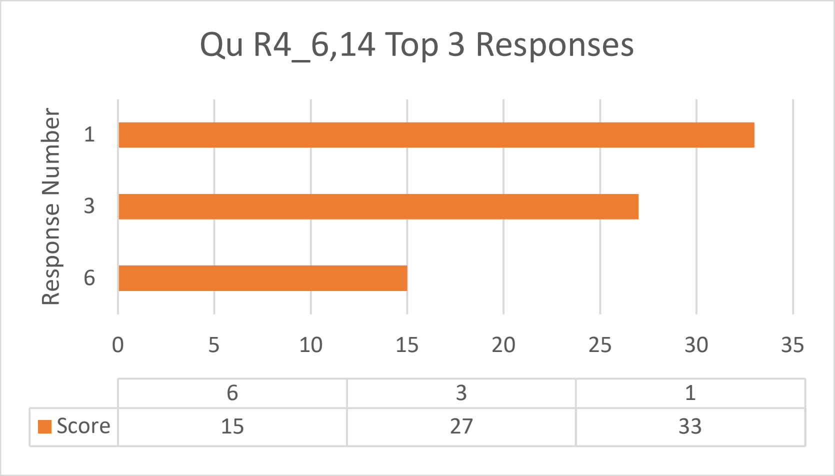
4) The public transportation sector and the government fleet of vehicles. These all-use fossil fuels the foremost source of pollution and GHG. Transportation sector, public transport – minibuses can be mandated to be replaced with hybrids or vehicles with an agreed fuel economy. Suggested lower import duties and road tax on these. The transportation and commercial sectors should receive support. Especially bus, taxi and government transportation.



4) Improve the reliability of the system to climate change and the yearly occurrences of adverse weather systems. Reliability and low environmental impact. Deliver reliable energy services, which is little affected by weather conditions (after a storm, heavy rains, lightning strikes). Limiting the impact of exogenous shocks in that sector, resilience to natural or manmade disasters. To limit the impact on the infrastructure from various events such as weather and cyber-attacks as well as having the means of restoring systems as quickly as possible. Micro grids will help in this regard, particularly if there is extensive damage to transmission and distribution networks. Establish an energy system that addresses the challenges and impact of climate change as well as Natural hazards, e.g., hurricanes. Ensuring energy security, efficiency and reliability. Decrease vulnerability of the energy system. Developing a system that can speedily recover from shocks. Reducing vulnerability to natural hazards. Decreasing the length of disruption in services following natural hazards. Decreasing time of restoration of services to critical infrastructure and services.

5) Sustainable, affordable and environmentally friendly energy systems should be our objectives. Cleaner energy. Enactment of policies to ensure that energy infrastructure is maintained and developed to continue to support energy system resilience. Our aims should be to operate in the most environmentally (friendly) ways, to reduce waste and emissions and to bring in more affordable energy sources. Overcome key risks and vulnerabilities (climate and otherwise) of the island's energy systems by enhancing resilience of entire energy value chain (infrastructure and processes). Reduced carbon emissions, healthier country. Less reliance on foreign assistance – leads to reduced debts.

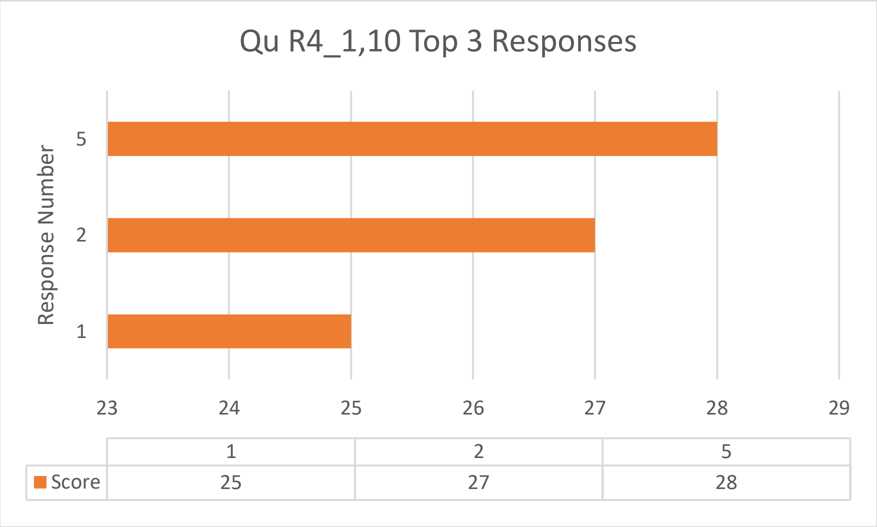
1) Cost reduction, cheaper energy. Reduce the financial cost of energy for businesses; Reduced cost of living (after the initial setup is factored). Opportunities to supply better services for the people since a major expense for the country is the importation of fuels. More stable cost of energy.



1) Ability to produce and therefore determine cost of energy. Reduce price volatility. Price containment in terms of the tariff. Introduce dividend programmes, incentives and subsidies for renewable energy use, and carbon taxes, loss of subsidies for less desirable forms of energy. Cheaper energy. Reduced energy cost and associated economic benefits to be derived. Economic benefits at the personal level. More useable income in the wallet. Energy security, limiting the impact on climate change as well as lowering cost to increase the country's competitiveness and standard of living. Reduce Energy costs. To benefit from the lower cost of energy generation from renewable energy. Achieve savings in fuel cost, redeployment of savings to other sectors, economic resilience building.

3) Reliability and low environmental impact. Achieving energy security, affordability while maintaining very reliable services.

6) Reduce greenhouse gas emissions by 50% and improve air pollution. As time goes by our quality of life is hindered by our use of fossil fuels for energy; more children are born annually with allergies and sensitivities with developmental issues. With a polluted environment, development and growth are stunted. With renewable energy and its efficient use, we will have less pollutants transmitted in the air we breathe, absorbed by the foods we eat, and carried in the water we drink. To reduce carbon dioxide emissions and attain Saint Lucia's NDC targets. Environmentally friendly, cleaner energy. Cleaner environment. Environmental protection and emissions reductions. Institute a cap on carbon emission.



	1	2	5
Score	25	27	28

5) Greater awareness for buy-in to shift to use of RE as users and practitioners, accessibility to incentives. Town hall meetings, call in programmes, radio and television talk shows, Target schools and hold discussions with students. Target workplaces, particularly those in the industrial/manufacturing sector which are significant contributors to carbon emission. Actively engage in consultative processes to shape policy. Advocacy with a view to motivating the late adopters and laggards, Testimonials. Provide opportunities and information for feedback on national energy plans and activities. For any country the success of transitioning to sustainable energy is dependent on acceptance and participation of the General Public. The public must be engaged and be made aware of the benefits associated with sustainable energy so that they can participate….

2) Purchasing energy-efficient appliances. Implement RE, energy conservation and energy efficiency measures that are affordable and cost effective, et cetera. This should be done through investments in energy-efficient vehicles like electric cars and buses. Adopting best practices and measures in the conservation of energy at their homes and businesses.

1) Think Green and getting into the habit of building houses that run on solar. Allowing them to generate their own energy. Persons who can afford should move to solar energy to run their homes and small businesses. Promoting self-generation and alternatives to fossil energy use. Provide opportunities for green business based on sustainable energy. Provide opportunities for accessing sustainable energy products. The ability to convert waste, for example, wastewater for use in other purposes and reviewing their energy consumption patterns.

Appendix B – Table of Delphi survey stakeholders

Stakeholder	Stakeholder Category	Profession	Round 1	Round 2	Feedback Round
Windward Islands Gases	Professionals from other Sectors	Manager	X	X	X
LUCELEC	Subject Matter Expert	Engineer	X	X	X
LUCELEC	Subject Matter Expert	Engineer	X	X	X
OECS Commission	Subject Matter Expert	Programme Coordinator - Sustainable Energy	X	X	X
National Utilities Regulatory Commission	Subject Matter Expert	Economist	X		X
St. Lucia Air and Seaports Authority	Professionals from other Sectors	Project Manager	X		X
St. Lucia Bureau of Standards	Professionals from other Sectors	Director	X		
The East Caribbean Financial Holding Company	Professionals from other Sectors	Banker	X	X	X
Goddard Enterprises Ltd	Professionals from other Sectors	Manager	X	X	X
Ministry of Agriculture	Professionals from other Sectors	Agriculture Officer	X	X	
ARMANA Consult	General Public	Engineer	X		
Ministry of Education	General Public	School Principal	X	X	X
Farmer	General Public	Entrepreneur	X	X	X
Auto Specialist Ltd.	General Public	Entrepreneur	X	X	X
The East Caribbean Financial Holding Company	Professionals from other Sectors	Engineer		X	X
Ministry of Education	General Public	School Teacher	X	X	
Export Saint Lucia	Professionals from other Sectors	Manager		X	
Innov8 Engineering Systems	General Public	Engineer	X	X	X

Department of Energy, Ministry of Infrastructure	Subject Matter Expert	Chief Energy Officer	X	X	X
Ministry of Sustainable Development	Subject Matter Expert	Chief Sustainable Development and Environment Officer	X	X	X
Retired Laboratory Technician	General Public	Technician	X	X	X
Farmers’ Cooperative Credit Union	General Public	HR Specialist	X	X	X
USAID	General Public	Social Sector Specialist	X	X	X

Appendix C – Renewable Energy Resource Potential

Wind Energy Potential

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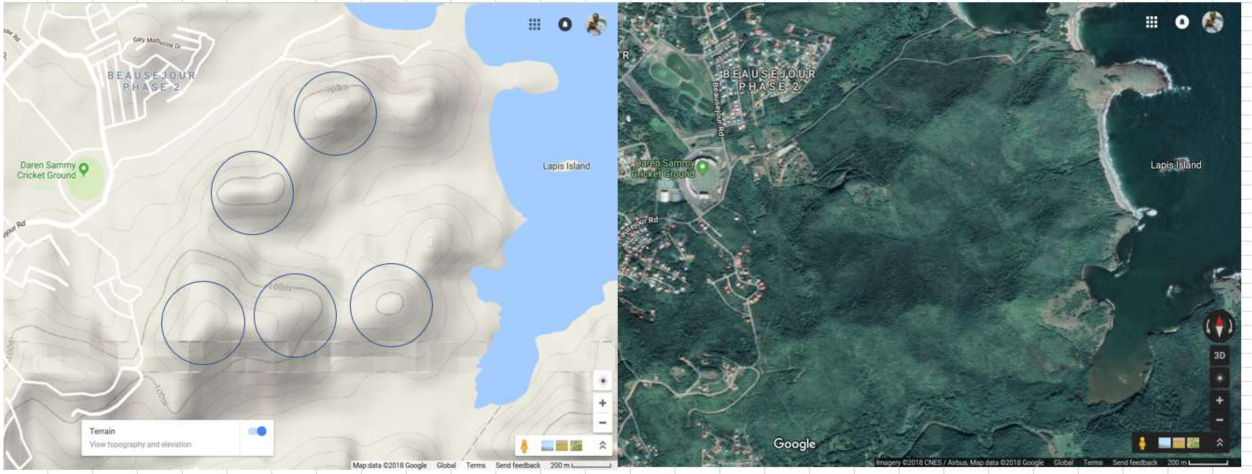

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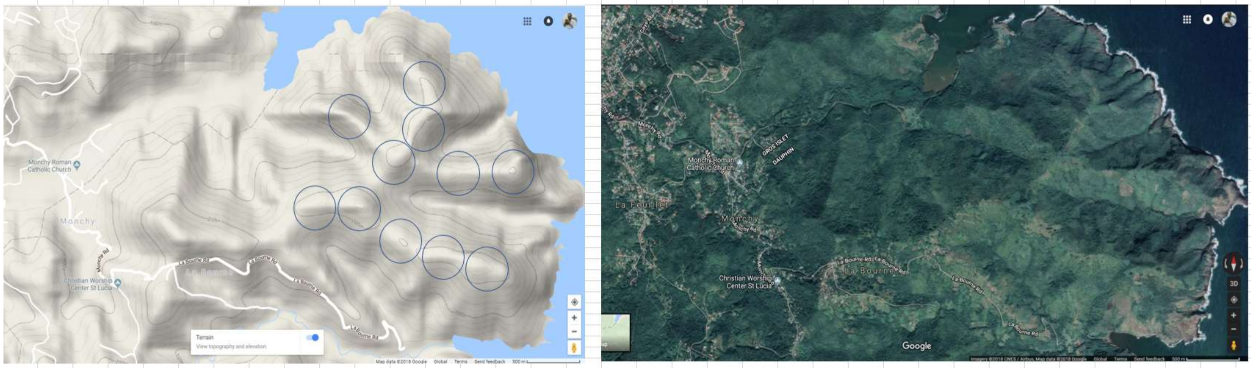

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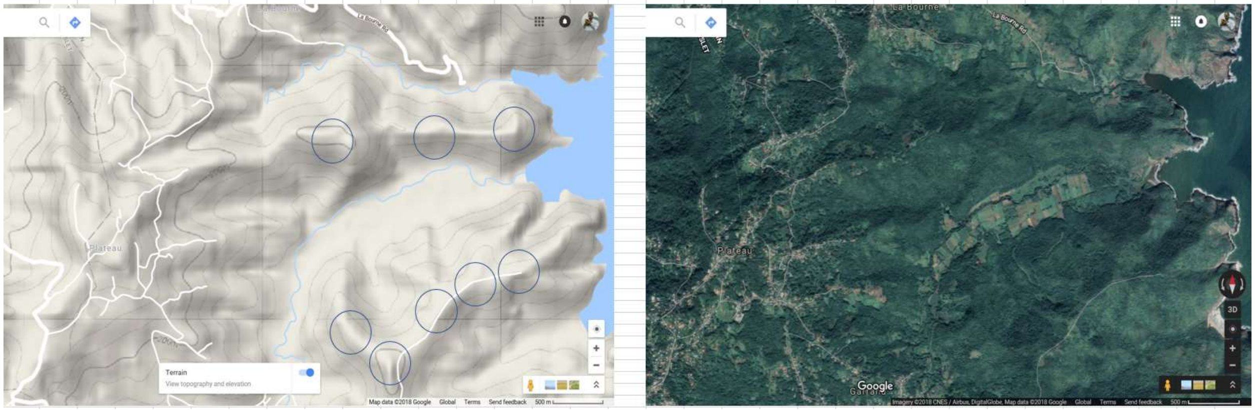

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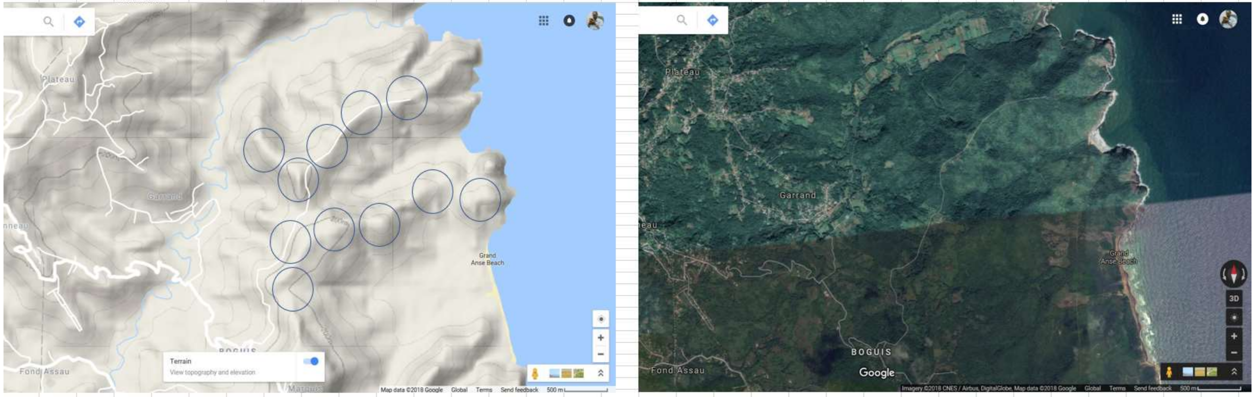
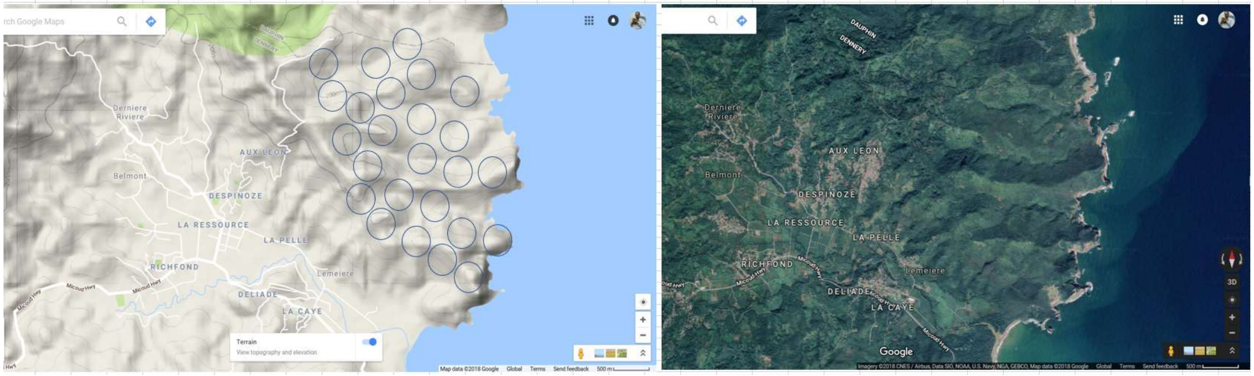


DENNERY



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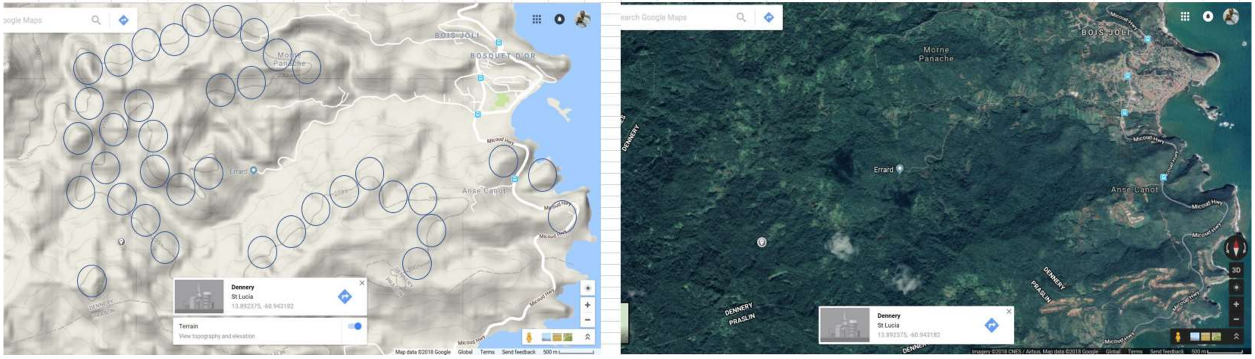
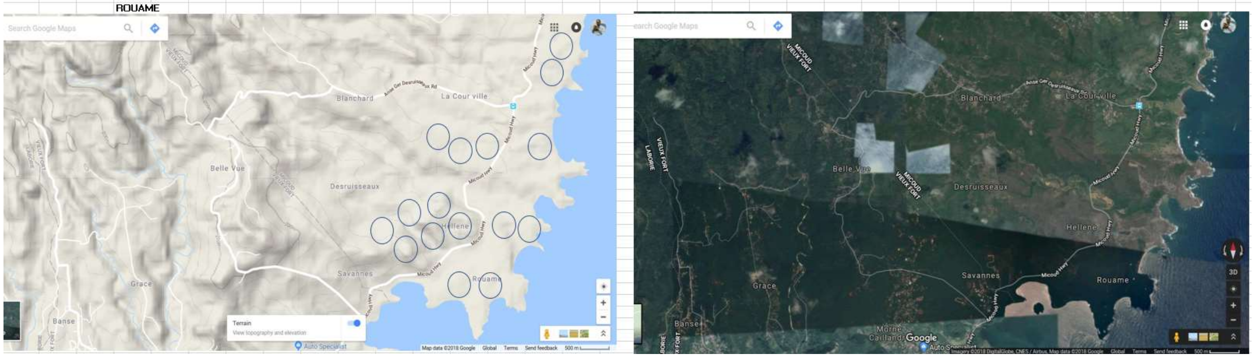
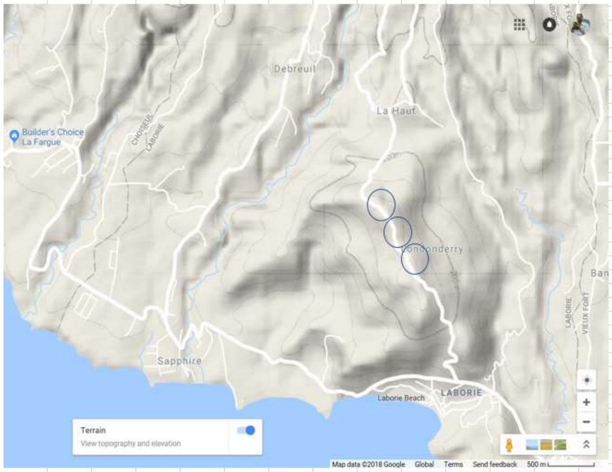
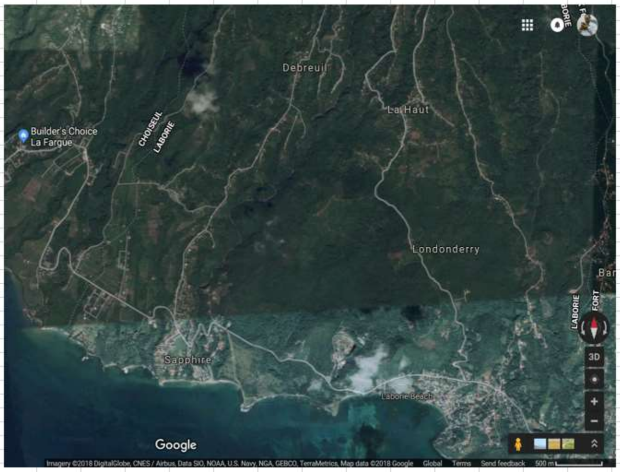


ROUAME



LONDONDERRY



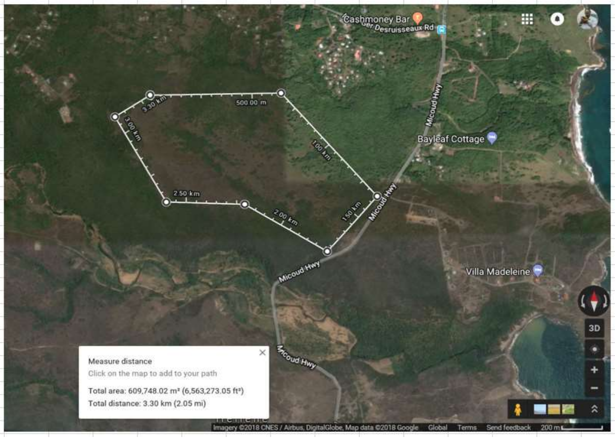


Individual turbine size 2.3 MW

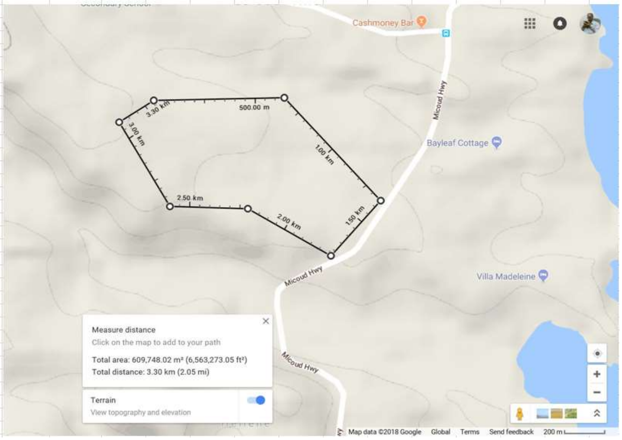
Location	No of Turbines	Total potential in MW
Dauphin	5	11.5
Dauphin 2	11	25.3
Dauphin 3	8	18.4
Dauphin 4	11	25.3
Dennery	25	57.5
Anse Canot	37	85.1
Rouame	16	36.8
Londonderry	3	6.9
	Total	266.8

Solar Energy Potential

Desruisseux

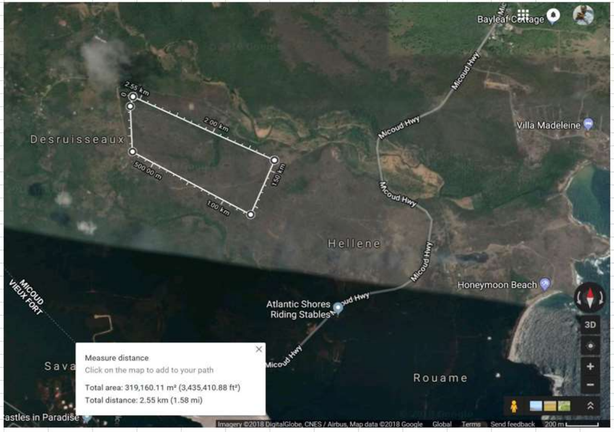


Measure distance
Click on the map to add to your path
Total area: 609,748.02 m² (6,563,273.05 ft²)
Total distance: 3.30 km (2.05 mi)

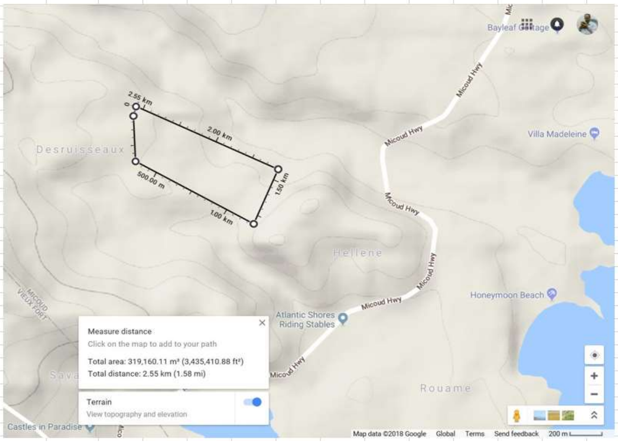


Measure distance
Click on the map to add to your path
Total area: 609,748.02 m² (6,563,273.05 ft²)
Total distance: 3.30 km (2.05 mi)

Desruisseux 1



Measure distance
Click on the map to add to your path
Total area: 319,160.11 m² (3,435,410.88 ft²)
Total distance: 2.55 km (1.58 mi)



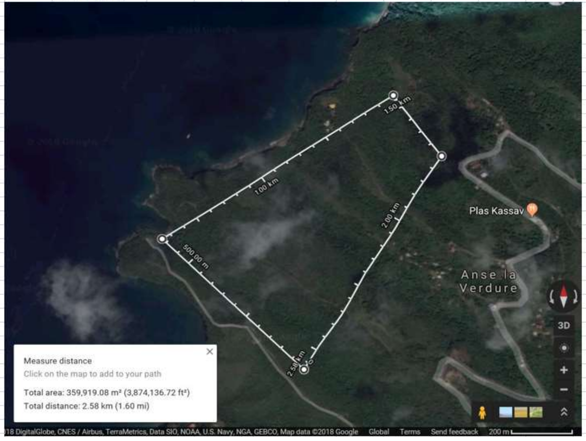
Measure distance
Click on the map to add to your path
Total area: 319,160.11 m² (3,435,410.88 ft²)
Total distance: 2.55 km (1.58 mi)
Terrain
View topography and elevation

Mahaut

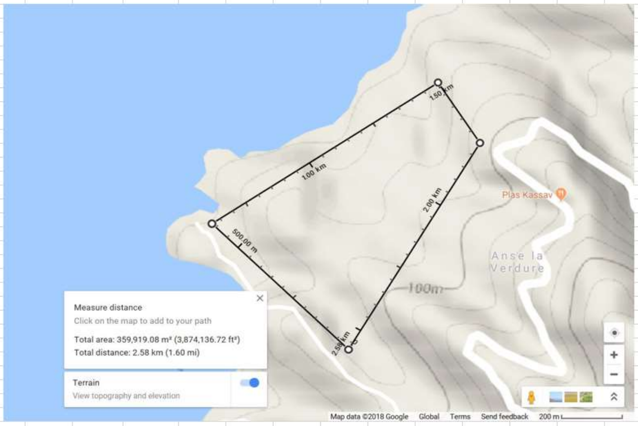
Measure distance
Click on the map to add to your path
Total area: 379,398.01 m² (4,083,806.21 ft²)
Total distance: 2.85 km (1.77 mi)

Measure distance
Click on the map to add to your path
Total area: 379,398.01 m² (4,083,806.21 ft²)
Total distance: 2.85 km (1.77 mi)
Terrain
View topography and elevation

Anse la Verdure



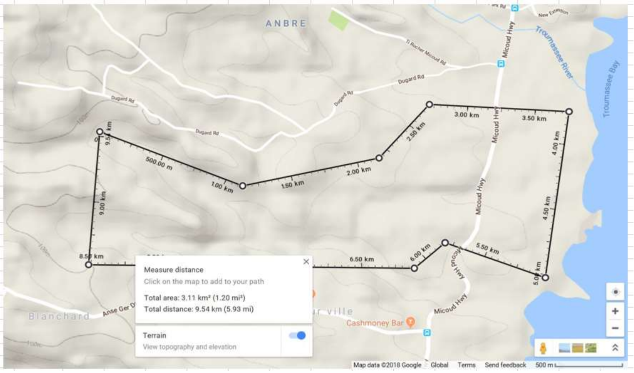
Measure distance
Click on the map to add to your path
Total area: 359,919.08 m² (3,874,136.72 ft²)
Total distance: 2.58 km (1.60 mi)



Measure distance
Click on the map to add to your path
Total area: 359,919.08 m² (3,874,136.72 ft²)
Total distance: 2.58 km (1.60 mi)
Terrain
View topography and elevation

Micoud

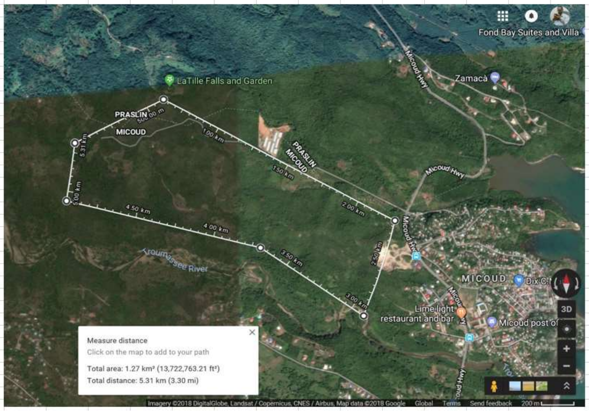
Measure distance
Click on the map to add to your path
Total area: 3.11 km² (1.20 mi²)
Total distance: 9.54 km (5.93 mi)



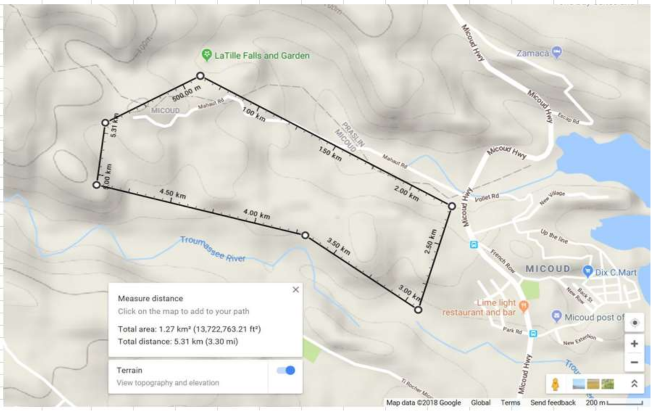
Measure distance
Click on the map to add to your path
Total area: 3.11 km² (1.20 mi²)
Total distance: 9.54 km (5.93 mi)

Terrain
View topography and elevation

Micoud1



Measure distance
Click on the map to add to your path
Total area: 1.27 km² (13,722,763.21 ft²)
Total distance: 5.31 km (3.30 mi)



Measure distance
Click on the map to add to your path
Total area: 1.27 km² (13,722,763.21 ft²)
Total distance: 5.31 km (3.30 mi)

Terrain
View topography and elevation

Location	Area available in m^2	Solar Potential in kWp
Desruisseux	609748	38334.19
Desruisseux 1	319160	20065.24
Mahaut	378398	23789.47
Anse la Verdure	359919	22627.72
Micoud	3110000	195522.3
Micoud 1	1270000	79843.52
	Total	380182.4