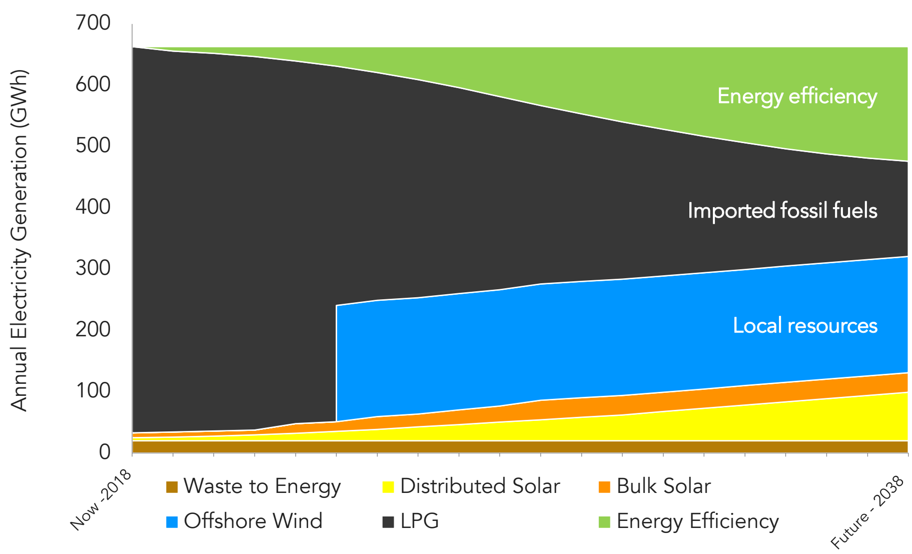
REGULATORY AUTHORITY OF BERMUDA

INTEGRATED RESOURCE PLAN CONSULTATION

Alternative proposal for bulk generation and demand side resources

THE BERMUDA BETTER ENERGY PLAN



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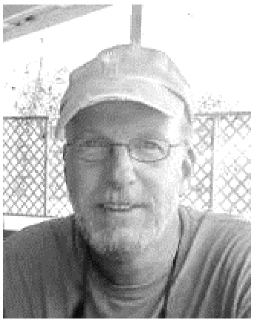
Etude

December 2018 | Rev E

IN MEMORY OF BARRETT LIGHTBOURN



At the request of Bermuda Engineering Company Limited (BE Solar), this alternative proposal has been dedicated to Barrett Lightbourn, one of the finest professional engineers and geniuses in the energy sector that Bermuda has ever known.

Barrett was far ahead of his time and since the 1970s has been responsible for countless energy conservation and renewable energy projects in Bermuda and beyond.

This report has been undertaken in Barrett's honour as a testament to a gentleman whose positive legacy will live on.

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1.0 EXECUTIVE SUMMARY

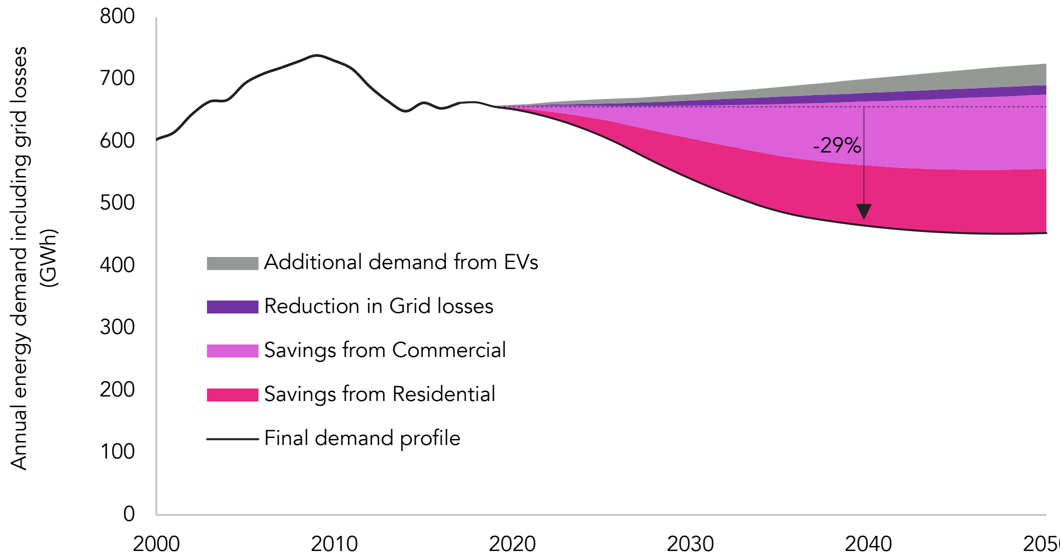
Bermuda is on the front line of climate change facing risks from sea level rise, more intense hurricanes and changing patterns of rainfall. These will affect Bermuda's entire way of life, from her ability to remain an attractive destination for international business and tourism, to being able to maintain supplies of drinking water. This Alternative Proposal examines whether Bermuda can reduce its contribution toward climate change from the use of fossil fuels, while minimising the cost of electricity.

This Alternative Proposal has been developed at the request of Bermuda Engineering Company Limited (BE Solar) as a response to the Regulatory Authority of Bermuda's consultation on the TD&R licensee's Integrated Resource Plan (IRP) for Bermuda. The approach used in this proposal follows closely the guidelines set out by the Regulatory Authority of Bermuda and the Electricity Act 2016 with regard to integrated resource plan development.

Global best practices in IRP development have also informed our work. We aim to provide transparency in terms of both our methodology and assumptions. We are aware that important decisions on the future of Bermuda's energy mix depend on the conclusions of this consultation, therefore we have consulted with industry experts in Bermuda and the UK, and combined hundreds of individual data points to produce robust results.

Based on the Integrated Resource Plan Guidelines Order issued by the Regulatory Authority of Bermuda, this Alternative Proposal considers a planning horizon of 20 years, from 2018 to 2038. A three-year plan is also presented, outlining key short-term actions arising from the conclusions of our analyses. Some projections are extended beyond 2038 to 2050, where this provides useful context.

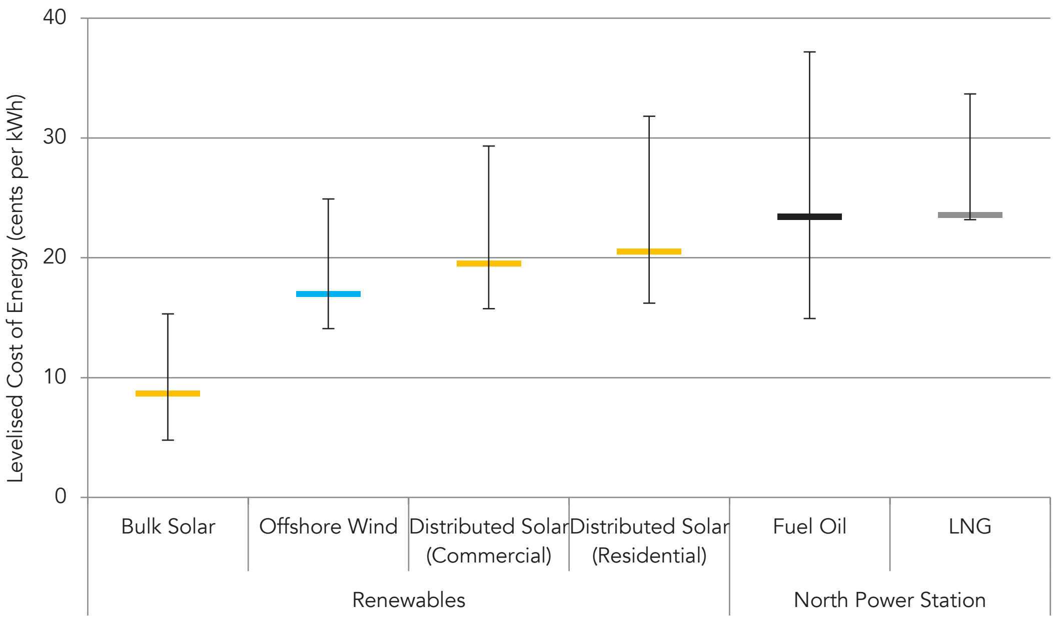
This proposal adopts the existing baseline demand and load forecast by the TD&R licensee's IRP, which has been reviewed for plausibility. The projection has been updated to use more recent consumption data, and to show change up to 2050 to allow comparison with international targets for carbon reduction. These forecasts suggest that growth in energy demand and peak load have stagnated, with little growth expected over the study period.



Projected energy demand up to 2050 showing additional demand from electric vehicles, and savings projected from commercial and residential efficiency

The potential for demand side resources have been considered through detailed sectoral level analyses, identifying likely demand reductions from the deployment of cost-effective energy efficiency measures. Although detailed financial analysis of these measures fell outside the scope of this proposal, evidence suggests they offer a least cost option relative to electricity generation. The uptake of electric vehicles has also been considered, with over 4,000 expected to be on the road by the end of the study period. These have been factored in to produce revised demand and peak load curves that account for both efficiency and electric vehicle uptake. This results in a 30% reduction compared to the baseline adopted from the TD&R licensee's IRP.

A range of mature electricity generation technologies are considered. These range from combustion-based generation using fuel oil or LNG to renewable technologies such as solar photovoltaics and offshore wind. Their suitability for use in Bermuda is assessed using a combination of technical performance data, historical weather data and the insight of experts from a broad range of sectors across the energy industry. This allows a robust set of levelized energy costs to be developed, which indicate that renewable energy sources offer the least-cost solution in 2022 and beyond.



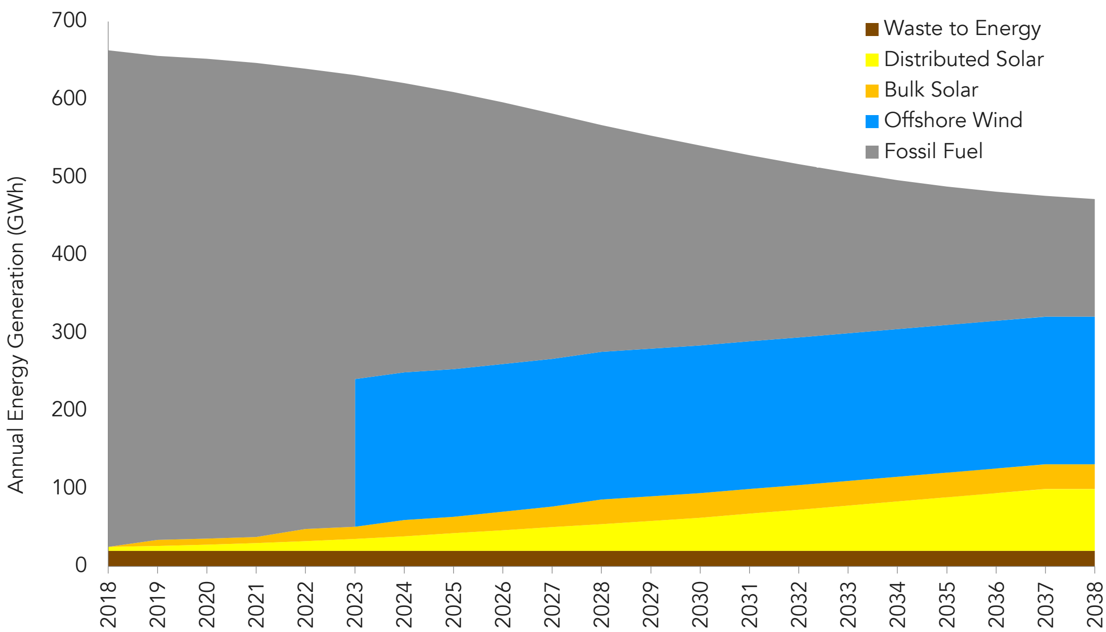
Levelized energy costs calculated for this study, in 2017 dollars
(Coloured bars indicate reference scenario used in dispatch modelling, error bars show high and low scenarios)

The levelized energy costs are applied iteratively to an hourly dispatch model to determine the optimum energy mix for Bermuda. This reveals that substantial carbon reductions of up to 62% are possible by 2038 through the use of solar photovoltaics and offshore wind energy, with balancing provided by LNG or LPG generation and battery storage. The dispatch modelling indicates that high proportions of renewable energy can be integrated into the grid without perceivable impacts on the cost of electricity, based on a conservative test case for 2022. With the cost of solar, wind and storage technologies steadily declining, it is likely that the financial case for low carbon electricity generation will continue to improve in the future.

Informed by the modelling output, a three-year action plan is presented. This represents an important period that is used to build consensus around an energy plan that all of Bermuda supports. The plan assumes that government works with the energy industry to introduce a range of legislative amendments to reduce investment risk for renewables, encourage continued development of distributed solar and ensure the TD&R licensee is able to remain profitable as their role begins to change in the early 2020s. Detailed technical studies into the feasibility of LPG and offshore wind are undertaken while the financial case for an LNG regasification facility in Bermuda is challenged by the prospect of the capacity factor for fossil fuels decreasing from 66% in the baseline scenario to less than 25%.

A longer-term plan covering the period through 2038 is also presented. The early 2020s see the North Power Station come online, together with Bermuda's first multi megawatt battery storage system. Steady growth is observed in distributed solar photovoltaic systems, which offer a least cost option to the consumer, while bulk solar grows quickly as a least cost option to the TD&R licensee.

Mid 2023 is a pivotal year for Bermuda's energy history as a 60MW offshore wind farm comes online, significantly reducing the island's use of fossil fuels in a single project. By the late 2030s several thousand electric vehicles, with a total battery capacity exceeding 145MWh, play an important role in providing demand response. By the end of 2038, wind and solar provide 64% of the island's energy for a stable cost. Around one hundred million dollars a year stays within the local economy that historically would have been spent importing fuel.



Bermuda's changing energy mix in the optimum renewables scenario

The purpose of this document is to provide an objective Alternative Proposal for Bermuda that is robust, forward thinking and will ensure the environmental, financial and societal costs of electricity are set onto a sustainable pathway, with minimal risk to the rate paying public. We believe this goal has been achieved and hope that the Regulatory Authority of Bermuda, TD&R licensee and other stakeholders in Bermuda consider our analyses and recommendations carefully as they decide the best course of action for Bermuda and her people.

2.0 BACKGROUND

This Alternative Proposal has been developed at the request of BE Solar as a response to the Regulatory Authority of Bermuda's consultation on the TD&R licensee's Integrated Resource Plan (IRP) for Bermuda.

The consultation process allows for the submission of alternative proposals for bulk generation and demand side resources. This document considers both bulk generation and demand side resource, while additionally considering distributed generation, which has the potential to form a significant part of Bermuda's electricity generation mix.

2.1 Regulatory Authority of Bermuda (RAB) Bulk Generation Guidelines

The Regulatory Authority of Bermuda (RAB) has set out clear guidelines on what should be included in a Bulk Generation Proposal, which have been followed in the preparation of this document. These requirements include:

- The input assumptions for alternative generation proposals to be consistent with the requirement for a quantitative modelling methodology, including data on capital, operating and fuel costs of future generation future costs;
- The data inputs and assumptions to be transparent and well documented.

2.2 Electricity Act 2016

The Electricity Act 2016 clearly outlines the legislative priorities for Bermuda's energy supply. Section 40 of the Act requires any person submitting an Alternative Proposal to demonstrate how its inclusion in the IRP would result in an electricity supply that is more consistent with the purposes of the Act.

In developing this Alternative Proposal, the purposes of the Electricity Act 2016 were specifically considered. These purposes are set out in Section 6 of the Act and reproduced below:

(1) to ensure the adequacy, safety, sustainability and reliability of electricity supply in Bermuda so that Bermuda continues to be well positioned to compete in the international business and global tourism markets;

(2) to encourage electricity conservation and the efficient use of electricity;

(3) to promote the use of cleaner energy sources and technologies, including alternative energy sources and renewable energy sources;

(4) to provide sectoral participants and end-users with non-discriminatory interconnection to transmission and distribution systems;

(5) to protect the interests of end-users with respect to prices and affordability, and the adequacy, reliability and quality of electricity service;

(6) to promote economic efficiency and sustainability in the generation, transmission, distribution and sale of electricity.

Section 40 of the Act also states that the IRP should consider the following:

- all possible resources, including new generation capacity, demand side resources (including demand response and energy efficiency), and retirement of generation capacity; and

- a range of renewable energy and efficient generation options, and a prudent diversification of the generation portfolio.

2.3 Approach

This alternative proposal is structured in seven sections:

2.0 The legislative and regulatory context surrounding this Alternative Proposal is considered. This ensures the Alternative Proposal is aligned with Bermuda's energy agenda.

3.0 Key assumptions are presented and the modelling methodologies used in the development of this alternative proposal are explained. This provides transparency and allows for replicability of results.

4.0 Demand and load forecasts for electricity are established through a sectoral level analysis and robust projections based on a variety of data.

5.0 The potential for demand side resources to reduce energy demand in Bermuda is assessed, considering current practices across the sectors and available technologies.

6.0 Bulk and distributed electricity generation options are examined using hourly dispatch modelling. They are compared in terms of cost, environmental impact, reliability and diversification of supply.

7.0 A three year action plan is presented that best meets the purposes of the Electricity Act 2016 over the proposal period, with longer-term projections provided for context.

8.0 Key insights arising from the modelling and research carried out to develop this alternative proposal are presented.

Appendices contain a range of background information and further detailed assumptions for reference.

3.0 METHODOLOGY AND ASSUMPTIONS

3.1 Methodology

3.1.1 Timeframe

The Alternative Proposal considers the 20-year period from 2018 to 2038, and then through to 2050. This is based on the Integrated Resource Plan Guidelines Order issued by the Regulatory Authority of Bermuda, which advises that given the asset lifetime for electricity infrastructure the planning horizon should be at least 20 years. Etude determined that considering the lifetime of many renewable and fossil fuel generators ranges from 25-30 years, the chosen timeframe is appropriate.

3.1.2 Modelling

A variety of modelling approaches have been adopted to forecast load, predict the potential for demand side resources and assess the carbon and cost impact of various generation mix scenarios. These are explained in more detail below.

A similar approach to the TD&R licensee integrated resources plan (TD&R IRP) has been used in this Alternative Proposal. Only proven technologies appropriate for the island of Bermuda have been considered. The mix of technologies has been optimised in eight scenarios based on the Levelized Cost of Energy and carbon emissions for each technology.

Demand Projections are developed on the same basis as the TD&R licensee's integrated resources plan. Energy demand is shown to follow economic indicators and so an economic forecast is used to extend historic consumption data normalised for weather. The peak load was derived from the annual demand on a percentage basis through comparison with historical averages. The baseline demand is shown excluding the impact of electric vehicles and energy efficiency so that these items can be considered separately.

Electric Vehicle Uptake is based on the annual vehicles sales on the island. A growing proportion are electric vehicles, and these replace the relatively stable number of existing vehicles. A moderately high case for the popularity of electric vehicles is used as a conservative case for increasing demand.

Energy Efficiency is considered in detail as the 'first technology' to use for electricity generation. Simply put, increasing efficiency reduces the amount of generation capacity required. To calculate the energy savings, demand is broken down by consumer type, and then by use. Change due to increased use is assumed to be included in economic growth. Conservative estimates of the effect of individual technologies on energy demand are considered to project overall demand reductions.

Levelized Cost of Energy calculations were performed using the standard approach of dividing total lifetime costs by the lifetime energy production for each generation technology. A high and low case was investigated for each generation technology to capture the inherent uncertainty and variation in energy costs. A levelized cost of energy screening did not rule out any electricity generation technologies as viable candidates for the dispatch modelling.

Dispatch Modelling was performed for a variety of future generation mix scenarios. This was carried out on an hourly basis using a simulated demand curve for electrical load based on historical data released by the TD&R licensee, and adjusted based on the most recent peak demand information available. Local data for the wind and solar resource was based on Bermuda Weather Service measurements from 2015 and adjusted to represent long term averages.

Planning Reserve Margin was forecast based on a similar approach to the TD&R licensee's IRP. The reserve margin considers a reduction in the ability to meet peak load in the case of failure of two of the largest capacity generators. As renewable generation resources do not provide firm capacity, they have been excluded from the planning reserve margin calculation.

Capacity Gap Analysis was performed using the TD&R licensee's projected generator retirement schedule. It was assumed that the new engines in the North Power Station would be installed. Peak system load was taken from Etude's baseline scenario including energy efficiency improvements. This factored in a revised model of electric vehicle uptake and additional reductions in demand based on a sectoral assessment of likely energy efficiency deployment.

3.2 Assumptions: demand forecast

The table below shows the assumptions taken directly from the TD&R licensee's IRP, and those which have been developed further by Etude in this report.

Impact on resources	TD&R licensee's IRP approach	Etude alternate IRP approach
Effect of weather on electricity demand	Historic energy demand compared to consumption normalized for weather and shown as similar.	TD&R licensee's IRP assumed robust. Historic energy demand used without correction.
Uncertainty of economic growth	Various sources of economic data considered. 0% growth assumed over study period.	No change
Electric vehicles	Uptake profile based on Bloomberg New Energy Finance report. 14GWh additional demand by 2037. Excluded from load projections.	Stated assumptions for uptake based on vehicle sales forecasts and updated Bloomberg report. 21GWh additional demand by 2037. Excluded from load projections.

Table 1 – Summary of assumptions for demand forecast

3.3 Assumptions: environmental impact

The environmental impacts from different generation technologies are quantifiable and should be considered for three reasons:

1. **Contribution toward climate change.** Emissions from electricity generation in Bermuda that contribute toward climate change are quantified as grams of carbon dioxide equivalent per kilowatt hour of electricity generated (gCO_{2eq}/kWh).
2. **Impact on human health.** Emissions from electricity generation in Bermuda that contribute toward negative impacts on human health include nitrous oxides, sulphur dioxide and particulate matter (PM10 and PM2.5). Additionally, Dioxins and Furans may be produced by waste to energy plants.
3. **Other environmental impacts.** There are a wide range of other environmental impacts from different electricity generation technologies. These may range from biodiversity loss resulting from extraction and processing of fuels and materials to disposal of technologies at their end of life. To limit the scope, these have not been considered in this study.

3.3.1 Greenhouse gas emissions from electricity generation

This report considers the global warming impact of electricity generation technologies using life-cycle greenhouse gas emissions. In the context of islands such as Bermuda, this is particularly important as emissions associated with extraction, manufacturing and transportation on the mainland can be significant. The following paragraphs describe the evidence used to establish carbon emissions factors for electricity generation technologies. The final figures assumed in modelling are in line with the findings of the International Panel on Climate Change[1], who have reviewed 125 separate sources.

Waste to energy

The emissions factor for waste to energy electricity generation depends on the fuel mix. A comparative study[2] of commercial technologies in the US concludes an emission factor of 1000 gCO_{2eq}/kWh for gasification of waste, and 1600 gCO_{2eq}/kWh when incinerated. Waste to energy by incineration in the UK produces 890 gCO_{2eq}/kWh[3] Error! Bookmark not defined.. A figure of 1000 gCO_{2eq}/kWh has been assumed for Bermuda.

1000
gCO_{2eq}/kWh

Oil

The life-cycle emissions of oil-based electricity varies from 700 to 1150 gCO_{2eq}/kWh[4,5]. Based on the latest figures published by the US Energy Information Administration, the emissions factor for oil generation is around 957 gCO_{2eq}/kWh. A baseline for Bermuda was established based on DEFRA carbon factors for fuel oil and generation efficiencies quoted in the TD&R licensee's IRP. A figure of 900 gCO_{2eq}/kWh has been assumed to allow for international shipping.

900
gCO_{2eq}/kWh

Liquified Natural Gas (LNG)

The life-cycle emissions of natural gas increases when converted to liquefied form (LNG) for transportation. A review of literature[6,7,8,9] indicates emissions range from 380-750 gCO_{2eq}/kWh. A baseline for Bermuda of 600 gCO_{2eq}/kWh was established based on DEFRA carbon factors for fuel oil and generation efficiencies quoted in the TD&R licensee's IRP. Future proposals to reduce emissions to 80-120 gCO_{2eq}/kWh[6, 10] by 2050 using carbon capture and storage are unlikely to be applicable to Bermuda due to geotechnical storage constraints.

600
gCO_{2eq}/kWh

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[1] IPCC (2011) *Special report on renewable energy sources and climate change mitigation.*
[2] Wilson et al. (2013) *A comparative assessment of commercial technologies for conversion of solid waste to energy.* (EnvironPower Renewable, Inc)
[3] Jeswani & Azapagic (2016) *Waste management.* (Elsevier)
[4] World nuclear association (2011) *Comparison of lifecycle greenhouse gas emissions of various electricity generation sources.*
[5] World Energy Council (2004) *Comparison of energy systems using life cycle assessment.*
[6] Ricardo-AEA (2013) *Current and Future Lifecycle Emissions of Key "Low Carbon" Technologies and Alternatives.* (Committee on Climate Change UK)
[7] IPCC (2014) *Chapter 7 Energy systems, Climate change 2014 fifth assessment report.*
[8] Hardisty et al. (2012) *Life cycle greenhouse gas emissions from electricity generation: A comparative analysis of Australian energy sources.* (MDPI)
[9] World nuclear association (2011) *Comparison of lifecycle greenhouse gas emissions of various electricity generation sources.*
[10] Pehl et al. (2017) *Understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modelling.* (Nature)

Solar

The only emissions from solar energy arise from manufacture, installation, maintenance and disposal. These vary depending on the cell chemistry, module type and location. Generally, emissions factors range from 20-85 gCO_{2eq}/kWh[11,6], with a nominal value of around 50 gCO_{2eq}/kWh[6,12]. The value for Bermuda is likely to lie at the lower end of the spectrum due to the high capacity factor from its sunny climate. The adoption and development of more efficient materials and structures are projected to further reduce the emission factor by 70% to less than 7 gCO_{2eq}/kWh[10] in 2050.

35
gCO_{2eq}/kWh

Offshore Wind

Generally, electricity generated by wind turbines produces the lowest greenhouse gas emissions over its lifetime when compared to all other technologies. As with solar, emissions occur due to manufacture, installation, maintenance and disposal. Emissions factors range from 6–34 gCO_{2eq}/kWh[6,9,11,11]. Offshore wind farms are the only viable option for Bermuda due to limited landmass. These typically exhibit lower life-cycle emissions as turbine size increases, resulting in greater lifetime energy production. Projected values for 2050 drop to 2 gCO_{2eq}/kWh[6,10] for a 5MW offshore wind turbine.

8
gCO_{2eq}/kWh

3.3.2 Impact of other emissions on human health

The impact of emissions from fossil fuel generation on human health is well established. There are a variety of health impacts from airborne exposure to NO_x, SO_x, PM_{10}, $PM_{2.5}$, nickel, chromium and other heavy metals[13]. These are recognised as risk factors for asthma, various types of cancer, heart disease and birth defects. A recent study[14] discovered a 20-25% decrease in the rate of premature births following the closure of oil and coal power stations. There is also an exposure pathway to combustion residues through drinking water due to ash accumulation on nearby roofs entering the water supply.

While it was beyond the scope of this alternative proposal to investigate and quantify these impacts, we recommend this is investigated in Bermuda. The cost of technologies to reduce emissions such as electrostatic precipitators and flue gas desulphurisation could be included in future IRP's, providing a more accurate indication of the broader environmental and societal costs of different generation technologies.

3.4 Assumptions: levelized cost of energy

A range of levelized costs of energy have been calculated for the generation technologies considered in this Alternative Proposal. The assumptions used to develop these will strongly influence the dispatch modelling and ultimate conclusions of this report. We have therefore researched multiple

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[11] Hertwich et al. (2015) *Integrated life-cycle assessment of electricity-supply scenarios confirms global environmental benefit of low-carbon technologies.* (PNAS)
[12] Nugent et al. (2014) *Assessing the lifecycle greenhouse gas emissions from solar PV and wind energy: A critical meta-survey.* (Energy Policy, Elsevier)
[13] Pudasainee et al (2008) *Hazardous air pollutants emission from coal and oil-fired power plants.* (Pohang)
[14] Casey et al. (2018) *Retirements of Coal and Oil Power Plants in California: Association with Reduced Preterm Birth Among Populations Nearby.* (Berkeley)

datasets and consulted with a range of industry experts across Bermuda and the UK to ensure our estimates are robust and transparent.

We have developed a high and low case for each technology to represent the likely cost range, and from these we have identified the most likely reference costs to use in the dispatch modelling. All levelized energy costs have been calculated for 2022, as this is the first year that LNG based generation is assumed to be available in the TD&R licensee's proposal. It should be noted that the levelized cost of energy for different technologies calculated in this report are different from those used in the TD&R licensee's IRP.

Although the number of assumptions used in levelized energy cost calculations varies depending on technology, they can generally be grouped into seven categories. Table 2 shows these categories and explores how different generation technologies respond differently to changes in these assumptions.

LCOE Assumptions	Comments
Capital Cost	Capital costs typically represent a greater proportion of overall costs for renewable energy than for fossil fuel generators. Levelized cost of energy (LCOE) calculations for renewables are therefore usually more sensitive to capital cost assumptions, relative to fossil fuel generators.
Weighted Average Cost of Capital (WACC)	Due to the dominance of capital costs, renewable energy projects also tend to be more sensitive to WACC assumptions than fossil fuel generators. Reductions in WACC for solar and offshore wind technology as they have matured has been one of the key drivers behind reductions in LCOE.
Lifetime	The assumed lifetime of generators directly affects the lifetime energy production, which is the main denominator in LCOE calculations. As renewable energy projects have high capital costs, low operational costs and no fuel costs the marginal cost of energy generation is minimal, therefore longer lifetimes reduce the calculated LCOE.
Operation & Maintenance Costs (O&M)	Distributed solar systems can be quite sensitive to O&M costs. Conservative assumptions can easily result in a significant and often unjustified increase in LCOE. Most small solar photovoltaic systems in Bermuda are assumed to be maintenance free.
Capacity Factor (annual energy generation)	The capacity factor for solar systems depends on their tilt, orientation, inverter technology and a range of other technical characteristics. The capacity factor for offshore wind farms also depends on specific turbine characteristics. As lifetime energy production is the main denominator in LCOE calculations, accurately forecasting capacity factor is essential to establishing a robust LCOE. System degradation must also be taken into account. The capacity factor for fossil fuel generators depends on the shape of the load curve and on how they interact with renewable energy and battery storage systems.
Fuel Costs	Applicable to fossil fuel plant only. These are naturally sensitive to fuel cost assumptions.
Efficiency	Applicable to combustion generation only. Generally easy to predict based on known performance of similar generators.

Table 2 – Summary of definitions and comments on the main LCOE assumptions

The following sections explore the assumptions made for each technology in more detail.

3.4.1 Bulk solar photovoltaic

This considers systems over 500kW of installed Direct Current (DC) capacity. Capital costs were assumed to be $1,300 per kW, with a weighted average cost of capital of 7.5%. A 30 year lifetime has been assumed based on power output warranties of this length being commercially available. Fixed maintenance costs of $15/kW per year were assumed based on industry guidance[15]. A capacity factor of 18% was assumed based on historical data from solar energy systems in Bermuda. Solar module degradation was assumed to be 0.4% per year, based on commercially available products.

3.4.2 Distributed solar photovoltaic

This considers systems under 500kW of installed DC capacity. Commercial systems are categorised as those above 15kW and residential systems below 15kW based on the existing interconnection thresholds established by the TD&R licensee.

Capital costs were assumed to be $3,250 and $3,700 per kW for commercial and residential systems respectively. This is based on local system pricing, adjusted using IRENA[16] data to account for future cost reductions while still reflecting the higher cost of solar installations in Bermuda. The weighted average cost of capital was conservatively assumed to be 7.5%. This is higher than current green loans offered by banks in Bermuda, as low as 6.25%. A 30-year lifetime was also assumed for these systems, while maintenance costs were assumed to be $10 per kW per year for commercial systems and $5 per kW per year for residential systems, as these are virtually maintenance free. A slightly higher capacity factor was assumed for residential systems, based on better orientation and tilt angles relative to commercial systems. Solar module degradation was assumed to be 0.4% per year.

Solar water heating was not considered as part of this study based on an analysis of system cost and energy savings, which demonstrated that solar photovoltaic systems and heat pump water heaters generally offer a lower cost solution.

3.4.3 Offshore wind

The capital costs for offshore wind were assumed to be $5,000 per kW. This reflects substantial cost reductions that have recently taken place in the industry, which would be expected to continue through to 2022, while considering their applicability to Bermuda may be limited. The weighted average cost of capital was assumed to be 7.5% based on IRENA guidance. While higher rates could be expected in Bermuda due to additional risks, it was assumed the government would be motivated to reduce these through non-subsidy measures to reduce the cost of electricity.

Turbine lifetime was assumed to be 30 years based on a 25-year baseline with 5-year lifetime extension. Fixed operational and maintenance costs were assumed to be $21 per kW per year while variable costs were assumed to be $0.04 per kWh. These were based on the Bren wind study[17] and independently verified by an industry expert. A baseline capacity factor of 45% was assumed based on Etude's analysis of Bermuda's wind resource, cross referenced with the Bren wind study. Losses of 11.6% were assumed for wake losses, line losses and availability.

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[15] IRENA (2018) *Renewable Power Generation Costs in 2017*
[16] IRENA (2016) *Solar and Wind Cost Reduction Potential to 2025*
[17] Bren School of Environmental Science (2014) *Offshore wind energy in the context of multiple ocean uses on the Bermuda Platform*

3.4.4 Oil generation

The following assumptions were taken from the TD&R licensee's IRP: Capital costs of $1,994 per kW, weighted average cost of capital of 8%, lifetime of 30 years, fixed operating and maintenance costs based on the North Power Station of $36.16 per kW per year, variable operating and maintenance costs of $0.0063 per kWh and an electrical generation efficiency back-calculated at 41%. The assumed capacity factor ranged from 66.54% in the baseline scenario to 41.95% in the high solar scenario and 23.35% in the optimum renewables scenario.

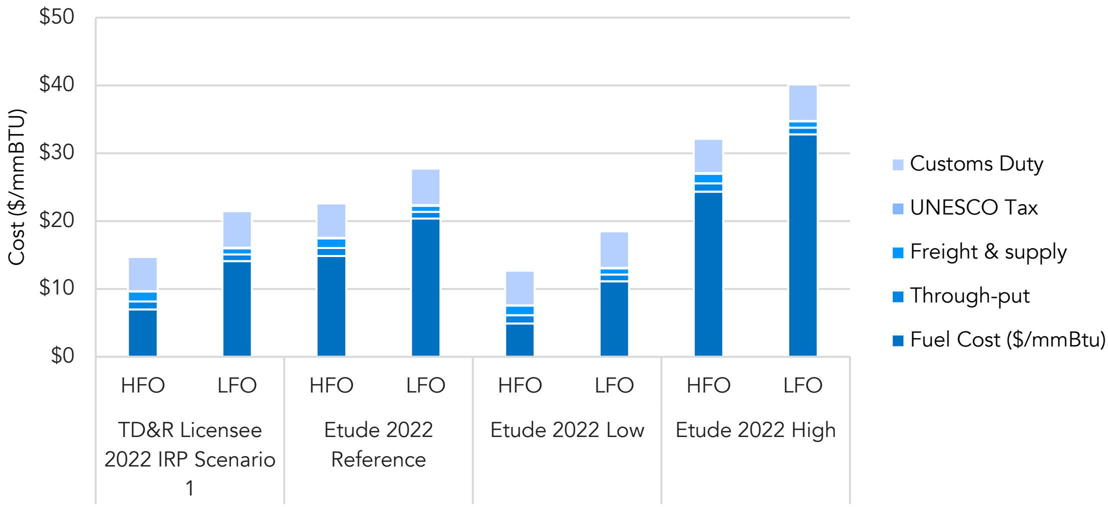

Figure 1 – Range of price assumptions for No 6 (HFO) and No 2 (LFO) fuel oil

As fuel costs represent one of the key sensitivities, they were broken down in detail as show in Figure 1. The reference scenarios for #6 residual fuel oil (HFO) and #2 distillate fuel oil (LFO) were adopted from the US EIA's Annual Energy Outlook 2018 for Etude's reference scenario. The percentage of generation from each fuel source was adjusted based on projections from the TD&R licensee's IRP, which indicated use of 99.57% #6 residual fuel oil and 0.43% #2 distillate fuel oil by 2022. This represents a departure from the historical ratio, which is closer to 74% fuel oil and 26% distillate. All other assumptions were identical to the TD&R licensee's IRP.

3.4.5 LNG generation

The following assumptions were taken from the TD&R licensee's IRP: Capital costs of $2,737 per kW, (assumed to include the cost of conversion to operate on LNG), weighted average cost of capital of 8%, lifetime of 30 years, fixed operating and maintenance costs of $36.16 per kW per year, variable operation and maintenance costs of $0.0063 per kWh and an electrical generation efficiency of 34%. The assumed capacity factor ranged from 66.54% in the baseline scenario to 41.95% in the high solar scenario and 23.35% in the optimum renewables scenario.

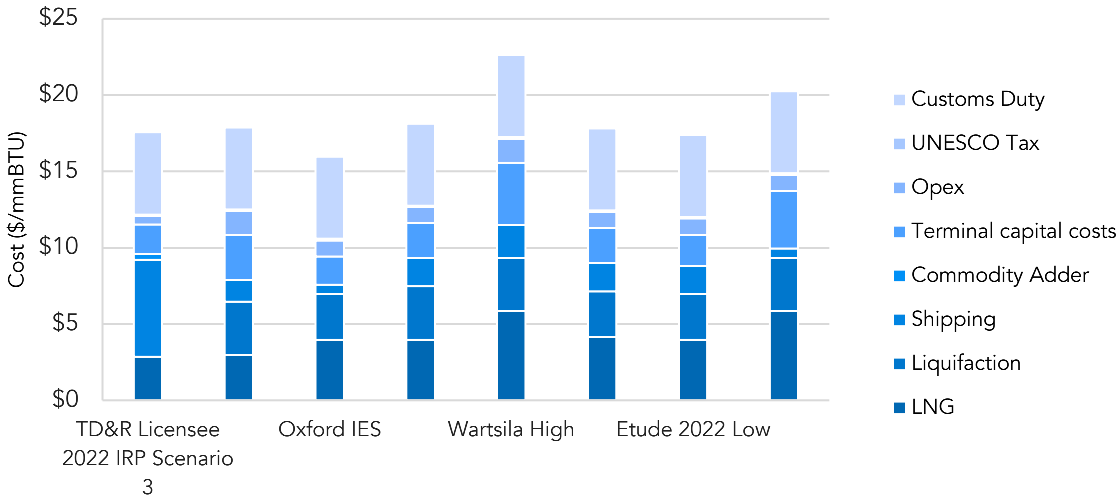

Figure 2 – Range of price assumptions for liquified natural gas in Bermuda

As fuel costs represent one of the key sensitivities, they were broken down in detail as show in Figure 2. The reference scenario for LNG was adopted from the US EIA's Annual Energy Outlook 2018 for Etude's reference scenario. A separate analysis was performed to assess regasification terminal capital costs considering the reduction in electrical energy sales projected by Etude. This indicated that terminal capital cost repayments would be $2.30 per mmBtu, increasing to $3.77 per mmBtu if the cost of a specialised $75M LNG ship is included as suggested by a report commissioned by the Bermuda Government into the feasibility of LNG in Bermuda[18]. A variety of studies and reports by McKinsey, Oxford Institute of Energy Studies[19] and Wartsila[20] were reviewed to develop detailed cost assumptions for the remaining components of LNG cost. Finally, the TD&R licensee's IRP was also used to cross-check these assumptions.

3.4.6 Energy storage systems

$0.20
per kWh

The levelized cost of storage (LCOS) is dependent on the capacity and type of technology specified[21]. For Bermuda, we assume storage will be lithium ion batteries based on current global market trends. The levelized cost of storage using lithium batteries is typically around $0.30/kWh[22], ranging from $0.28-0.80 per kWh[23,24]. The World Energy Council and IRENA predict that costs will drop to $0.15-0.20 per kWh[24,21] by 2030. This value is in line with Etude's calculations for a 4MW / 16MWh system[25] in 2022, based on a 35% reduction in capital costs expected in the next 5-year period[23]. In the future, overall battery capacity of the grid is also likely to include some proportion of electric vehicles.

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[18] Castalia (2014) *Viability of Liquified Natural Gas in Bermuda*
[19] Oxford Institute for Energy Studies (2018) *The LNG Shipping Forecast: costs rebounding, outlook uncertain*
[20] Wartsila (2014) *Small and medium size LNG for Power Production*
[21] IRENA (2017) *Electricity storage and renewables: costs and markets to 2030*
[22] IRENA (2012) *Electricity Storage and Renewables for Island Power*
[23] Lazard (2017) *Lazard's levelized cost of storage analysis version 3.0*
[24] World Energy Council (2016), *E-Storage*.
[25] HDR (2017) *Energy storage technology assessment* (Public Service Company of New Mexico)

3.5 Assumptions: dispatch modelling

Hourly dispatch modelling has been carried out for four different energy generation mix scenarios. Each set of four scenarios has been run assuming the fossil fuel plant operates either on fuel oil or LNG. This resulted in a total of eight scenarios that have been used to compare different options for energy generation in Bermuda.

The total installed capacity of each technology is outlined in Table 3, with the exception of waste to energy as this is assumed to be a constant 2.29MW across all scenarios. This reflects a derated value relative to the 4.00MW peak capacity of Tynes Bay, adjusted so annual energy production matches that assumed in the TD&R licensee's IRP. Local solar and wind resource data from 2015 have been used, calibrated to match long-term annual averages.

The modelling has been carried out for a single reference year in 2022, with all key assumptions based on that year[26]. This year was selected as it is the first year that LNG could become available to include as part of the supply mix. Whilst complete deployment of renewables assumed in the High Solar and Optimum Renewables scenarios is not achievable by 2022, full deployment is assumed in the model as this indicates the cost and carbon implications of each scenario. This approach is deemed to be conservative in favour of fossil fuels as their levelized energy costs will tend to increase over time above the rate of inflation, while those for renewables and energy storage are likely to fall.

	Nominal Generation Capacity (MW)				Battery Storage Capacity (MWh)	
Technology Mix	Fossil Fuel	Bulk Solar	Dist. Solar	Offshore Wind	Bulk	Dist. + EV
1. Baseline	139	6	4	0	5	0
2. Energy Efficiency	139	6	4	0	5	0
3. High Solar	139	24	106	0	100	20
4. Optimum Renewables	139	24	60	60	120	20

Table 3 – Scenarios investigated in dispatch modelling

1. Baseline
The baseline scenario is similar in technology mix to the TD&R licensee's preferred plan (Scenario 3) outlined in their integrated resource plan. This allows for a basis to compare the alternative scenarios in terms of costs and greenhouse gas emissions. The baseline demand projection is used, excluding additional energy efficiency measures. Bulk solar is from the planned phase 1 (6MW) solar PV array on the Airport Finger site, while distributed solar is based on information from local solar installers.

2. Energy Efficiency
This scenario adopts a modified demand projection with no changes to the baseline generation technology mix. The alternative projected demand considers future load reductions from energy efficiency and impact of electric vehicles. This is reflected as a 29.6% decrease in total energy consumption by 2038.

[26] Costs are expressed in 2017 dollars.

3. High Solar

This scenario explores the extent to which Bermuda can exploit solar energy[27] by testing a relatively high adoption of solar PVs. The maximum capacity of useful solar PVs, or renewables in general is restricted by the amount of storage, or demand resource that can be moved to peak generation. Battery storage is assumed to be primarily from centralised bulk batteries, with a small portion of distributed storage expected in the residential and commercial sectors[28]. The levelized cost of energy for Fuel Oil and LNG are adjusted in this scenario to account for the reduced capacity factor of the generating plant.

4. Optimum Renewables

This scenario shows a balanced renewables mix (60MW offshore wind; 84MW solar) to represent an achievable amount of renewable generation on the island. The dispatch model was used to carry out optimisation on the size and proportion of renewable mix based on a reasonable battery capacity and infrastructure deployment. The levelized cost of energy for Fuel Oil and LNG are adjusted in this scenario to account for the reduced use of the generating plant (capacity factor).

[27] Solar PV is very appropriate for Bermuda as it reliably follows the approximate demand profile with peak generation during the day. Up to around 90MW of solar PV installation is possible with no further battery storage than currently installed. Above this the amount of solar energy curtailed, or generated and discarded, in that period is above 5% and seen as too high. In this scenario additional battery storage has been included to allow additional useful solar energy to be used when there is no generation, and the size of array to be increased to a total of 130MW of capacity.

[28] The increase in electric vehicle use gives an emerging distributed resource of storage. Approximately 10% of total electric vehicle battery capacity on the island is assumed to be available to the grid at any one time.

4.0 DEMAND PROJECTIONS

The purpose of this section is to establish a robust projection of future annual electrical energy demand (GWh) and peak electrical load (MW). 'Baseline' is defined as the likely future requirements if there are no changes in equipment efficiency, so excluding any Demand Side Resource.

Historic energy demand data and the breakdown between commercial, residential, other sales and system losses is drawn from Ascendant and BELCO shareholder reports. Existing baseline energy demand and peak load forecasts are taken from the TD&R licensee's IRP. This allows for direct comparison with this Alternative Proposal, without introducing change from external factors such as differences in economic projections or weather forecasts.

The TD&R licensee's IRP forecast has been reviewed for plausibility. It is based on recent economic and weather forecasts and is considered a reasonable estimate. The projection has been extended to use more recent energy consumption data, and to show change up to 2050 to allow comparison with international targets for carbon reduction.

4.1 Baseline demand

Overall annual growth in electricity demand for the period is assumed as 0.1% up to 2027 and 0.2% up to 2037 as per the TD&R licensee's IRP. This 0.2% growth rate has also been used through to 2050. This tallies with historic growth in electricity demand, which shows a 20-year mean of 0.16%. The baseline demand includes street lighting on the island. Potential reductions in energy demand from street lighting and other grid losses are explored in the Demand Side Resources section.

4.1.1 Electric vehicles

In addition to the baseline economic growth there are some known emerging technologies that, if adopted, will have a large impact on electricity demand. In Bermuda the main impact is likely to be through uptake of electric vehicles, a trend that is starting to be seen in markets globally[29].

The uptake of electric vehicles has been estimated using the current total number of vehicles on the island, new car sales figures[30] for the island, and a prediction for proportion of new car sales that will be electric vehicles based on international sales forecasts.

Bloomberg New Energy Finance predict that around 55% of new cars sold will be electric vehicles by 2040. Using this growth and based on a slow initial take up, it is estimated that electric vehicles will make up 20% of all private vehicles in Bermuda by 2038.

Electric vehicles are assumed to have smart charging capability and to not charge during peak periods. They have therefore been excluded from peak load predictions.

[29] Bloomsberg New Energy Finance (2018), *Electric Vehicle Outlook 2018*
[30] Car sales base (2018) *Total market sales by country*

4.1.2 Baseline demand forecast

Figure 3 below shows the historic energy demand, and the projected baseline demand for the study period. The energy demand is energy consumption plus generation and transmission losses. Projected losses including street lighting are based on the 20-year historic average of 11.0% using information from the TD&R licensee.

The projection is carried beyond the study period to 2050 to allow comparison against international targets for energy demand.

The baseline demand is assumed to increase steadily over the period. The historic profile includes the effect of energy efficiency improvements, however for the projections these changes are considered and added to the demand profile in the next section.

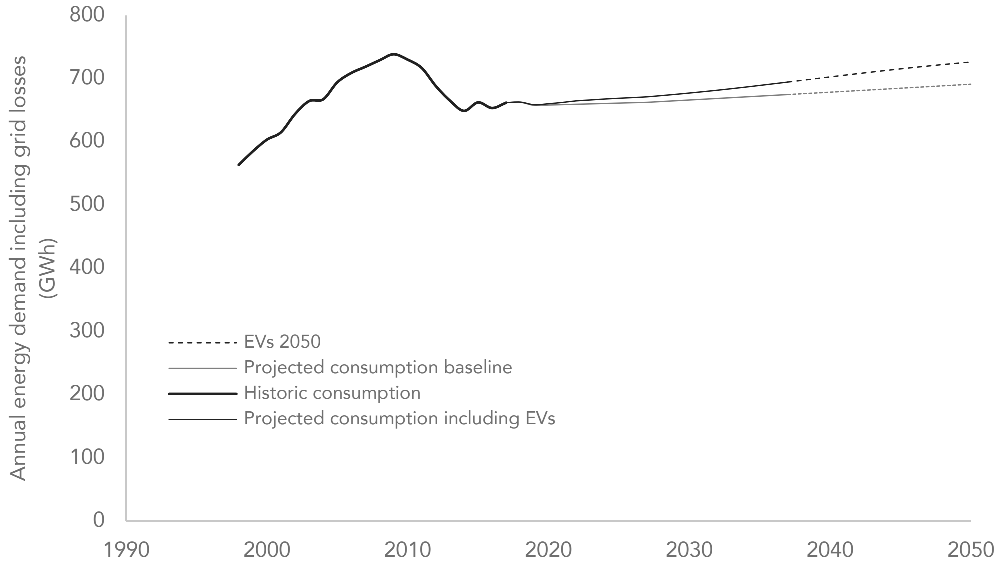


Figure 3 – Historic and projected forecast for baseline demand showing additional demand from uptake of electric vehicles

4.2 Baseline load

The 20-year historic ratio of average annual load to peak load is 68.2%. The TD&R licensee's IRP forecasts peak load from average annual load, based on a ratio of 66.7%. As this is a conservative estimate, it has been adopted for this study. Figure 4 shows the projected baseline peak load based on the annual average baseline load determined by Etude previously.

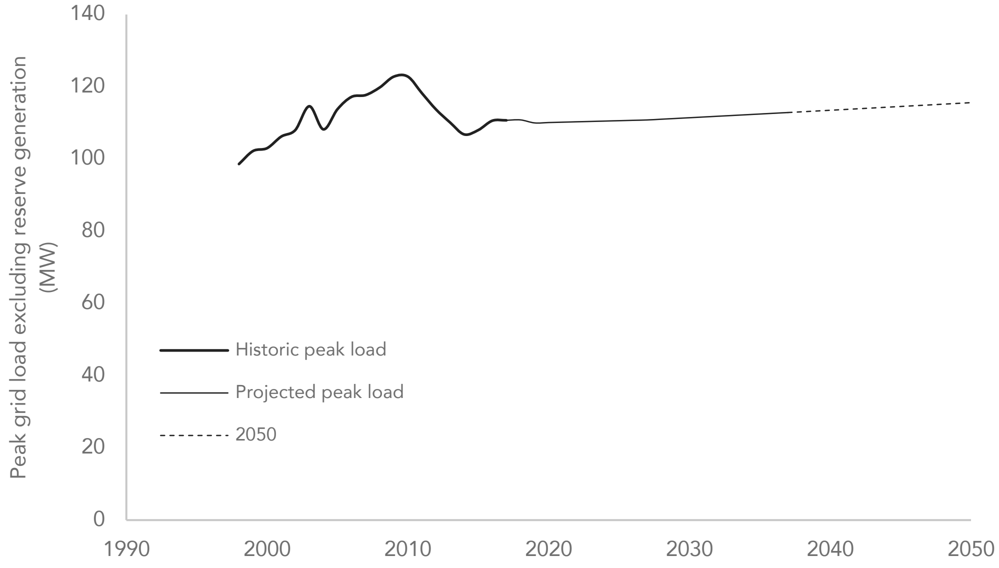


Figure 4 – Historic and projected forecast for baseline peak load

5.0 DEMAND SIDE RESPONSE – ENERGY EFFICIENCY

The purpose of this section is to consider the potential for demand side response, as defined in the Electricity Act 2016. This is considered more specifically through the potential for energy efficiency; achieving the same amount of useful work with less energy input. There is significant potential for energy efficiency in Bermuda to reduce both electrical energy demand and peak loads.

Globally, the energy consumption of buildings is recognised as a key opportunity to reduce carbon emissions and expenditure on energy. For example, the EU has set a binding target for a 30% reduction in energy use through energy efficiency measures by 2030, while Germany aims to reduce primary energy use within buildings 80% below 2008 levels by 2050. The key references used in this section can be found in Appendix D.

5.1 Domestic energy efficiency

Residential buildings consume 38% of electrical energy in Bermuda[31]. To assess the potential for reduction the historic residential energy consumption data has been broken down by usage type, then the potential for efficiency savings is considered separately based on trends and available technology. The graph below shows the breakdown by use assumed in this report, this is based on monitoring of residential properties on the island, and Department of Energy Public Opinion Survey data[32]. The cooling energy consumption also includes a small amount of space heating, typically this is by the same technology and so they have been included together.

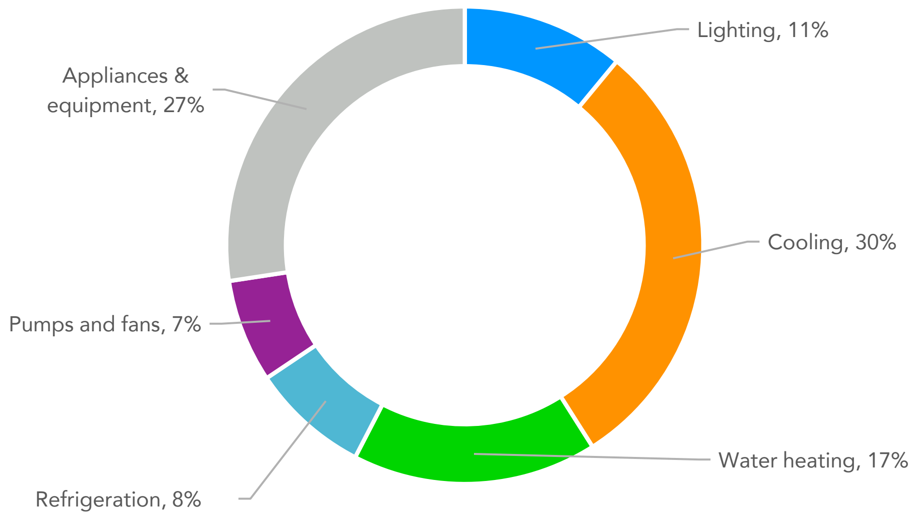


Figure 5– Assumed historical breakdown of residential energy consumption based on end use

[31] Ascendant (2018) *Annual Report 2017*
[32] Bermuda Government (2010) *Bermuda Government Department of Energy Research Report*

Predicted potential savings for each end use have then been forecast. These are thought to be realistic based on technology, availability, and benefits to the consumer, however some are likely to require central policy or incentives to support take up.

5.1.1 Domestic lighting

Improving lighting efficiency reduces energy consumption, internal heat gains to homes, and waste from disposing of products due to longer lifespan. There are considerable drivers for consumers to adopt the technology and uptake of energy efficient lighting, particularly LED lighting, is shown to be happening very quickly at a global level. The technology has more or less replaced compact fluorescent (CFL) technology due to the faster response and suitability as a replacement for recessed halogen ceiling lights, which are popular in Bermuda. In a domestic setting most improvements are through bulb replacement in existing fittings.

From projected consumer information it is assumed that 20% of households already use LED or CFL bulbs with an average lighting efficacy of 50 lumens per Watt. Other households are assumed to be split equally between halogen and incandescent lighting, with a typical lighting efficacy of 10 lumens per Watt.

The potential for savings is calculated by assuming that the vast majority of households (95%) are using LED replacement bulbs by 2038. The lighting efficacy is assumed to be 75 lumens per Watt, which is in line with good practice, currently available technology and likely to be conservative given the fast improvement in this market. An allowance of 5% is included to account for potential 'rebound effect', where more lighting is used due to consumer awareness of reduced operating costs.

5.1.2 Domestic cooling

Cooling is the largest end use of electrical energy in domestic properties on Bermuda. Over 80% of homes have some form of active cooling with most using window units or a split packaged system. A significant minority of homes (less than 15%) use a central ducted cooling system.

The global domestic cooling market is dominated by split packaged systems. These command much better seasonal performance efficiencies than other available technologies. These have seen less penetration into the Bermudian market, however it is assumed that all properties using window cooling units could readily change to split units. Central systems could move to a Variable Refrigerant Flow (VRF) system which has similar efficiencies.

The potential for savings is calculated by assuming domestic properties move from window and central systems to split packaged units or VRF systems, and that all new split packaged units use good currently available technology with a seasonal energy efficiency ratio (SEER)[33] of higher than 4.0 (units with SEERs greater than 8.0 are commercially available). The existing average SEER of residential air conditioning systems in Bermuda is estimated to be 2.4, giving a maximum available improvement of 69%.

There is likely to be slower take up of different cooling technology and incentives may be required in this area. To account for this it is assumed that a 75% market take up is achieved by 2038.

[33] Based on EN14825:2016

5.1.3 Domestic building fabric improvements to reduce cooling

It is possible to drastically reduce the cooling demand for a building by improving building fabric. Potential interventions are:

- Roof and wall insulation
- Improved airtightness of doors, windows and building junctions
- Improved window thermal performance, for example double glazing
- Mechanical ventilation with energy recovery.

Given the current building stock and cooling performance this could theoretically result in a further 50-70% reduction in cooling energy.

There is very little precedent for building improvements to improve thermal performance in Bermuda. In this study savings from building fabric improvements have therefore been excluded, however it should be noted that there is significant potential in this area.

5.1.4 Domestic water heating

The majority of Bermudians (around 88%) heat water using a direct electric water heater[34]. Alternative options are roof mounted solar thermal systems, gas heating, or a water heat pump. Water heat pumps are used in this study to show potential for energy reductions. They offer a substantial energy saving for similar levels of convenience, and have the added benefit of providing a small amount of space cooling when in operation.

A maximum reduction in energy consumption of 60% is used in the demand forecast. This is based on use of a heat pump water heater with a seasonal coefficient of performance of (SCOP) of 2.5 compared to a baseline of direct electric water heating, which is 100% efficient. System losses attributable to heat loss through the tank insulation and pipework are assumed to be similar for both systems. Manufacturer data supports this assumption with potential savings of 70% quoted[35]. Potential savings assume a modest uptake of heat pump water heaters resulting in 50% market penetration by 2038.

5.1.5 Domestic refrigeration

Fridges and freezers are assumed to account for 8% of domestic energy use. The largest and oldest fridges use 800-900kWh/yr, this is compared to European best practice of around 160kWh/yr. Given the typically larger domestic refrigeration requirements in Bermuda an achievable consumption of 350kWh/yr has been used with 50% of current fridges already achieving this target, increasing to 80% by 2038, resulting in a total reduction of energy consumption of 33%.

[34] Mindmaps. (2010) *Department of Energy Research Report: Energy opinion survey* (Bermuda Government)
[35] Daikin Altherma domestic hot water heat pump ECH$_2$O - *https://www.daikin.co.uk/en_gb/product-group/domestic-hot-water-heat-pump.html* (Retrieved 13/8/2018)

5.1.6 Domestic pumps, fans and auxilliary

The majority of this consumption is from pool pumps, hot water circulation pumps, and ceiling fans. Electric motors are subject to increasing regulation in large jurisdictions such as the European Commission Ecodesign requirements and the North American Minimum Energy Performance Standards. These affect the global supply chain and range of products available for import to Bermuda. It is assumed that this will have some effect on products available in Bermuda, therefore a modest reduction of 10% is assumed to occur by 2038.

5.1.7 Appliances

Energy consumption by appliances, equipment and other plug socket loads is more dependent on consumer behaviour than other usage types. There is a rapid move to improved efficiency of equipment, however this is balanced by an increase in the amount of equipment owned and used. For example, computers have become more efficient, but now a user might have more than one computer as well as a tablet and a smartphone.

For the purpose of this study a net reduction in consumption of 20% has been assumed for this category. This is based on a comparison between current best practice efficiencies for consumer appliances and the estimated efficiency of equipment owned by consumers in Bermuda. It is thought to be suitably conservative due to the high cost of importing consumer goods to Bermuda, which may reduce replacement rates.

5.1.8 Forecast for domestic energy demand

The graph below shows the historic and estimated forecast for domestic energy demand. Lighting, domestic hot water, and cooling are shown to be the biggest opportunities for reduction in this sector. A total reduction of 38% by 2038 is shown. From sensitivity testing the potential demand reduction is as much as 48% with no major infrastructure or building upgrades.

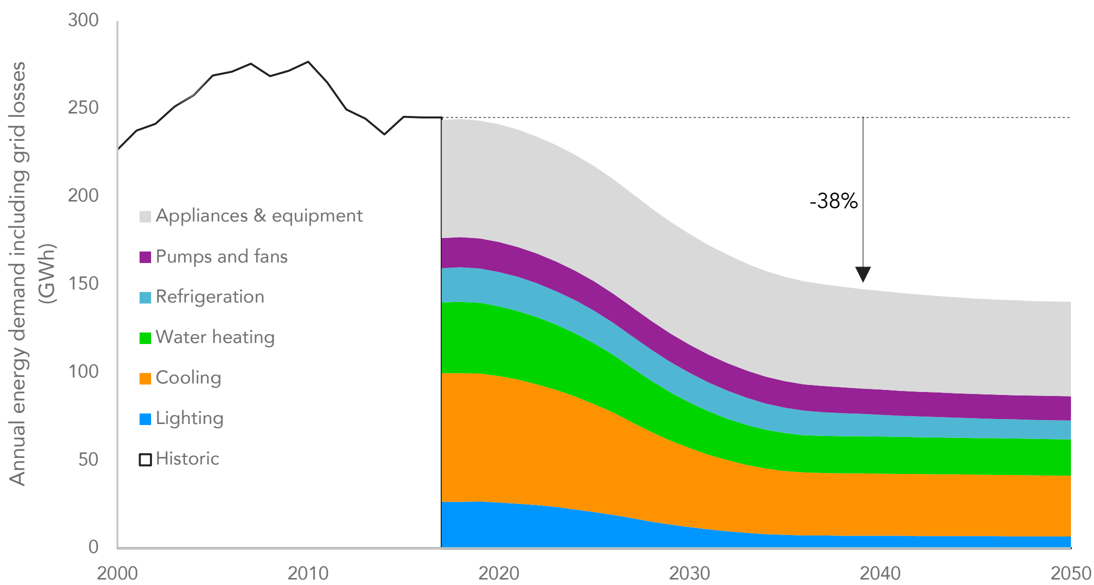


Figure 6 – Potential impact of energy efficiency on domestic energy demand

5.2 Commercial energy efficiency

The commercial building sector covers a very wide range of end uses therefore it is much harder to generalise demand reduction. The approach here has been to broadly categorise commercial energy consumers where there is clear opportunity for reduction by use, and then use case study information to illustrate how the potential savings can be achieved. The uses chosen are offices and hotels as they have different consumption patterns and so potentially different efficiency savings available. In this report the 'office' sector has been extended to other smaller groups of actively cooled buildings with high occupancy.

Sectors where information is unknown are assumed to have no change in energy demand. This is deemed reasonable based on increase in demand being balanced by improvement in efficiency. Based on global trends it is likely that this unknown demand would in fact see a small reduction.

5.2.1 Main opportunities for commercial energy reduction

In the commercial sector the main energy end uses are lighting, cooling and equipment. Very significant savings are available in all these areas over the current use in Bermuda, even assuming increased use or economic activity. The savings can be made through change in user behaviour, demand reduction, and improvements in technology. The main mechanism assumed in this report is through technology improvements due to routine maintenance and replacement cycles, and available products. The high cost of equipment in Bermuda has been factored in to the projected take up of technology.

Reducing commercial lighting demand

Lighting savings are mainly achieved through better control systems, and improved technology. Better control is aimed at switching lights on only when they are required and can include daylight dimming and occupancy sensing. Improved technology delivers the same amount of light for less energy.

Commercial buildings typically use T12, T8 or more recently T5 type fluorescent tubes. These have a luminous efficacy of 60-100 lumens per Watt. The best LED tube replacements currently available have a luminous efficacy of 100-200 lumens per Watt[36]. While a combination of higher efficacy lighting and controls can deliver reductions of up to 90% compared to older T12 based systems, a reduction of 70% has been assumed to account for more efficient systems that have already been deployed in some buildings.

Reducing commercial cooling demand

Building improvements can have a significant effect on cooling load and there have been examples of successful deployment in Bermuda. In particular insulating roofs, and applying tinted window films significantly reduce solar heat gain. On top of this, cooling technology has developed very quickly, with VRF systems achieving efficiencies[37] over 4.0 compared to 2.6 for older less efficient units. This represents a reduction in energy use of over 70%. Substantial opportunities exist for reducing energy consumed by cooling in commercial buildings.

[36] Philips (2018) *Lighting world first: Philips breaks 200 lumens per watt barrier*
[37] Measured in terms of the Seasonal Energy Efficiency Ratio as defined in EN14825:2016

An overall reduction in cooling demand of 73% has been assumed by 2050. This is made up of a partial replacement of older less efficient cooling systems with VRF type systems, coupled with a modest degree of refurbishment work to existing offices. By 2050, 80% of cooling systems are assumed to be replaced with systems achieving efficiencies equivalent to the best available technology in 2018. A 15% reduction in cooling load from building improvements is also assumed to be achieved by 2050.

5.2.2 Commercial office efficiency savings

Office buildings make up a large proportion of commercial electricity sales. An approximate proportion has been estimated from census data on employment and occupation type. The basis for this being that energy use in offices is often linked to occupancy. Just over 61% of employed people in Bermuda operate from an office or similar building type.

Office energy consumption data has been based on U.S. Energy Information Administration data for hot climates, and has been reviewed by a facilities manager in Bermuda. The estimated breakdown is shown below and indicates that cooling, lighting and equipment make up over 75% of all office energy consumption.

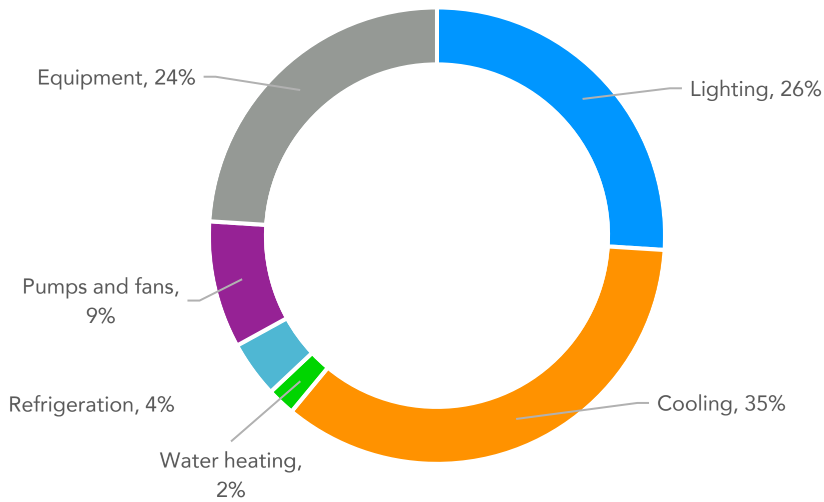


Figure 7 – Assumed historical breakdown of office energy consumption based on end use

5.2.3 Hotel efficiency savings

No energy consumption data was available for Bermuda's hotel sector. The consumption was estimated using the total number of hotel guests from Government of Bermuda data[38], and then applying an average energy consumption figure of 45 kWh per guest from research carried out into hotel energy consumption in the Caribbean[39]. The total energy consumption estimated using this approach closely matched a separate estimate derived using employment levels per sector.

[38] Government of Bermuda (2016) *Facts and Figures*

[39] Caribbean Hotel Energy Efficiency Action Programme (2012) *Energy Efficiency and Micro-Generation in Caribbean Hotels Consultancy, Final Report*

The breakdown by end use is shown below and was based on hotel energy consumption data from the Caribbean. This shows a reduced lighting and equipment demand with much more dominance from cooling.

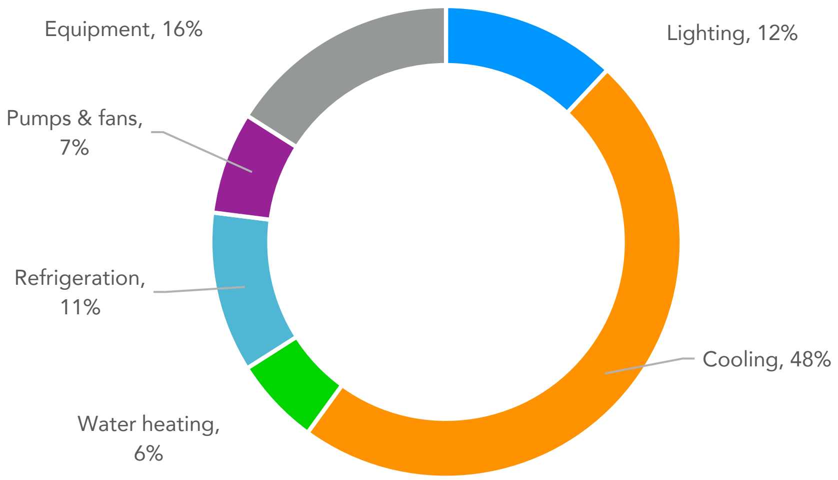


Figure 8 - Assumed historical breakdown of hotel energy consumption based on end use

5.2.4 Case studies

The potential for savings of the scale assumed in this section are supported by case studies of building improvements recently undertaken on the island.

Project	Use	Intervention	Reduction in energy consumption
Masters Home store 2017	Retail	Lighting replacement	26%
Bermuda High School 2010-2017	School	Lighting replacement Window film Hot water efficiency	33%
Cumberland house	Office	Lighting replacement Submetering BMS Control	40%+

Table 4 – Summary of energy efficiency case studies

In particular the case study of Cumberland House should be highlighted. The cost of these works was $600,000 with retrofit measures completed in 15 months. The electricity consumption was nearly halved, and the project completely paid for itself in 33 months.

5.2.5 Other uses

The "other/unknown" category includes buildings used for a wide range of purposes including industrial processes, desalination, and manufacture. It is highly likely that some efficiency savings are available in these sectors, however for the purpose of this study no change is included.

5.2.6 Forecast for commercial energy demand

Figures 9 and 10 show the historic and estimated forecast for commercial energy demand by sector and by end use. Cooling, equipment and lighting are shown to be the biggest opportunities for reduction in this sector. A total reduction of 34% by 2038 is shown.

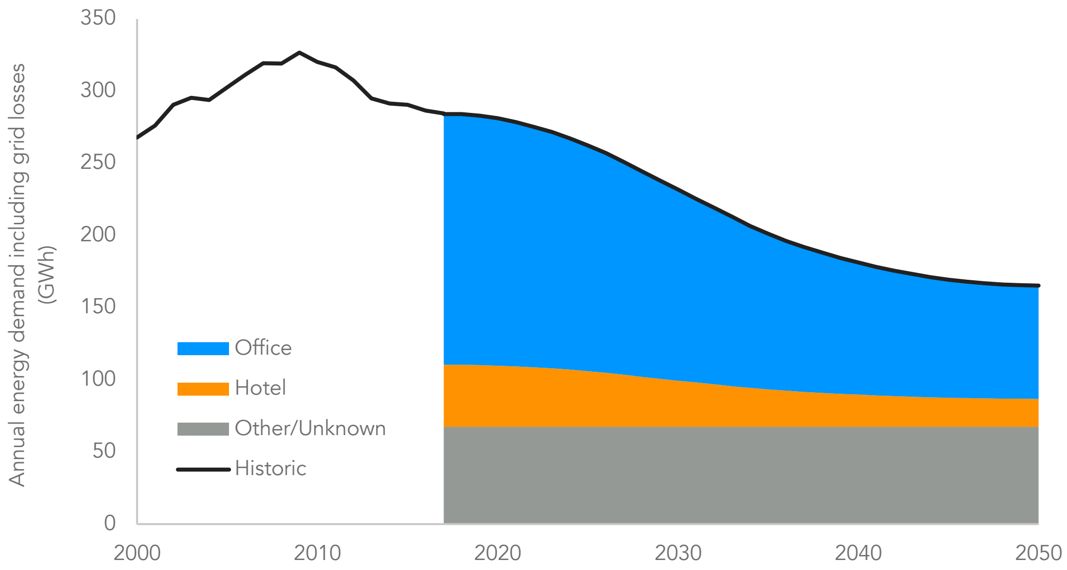


Figure 9 – Projected commercial energy demand with approximate break down by sector

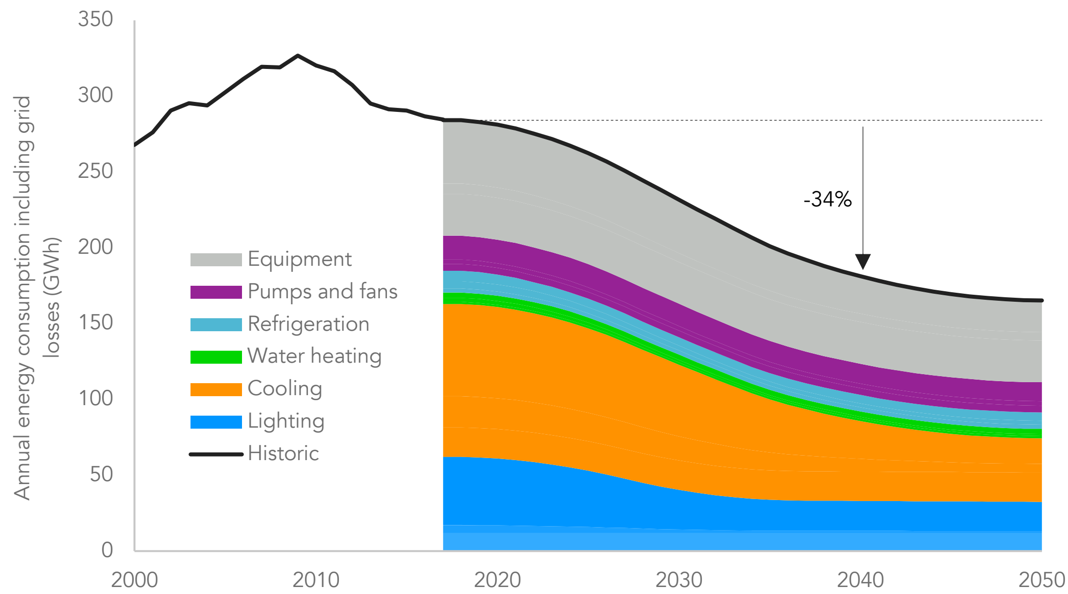


Figure 10 – Projected commercial energy demand with approximate break down by end use

5.3 Transmission losses

The current generation and transmission losses averaged over the last 20 years are 11.0% of generation. There has been little change in this percentage over time, and in 2017 grid losses increased to a five year high of 11.7%.

The TD&R licensee provides street lighting directly through the grid and this energy consumption is also included in 'losses'. There are approximately 4000 High Pressure Sodium street lights and these are currently being replaced with LED lights.

Good practice grid losses reported globally are around 6-7% of generation. Bermuda has a small grid and much of it is at lower less efficient transmission voltages, however the current global experience is thought to represent a reasonable long-term target in efficiency improvements. In this study grid losses including street lighting are assumed to steadily reduce to a 2050 optimum of 7%.

5.4 Projected demand including energy efficiency

The graph below shows the projected total energy demand up to 2050. The demand is shown to reduce 29% below current values by 2038, with further reductions to 33% by 2050. This projection is proposed as a conservative estimate, as the potential for further demand reduction through appropriate policy measures to is substantial.

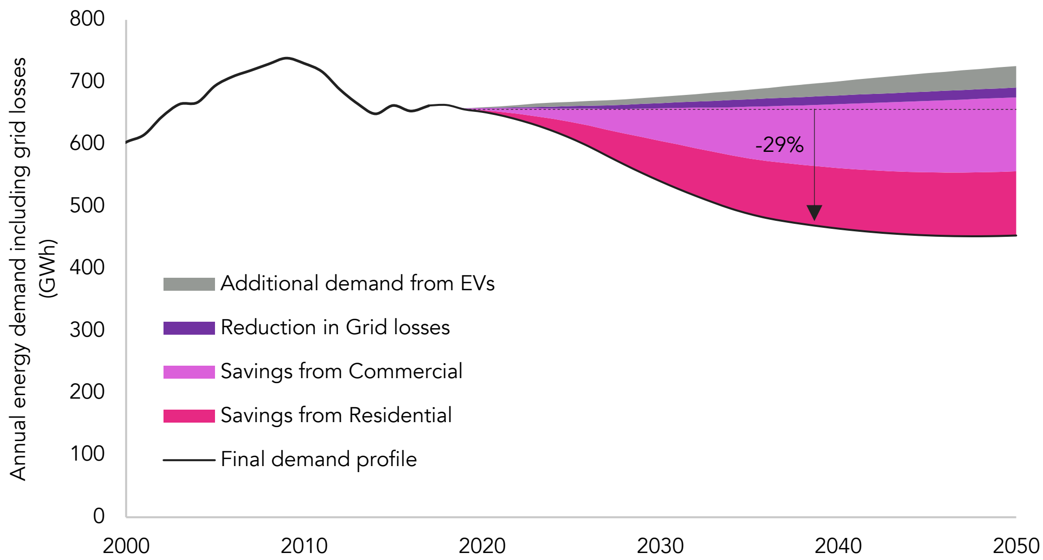


Figure 11 – Projected energy demand up to 2050 including additional demand from electric vehicles, and commercial and residential energy efficiency savings

5.5 Projected peak load including energy efficiency

The graph below shows the projected peak power load on the grid. A reduction of 26% is achieved by 2038 and 30% by 2050. As with the energy demand the projection is judged to be relatively conservative.

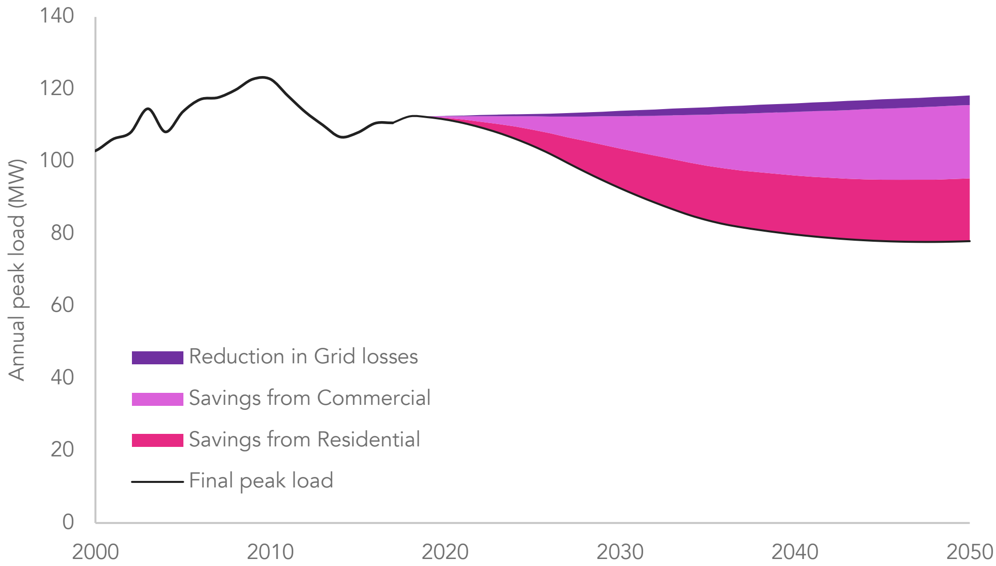


Figure 12 – Projected peak load up to 2050 showing savings projected from commercial and residential efficiency

6.0 BULK AND DISTRIBUTED GENERATION

6.1 Generation resources

6.1.1 Bulk solar photovoltaics

The technical potential for bulk generation from solar photovoltaic technology principally depends on the number of suitable sites. A variety of data sources were reviewed and used to develop a conservative estimate of the potential for deployment in Bermuda. This was then cross-checked with satellite photography and local planning zoning maps. The results of this analysis are summarised in Table 5 and indicate a total potential for up to 24MW of bulk solar generation.

Location	Potential Installed Capacity (MW)	Comments
Airport Phase I	6	Based on planned development.
Airport Phase 2	6	Based on TD&R licensee's IRP assuming a second phase of development.
St. David's Water Catchment	1.5	Orientation and tilt of this site are close to optimal, allowing for high panel density.
Cooper's Island Water Catchment	3.5	Tilt angle is not optimal, use of east-west facing arrays could increase panel density and broaden daily power generation curve.
Tudor Hill	3	Orientation and tilt of this site are close to optimal, allowing for high panel density.
Other Catchments	2	Conservative estimate for various other disused water catchments.
Roofs exceeding 500kW	2	Conservative estimate for various commercial and institutional buildings.

Table 5 – Potential sites for bulk solar generation

In some cases, the estimates assume relatively high density of panel deployment based on the use of east-west facing arrays, rather than south facing arrays. These allow greater panel density due to reduced inter-row shading. They have increased in popularity as solar panel costs have reduced as they allow more energy to be generated per unit area of land or roof.

Traditional south-facing array

East-west facing array

6.1.2 Distributed solar photovoltaics

A geographic information systems (GIS) analysis of buildings in Bermuda revealed their total footprint to be over 422,000m². Etude determined that at least 15% of this area is likely to be suitable for rooftop solar based on application of technical system constraints such as orientation, tilt angle and shading. This represents a maximum installed capacity of 116MW.

6.1.3 Offshore wind

The viability of an offshore wind farm in Bermuda has been investigated several times. Initially through studies commissioned by the TD&R licensee and more recently by the Bren School at University of California, Santa Barbara. Etude considered these studies and consulted with experts in the UK offshore wind industry to determine the potential for the technology in Bermuda.

Etude also analysed historical wind speed data from Bermuda Weather Service, which confirmed there is a good wind resource, with modern offshore turbines expected to achieve a capacity factor of around 45% before losses.

Industry sources indicated that turbine sizes are generally increasing, with current ranges from 3MW – 9MW, and 12MW turbines planned for the near future. Larger turbines have been a key strategy to achieve cost reductions in mature markets throughout Europe, however their suitability for Bermuda would need to be assessed by an experienced project developer within the context of a broader technical feasibility study.

As proposed turbine locations are less than 6 miles from land, which is very close compared to wind farms globally, connection costs are expected to be relatively low. Operational and maintenance costs are well understood and have been considered in the levelized cost of energy analysis.

The dispatch modelling indicated that a 60MW offshore wind farm represents the optimal solution for Bermuda. This would likely consist of 12 individual 5MW turbines, or 20 smaller 3MW turbines.

6.1.4 Fossil fuel generation

The TD&R licensee's IRP was used as a baseline for the fossil fuel generation capacity during the study period. This included planned retirements and the installation of replacement generation and battery energy storage in the North Power Station, which was assumed to occur in all Etude scenarios.

Technical and operational cost data on the generation plant were taken from Appendix II.B and II.D of the TD&R licensee's IRP. This included data on the capital costs, operational costs and operational efficiencies. Fuel cost projections for fuel oil, LNG and LPG were developed separately and accounted for any capital costs associated with additional fuel handling infrastructure as outlined in Section 3.4.

6.1.5 Waste to energy

The Tynes Bay waste to energy plant was assumed to operate as outlined in the TD&R Licensee's IRP. While the peak output of the plant is 4.0MW, a reduced figure of 2.29MW has been adopted in this study to account for periods of time when the facility is not exporting power. This results in the same annual energy production as indicated in the TD&R licensee's IRP.

6.2 Levelized energy cost results

The results of the levelized energy cost calculations for each generation technology in 2022 are presented in Figure 13. These show that in the reference scenario[40] bulk solar is the least cost energy source, followed by offshore wind and distributed solar. Electricity produced from fuel oil and LNG is the most expensive, and their costs are similar.

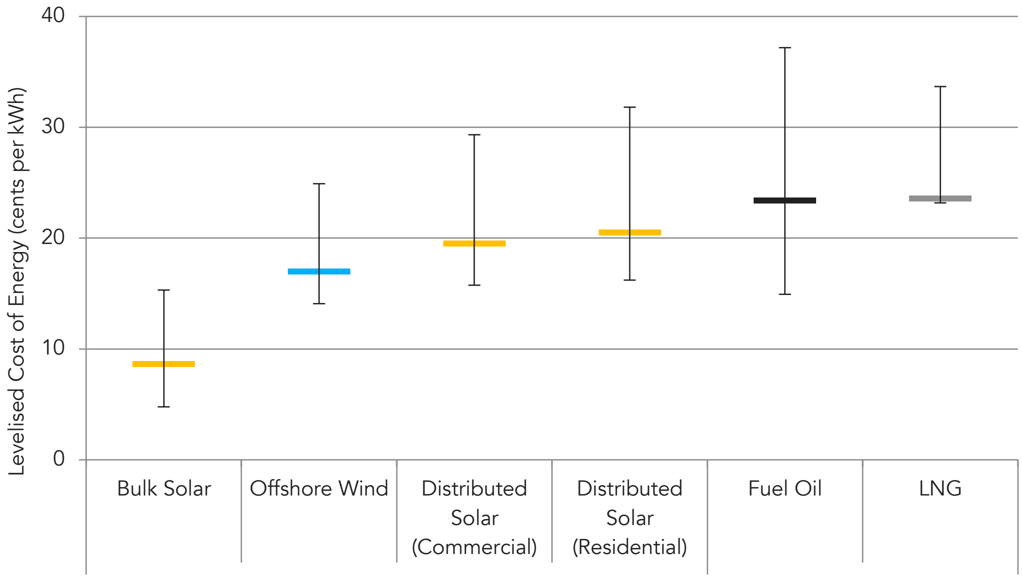


Figure 13 – Levelized energy costs calculated for this study, in 2017 dollars

(Coloured bars indicate reference case, error bars show high and low cases. See Appendix C for assumptions)

The range of costs for fossil fuels depends primarily on the fuel cost and the capacity factor. The fuel cost ranges assumed were taken from the US EIA's Annual Energy Outlook, and include a detailed breakdown of supply chain costs for delivery to Bermuda. The capacity factor was adjusted based on hourly dispatch modelling results for each technology scenario. The high-cost and low-cost scenarios for fuel oil and LNG result in a large potential error range for future projections. This reflects the volatility of fuel costs and the cost of operating at reduced capacity factors.

The range of costs for renewable energy technologies depends primarily on the capital cost, the weighted average cost of capital, maintenance costs, system lifetime and capacity factor. Upper cost scenarios assume capital costs close to today's most expensive prices, conservative weighted average costs of capital, shorter system lifetimes and reduced annual energy production. Lower cost scenarios represent likely future cost reductions, lower feasible weighted average costs of capital, longer system lifetimes based on commercially available technology and higher annual energy production.

[40] For each energy source three levelized cost of energy scenarios were investigated; a high-cost scenario, a low-cost scenario and a reference scenario based on conservative assumptions. The assumptions used for the reference scenario are outlined in Section 3.4, while Appendix C contains the assumptions used for the high-cost and low-cost scenarios.

6.3 Dispatch modelling results

The dispatch modelling indicated that the least cost scenario is the energy efficiency scenario where the TD&R licensee continues to use fuel oil. The average levelized energy cost in this scenario is $0.2256 per kWh. The highest cost is $0.2387 per kWh for the optimum renewables scenario with LNG conversion. The variation in average energy cost between each scenario is minimal within the context of the broader environmental and economic impacts: average carbon emission from electricity fell from 886 gCO2/kWh in the baseline fuel oil scenario to 341gCO2/kWh in the optimum renewables with LNG scenario, a reduction of 62%. These results are summarised in Figure 14.

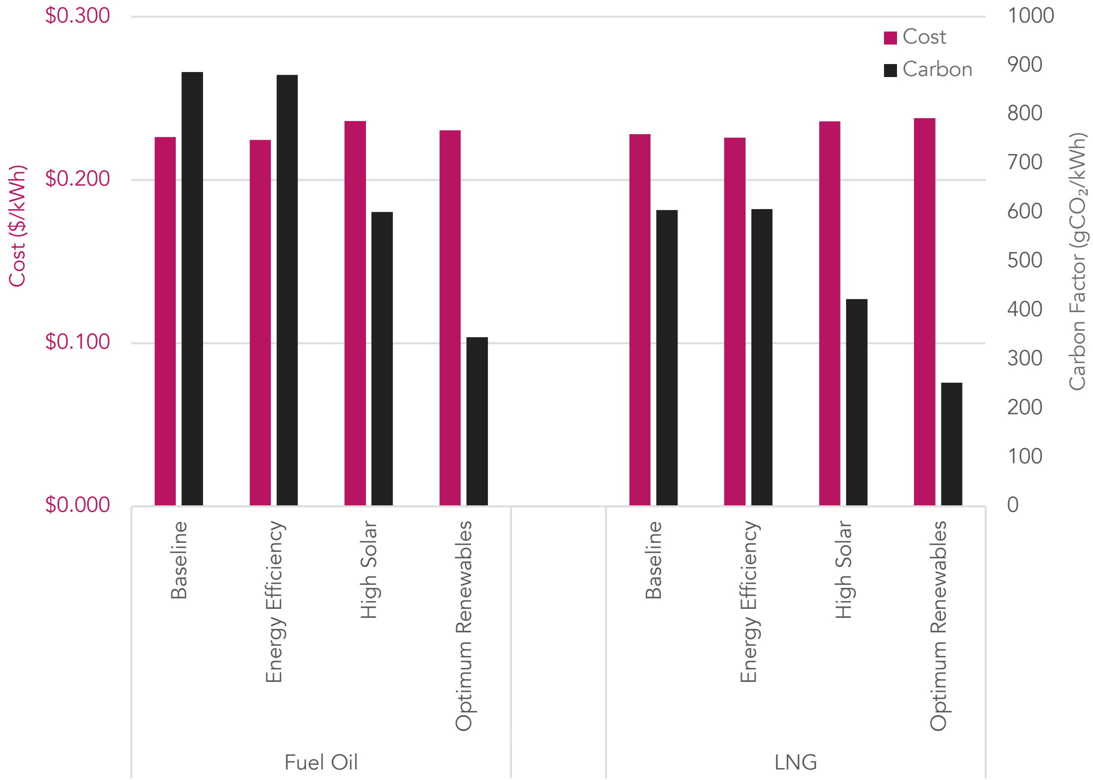


Figure 14 – Annual average carbon and cost from dispatch modelling

Although not reflected in the dispatch modelling, the impact on human health will also vary between scenarios. The carbon factor for electricity may be used as a proxy for the emission rate of harmful compounds such as NO_x, SO_x and particulates outlined in Section 3.0. Scenarios with high proportions of renewable energy and LNG are likely to result in significant reductions in these emissions.

6.3.1 Focus on cost

A key trend in all scenarios was the stability of the price of renewables. The cost of electricity from fossil fuels varied depending on capacity factor and would also be subject to fuel price inflation. As greater proportions of renewable energy enter the generation mix, the capacity factor of fossil fuel plant reduces. This increases the cost of energy from fossil fuels, as shown in Figure 15. An iterative approach was taken in the dispatch modelling to account for this variation, with the levelized energy cost for fossil fuels recalculated based on the capacity factor for each scenario.

Additional costs are incurred in the high solar and optimum renewables scenarios for energy storage and curtailment of renewable energy. These additional costs are almost completely balanced by the lower cost of energy from renewables.

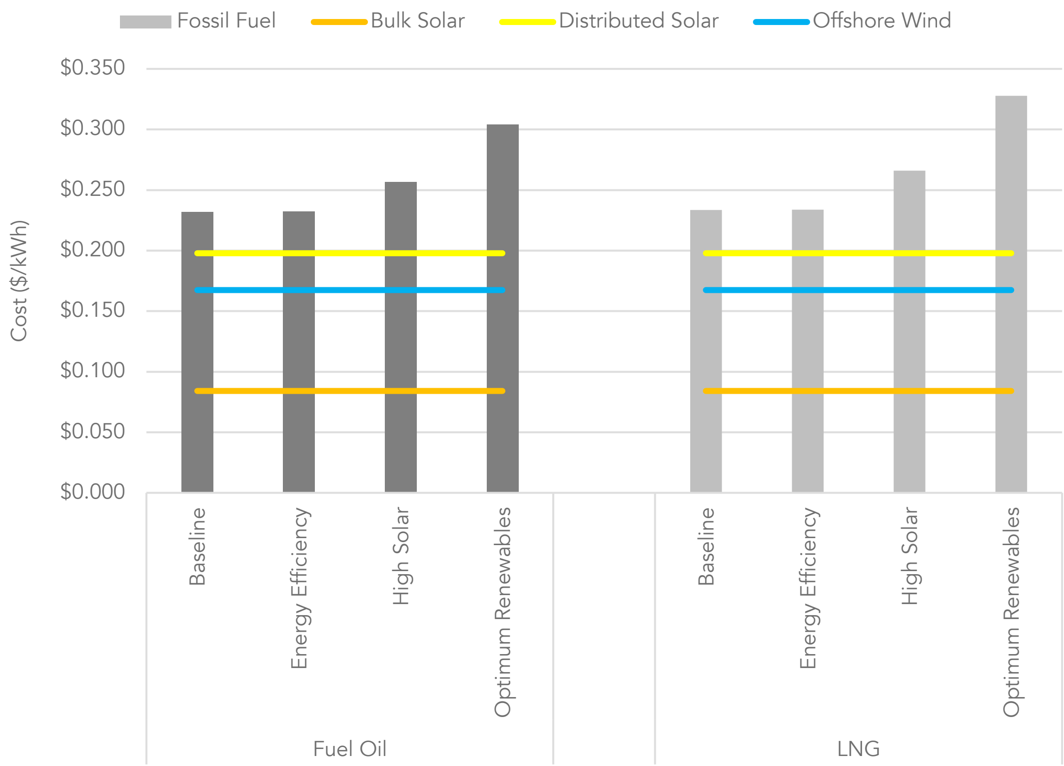


Figure 15 – Cost of electricity from fossil fuels and renewables in each scenario

The capacity factor of fossil fuels in the high solar scenario falls from the baseline value of 66.54% to 41.95%. It falls further still in the optimum renewables scenario, where only 23.35% of electrical energy is produced from fossil fuels. This results in in significantly reduced exposure to fossil fuel price variation compared to any of the baseline or energy efficiency scenarios.

6.3.2 Focus on carbon

The difference in carbon emissions between scenarios is significant. Lower carbon emissions are associated with the use of renewable energy and LNG. The baseline grid carbon factor assuming continued use of fuel oil is 886 gCO_2/kWh, which is reduced from 900 gCO_2/kWh by existing solar generation. Conversion to LNG reduces the baseline scenario to 602 gCO_2/kWh.

Introducing high levels of solar photovoltaics reduces the emissions of these scenarios to 599 gCO_2/kWh with fuel oil and 418 gCO_2/kWh with LNG. The introduction of offshore wind to the generation mix leads to the greatest emission reductions with the optimum renewables scenarios achieving average grid carbon intensities of 418 gCO_2/kWh for fuel oil and 341 gCO_2/kWh for LNG.

6.3.3 Focus on generation mix

The generation mix for each scenario is shown in Figure 16, expressed in annual MWh generated from each resource. The dispatch modelling revealed the maximum practical capacity of solar photovoltaics in the high solar scenarios to be around 104MW. Increasing the levels of solar beyond this resulted in a decreasing ratio of carbon savings to cost as the costs of storage and curtailment increased. 120MWh of demand response and storage was required in the high solar scenarios.

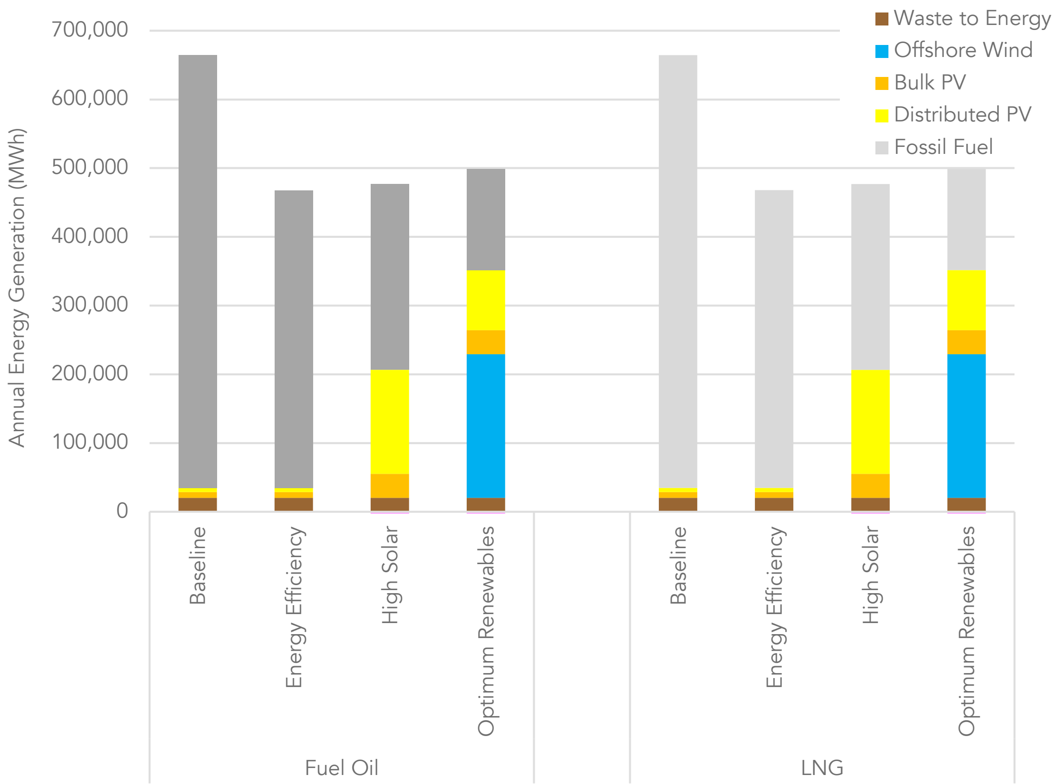


Figure 16 – Annual energy generation from dispatch modelling

Dispatch modelling indicated the optimum balance of renewables to be a 60MW wind farm, complementing 84MW of solar photovoltaics. This resulted in the greatest carbon reductions possible while minimising the average cost of electricity. Increasing either solar or wind generation beyond these levels resulted in excessive requirements for demand response, storage or curtailment.

The optimum renewables scenario requires the use of 140MWh of demand response and storage. Slightly more than 9% of renewable generation in this scenario would likely be curtailed without further demand response measures.

6.4 Demand response

The requirement for demand response is evident in Figure 17, which shows the hourly dispatch modelling results for July where large peaks in solar energy production exceed peak demand for electricity. Without sufficient energy storage or demand response measures, this could result in costly curtailment of renewable energy production.

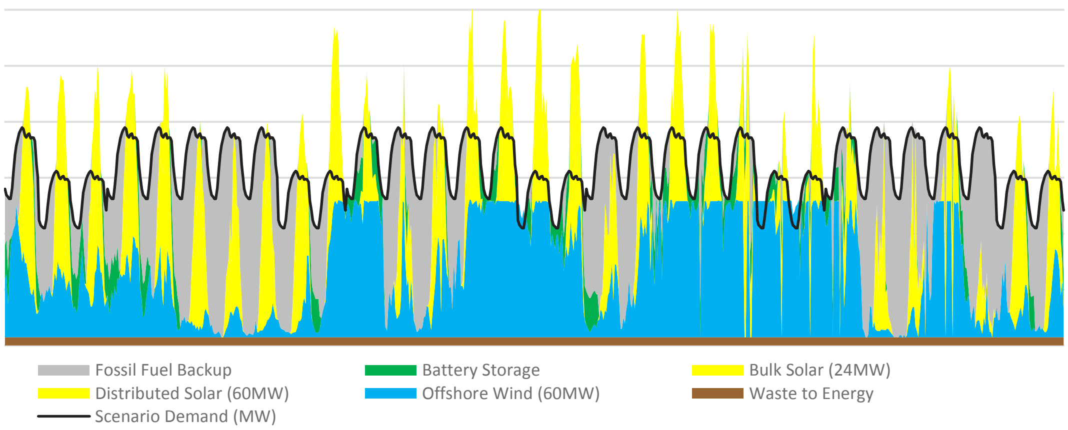


Figure 17 – Hourly dispatch modelling for July in the optimum renewables scenario

The intermittency of renewables can in part be addressed through demand response measures, which can change the time of day at which demand for electricity occurs. In many cases this may represent a least-cost option compared to the use of battery-based energy storage. Demand response may also provide environmental advantages, as they often use compact control gear and typically exhibit long cycle-life. The strongest candidates for Bermuda are likely to be time-of-use based charging of electric vehicles, smart optimisation of HVAC and water heaters, and ice energy storage.

With total electric vehicle battery capacity on island projected to reach over 145MWh by 2038, relatively small adjustments to charging behaviour could shift significant amounts of energy by several hours at a time. The UK National Grid has stated recently that all charging facilities installed going forward should be capable of smart charging.

Smart HVAC and water heating controls take advantage of the thermal mass of buildings and potable water stored in hot water tanks. Various control strategies can be adopted, ranging from simple time switching to more complex algorithms that vary temperature. User overrides or priorities are typically featured to ensure the desired building or water temperature is maintained within acceptable limits. The island-wide potential for these technologies is estimated to be dozens of megawatts.

Ice energy storage has already been trialled in Bermuda at both BUEI and the AIG building. These trials revealed it is practically achievable to shift load for air conditioning by up to 12 hours, given suitable energy efficiency measures to reduce internal heat gains combined with building fabric retrofit measures to reduce solar gains. Ice energy storage systems are commercially available and represent a significant potential resource that should be investigated.

6.5 Target planning reserve margin

The reserve margin analysis in this report is based on Etude's energy efficiency scenario, where peak energy demand gradually decreases as energy efficiency increases. The figure below shows the baseline peak demand forecast until 2038, and the additional reserve capacity required accounting for the failure of the TD&R licensee's two largest capacity generators.

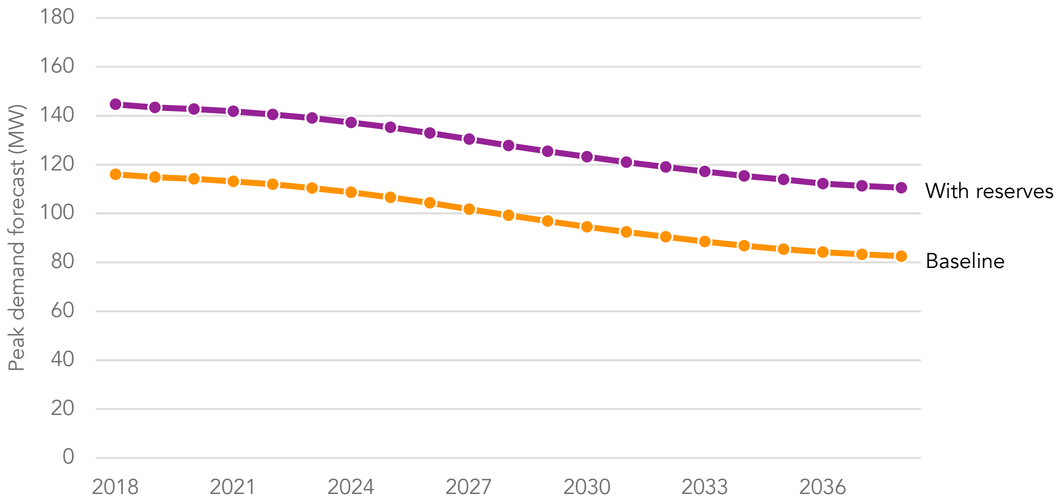


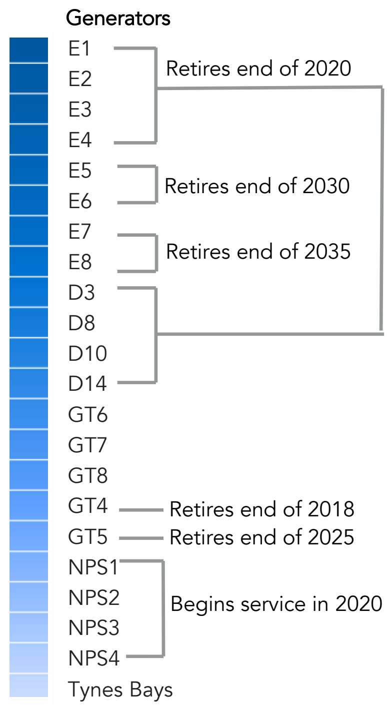
Figure 18 – Reserve margin planning based on Etude's energy efficiency & EV projections

6.6 Capacity gap analysis

A capacity gap analysis was carried out based on Etude's revised peak demand forecast in the energy efficiency scenario. This analysis was based on the TD&R licensee's existing and new planned generators, and considers the target planning reserve margin calculated previously. Our analysis includes only the dispatchable generation resources and excludes all intermittent sources such as distributed solar and the airport solar array.

Figures 19 and 20 list the generators, their planned retirement dates and their in-service dates. The total capacity of all generators is then used to derive the yearly dependable capacities. The difference between total generation capacity and the forecast peak load with reserve equals the capacity gap for each year.

Figure 19 - Legend for Figure 20, showing planned retirement and in-service dates of various generators



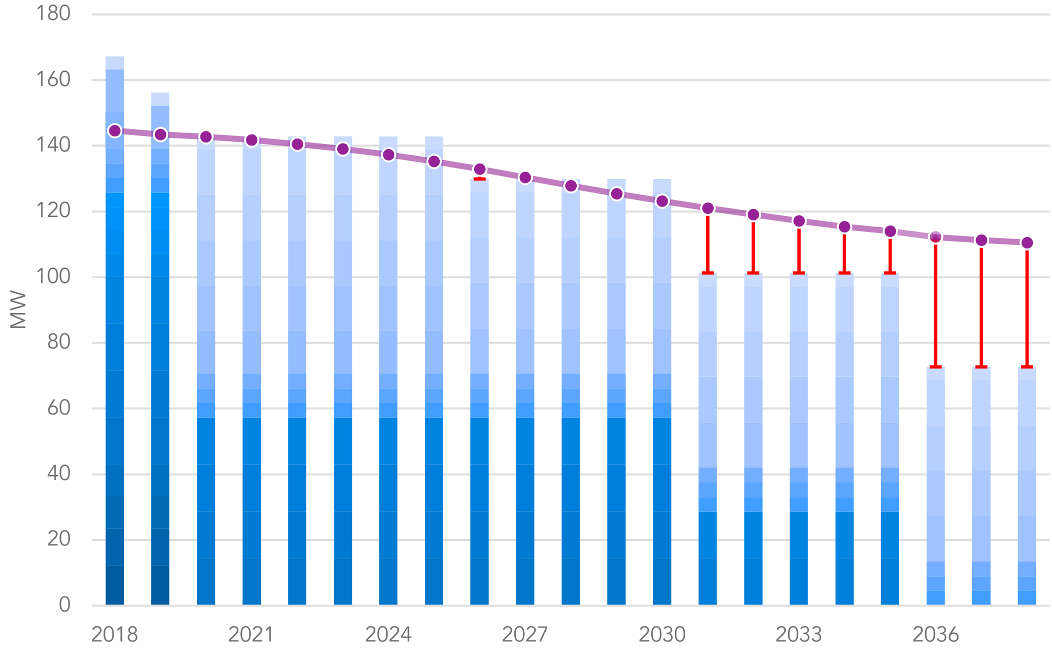


Figure 20 – Capacity gap analysis based on Etude's energy efficiency & EV projections

Figure 20 shows capacity gaps where total capacity falls below the forecast demand, marked in red. With the exception of 2026, the existing and new generators should meet forecast peak demand including the target planning reserve margin until 2030. After 2030, a capacity gap of 20-40MW develops.

Anticipated reductions in peak load that result from the deployment of energy efficiency measures delay the onset of capacity gaps and reduce their magnitude once they do occur. This demonstrates the importance of energy efficiency as a part of overall capacity management strategy as it can delay and reduce expenditure on new generation capacity.

7.0 ACTION PLAN

This action plan outlines key steps required to develop an optimal energy generation mix in Bermuda, measured in terms of stabilising energy prices and dramatically reducing carbon emissions. Short term actions over the next three years are presented in compliance with the Regulatory Authority of Bermuda's consultation requirements. Longer term actions arising out of the analyses within this proposal are then proposed to present a clear pathway toward decarbonising Bermuda's electricity supply.

Figure 21 outlines the optimum renewables scenario that has been identified for Bermuda. This scenario has been developed to offer a least-cost solution to achieve deep reductions in carbon emissions, up to 62% less than a business as usual case based on fuel oil. It takes full advantage of Bermuda's excellent solar and wind resources to minimise dependency on imported fuels and exposure to fossil fuel price volatility. It also encourages the up-take of distributed solar energy resources, reducing annual energy costs for consumers by over $10M a year.

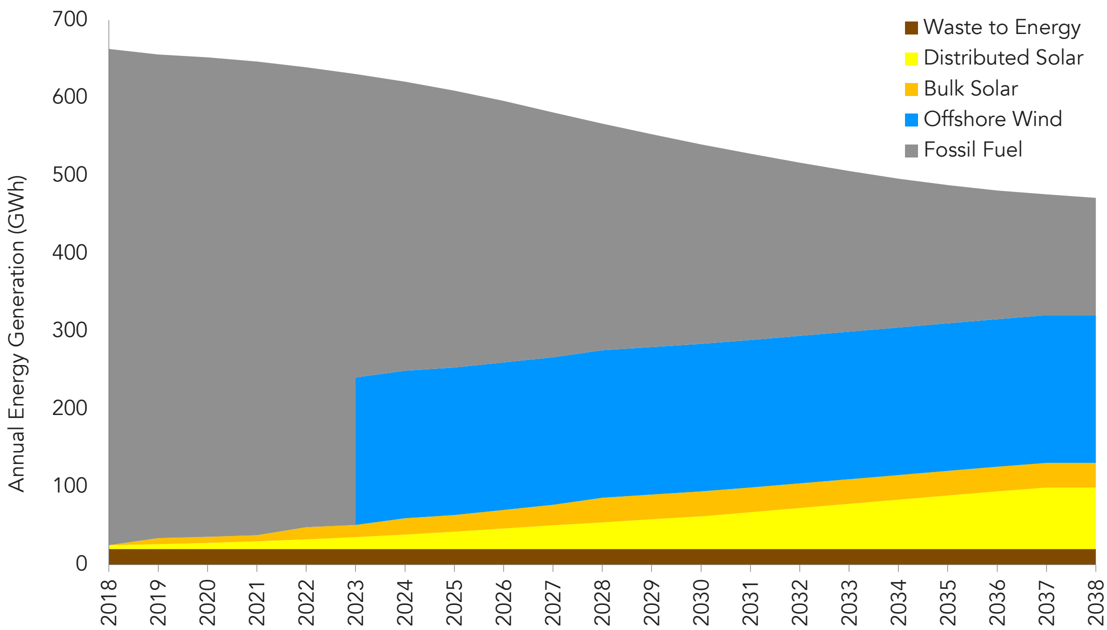


Figure 21 – Bermuda's changing energy mix in the optimum renewables scenario

There is a diverse range of stakeholders in Bermuda who are involved in the development of the energy sector. These include the Government, the Regulatory Authority of Bermuda, the TD&R licensee, solar installation companies, independent power producers, building service engineers, architects, facilities managers and many more. As a consequence, it is not possible to outline a specific action plan as it could be interpreted as imposing requirements upon these stakeholders. The action plans outlined below have therefore been expressed in terms of outlining a vision explaining likely trends and key actions that would result in development of the optimum renewables scenario.

7.1 Three-year plan: 2018-2022

The first three years are an important period that is used to build consensus around an energy plan that all of Bermuda supports. The government is assumed to work with the energy industry to introduce a range of legislative amendments to reduce investment risk for renewables, encourage continued development of distributed solar and to ensure the TD&R licensee is able to remain profitable as their role begins to change in the early 2020s.

7.1.1 Fossil fuels

Construction of the TD&R licensee's North Power Station begins. Plans for an LNG regasification terminal are abandoned as projected reductions in the future capacity factor of fossil fuel generation raises questions over the ability to repay capital costs while maintaining affordable electricity prices.

Attention shifts to assessing the feasibility of LPG, which can offer similar advantages to LNG in terms of cost and carbon, while providing greater flexibility and being better suited to an environment of declining fossil fuel use. The first large scale battery storage system in Bermuda becomes operational, allowing the TD&R licensee to gain experience in operating storage for system stability.

7.1.2 Distributed solar

Structural issues that have developed within the solar market are addressed to steadily ramp up installation of distributed solar systems. These include developing a feed in tariff that is based on the levelized energy cost of distributed solar, rather than the avoided cost of oil generation. Setting tariffs based on encouraging steady long-term investment at fair rates of return becomes commonplace for renewables as well as the TD&R licensee. The facilities charge structure is overhauled to remove discriminatory charges for solar and open up the market to smaller homes. As a result 1.5MW of distributed solar is being installed each year by 2021.

7.1.3 Bulk solar

Bermuda's first bulk solar installation comes online in 2019, immediately providing the island's least-cost source of energy. The cost of a unit of electricity sold from this system is lower than the cost of fuel required to generate a unit of electricity from fuel oil. A second phase at the airport is deployed while the government and quangos initiate separate projects on their land, increasing bulk solar capacity to 15MW by 2021.

7.1.4 Offshore wind

Technical feasibility studies begin in 2018 to determine the most suitable locations for offshore wind turbines. Once these are complete in 2019, the government develops a Renewable Energy Act which sets aside appropriate areas of seabed for offshore wind generation and contains provisions to minimise the risks of investment in offshore wind. This acts as a signal of support to investors, reducing the weighted average cost of capital for offshore wind projects and lowering the future cost of electricity. The government works with the TD&R licensee to establish a competitive bidding process. Construction is planned for the early 2020s.

7.2 Longer term plan: 2022 – 2038

The optimum renewables scenario sees the momentum of both distributed and bulk solar photovoltaic systems build rapidly in the early 2020s as the costs of solar technology continue to fall. Bulk solar is already the least cost energy source to the island at wholesale electricity prices, while distributed solar offers a least cost solution to end-users relative to retail electricity prices. Offshore wind joins the generation mix in 2023, signifying the beginning of a new energy era for the islands.

The use of electric vehicles becomes more common, with several thousand on the road by the late 2030s. The total battery capacity of these vehicles is over 145MWh, with smart charging providing a valuable form of demand response. By the end of 2038, wind and solar provide the majority of the island's energy for a stable cost. Hundreds of millions of dollars a year stay within the local economy that historically would have been spent importing fuel.

7.2.1 Fossil fuels & storage

The TD&R licensee's North Power Station comes online in 2022, replacing aged generation plant with modern reliable assets that work in harmony with solar and wind energy generation systems to provide the island's power. Compatible generators are gradually converted to run on LPG, leading to improvements in local air quality and substantial reductions in carbon emissions.

With the new power station operational and several years' experience operating the island's first large scale battery the TD&R licensee is able to focus on the challenge of integrating offshore wind and increasing amounts of solar into the generation mix. The government works with the energy sector to develop new legislation, which separates generation of electricity from delivery and balancing. These are regulated separately and a managed decline in the use of fossil fuels begins. This is supported by the TD&R licensee as the new regulations provide for a fair rate of return as their role changes.

7.2.2 Distributed solar

Throughout the 2030s the cost of solar continues to reach new lows, with global cost reductions gradually being reflected in local system pricing. The government works with the solar industry to minimise the soft costs of small solar systems. This reduces the installed cost per kW from $3,700 in 2022 to under $3,000. The levelized energy cost from small solar systems drops to $0.15 per kWh. The rate of installations increases steadily throughout the early 2020's to reach 3MW per year by 2030 and 4MW by the early 2030s as costs continue to decline.

Initial adoption of residential energy storage systems driven by the high facilities charge for solar systems reduces after the facilities charges are restructured to reflect the cost of bulk storage for the TD&R licensee, which is more cost effective than distributed storage. Feed in tariffs, which had initially been increased in 2019 to meet the expected levelized energy cost are gradually reduced to reflect reductions in system cost. By 2038 over 60MW of distributed solar systems have been installed.

7.2.3 Bulk solar

A steady pipeline of projects are delivered in the early to mid-2020s, with contracted power purchase costs falling from $0.10 per kWh to below $0.08 per kWh. By the late 2020s the majority of viable large-scale sites have been utilised, providing 24MW of installed capacity. Future plans are developed to repower the airport solar array and other early projects in the late 2030s based on improving energy yields through greater panel density and modest efficiency improvements.

7.2.4 Offshore wind

Mid 2023 is a historical turning point for Bermuda's energy supply as a 60MW offshore wind farm comes online. This results in an immediate reduction in the grid carbon content and significant long-term reduction in Bermuda's dependence on fossil fuels. A marine conservation area is established around the windfarm, which is frequented by recreational boats and tourist charters. Bermuda becomes an example to other small islands in how offshore wind can reduce their fossil fuel dependency.

8.0 KEY INSIGHTS

8.1 Key insights

The insights below summarise the key findings from our work developing this Alternative Proposal. When considered within the context of the purposes of the Electricity Act, these provide a clear message in terms of the optimum generation mix for Bermuda.

8.1.1 Energy efficiency

Energy efficiency reduces peak demand with no investment by the TD&R licensee. This is the most effective strategy to reduce installed capacity requirements. Case studies indicate the financial returns are excellent.

8.1.2 Energy security

Compared internationally Bermuda has very good solar and wind resources. It has no fossil fuel resources and relies completely on imports.

Operation on LNG is more complex than oil and less flexible. The LNG supply chain involves liquefaction of the fuel, transport via highly specialised ships, which might have to be specifically constructed for Bermuda, regasification in Bermuda and delivery through a new pipeline. This introduces multiple potential points of failure to the supply chain and may reduce the diversity of potential supply chain options relative to fuel oil or LPG.

Investment costs are spread in the optimum renewables scenario among a large number of stakeholders in the electricity sector. This naturally results in a more diverse competitive energy sector that is likely to drive prices down. This is demonstrated by Bermuda's first bulk solar project, which is contracted to sell electricity for less than the current fuel cost alone.

8.1.3 Carbon

The carbon difference between scenarios is significant. The relative difference in average grid carbon content between scenarios is unlikely to change over time.

Scenarios with LNG or LPG are lower carbon than for fuel oil. The carbon content of LNG or LPG fuel is lower than for fuel oil, therefore using either fuel is an effective way to reduce emissions relative to oil.

High solar and optimum renewables scenarios with fuel oil are lower carbon than the baseline LNG scenario. Renewable energy is an essential tool to achieve deep carbon reductions.

8.1.4 Cost

The cost difference between scenarios is negligible. Bermuda can decarbonise its electricity supply, reduce harmful emissions and develop a more diverse secure energy mix with minimal exposure to fossil fuel price inflation for a similar cost to other options.

Bulk solar is currently the least-cost option to Bermuda, as evidenced by the power purchase agreement for the bulk solar systems at the airport.

Distributed solar is already a least-cost solution to many consumers. Distributed solar is a unique resource as it allows property owners to generate their own electricity, avoiding the costs associated with the grid. Systems with battery storage are becoming cost competitive with grid electricity and represent a risk of grid defection due to the high facilities charge for solar.

The cost of solar photovoltaics, offshore wind and energy storage is dropping. Their costs are also straightforward to predict based on well-established industry trends. The cost of fossil fuels is increasing and can be volatile. The financial case for the high solar and optimum renewables scenarios is therefore likely to improve over time. Scenarios that lock in high proportions of fossil fuel generation are likely to be the most expensive over time.

The government can reduce the cost of renewables without using subsidies. Examples include: Taking actions that reduce the risk to investors, reducing the weighted average cost of capital; Developing a streamlined planning and interconnection process for distributed solar.

The current feed in tariff is below the LCOE for distributed solar. Feed in tariffs for solar need to be designed to encourage steady investment in the technology while providing reasonable rates of return. Designing tariffs based on avoided fuel cost risks introducing unnecessary volatility to the sector and could discourage long-term growth.

Electricity costs from fossil fuels increase with high penetrations of renewable energy due to reduced capacity factors. This is likely to further incentivise adoption of renewables by either the TD&R licensee or end users.

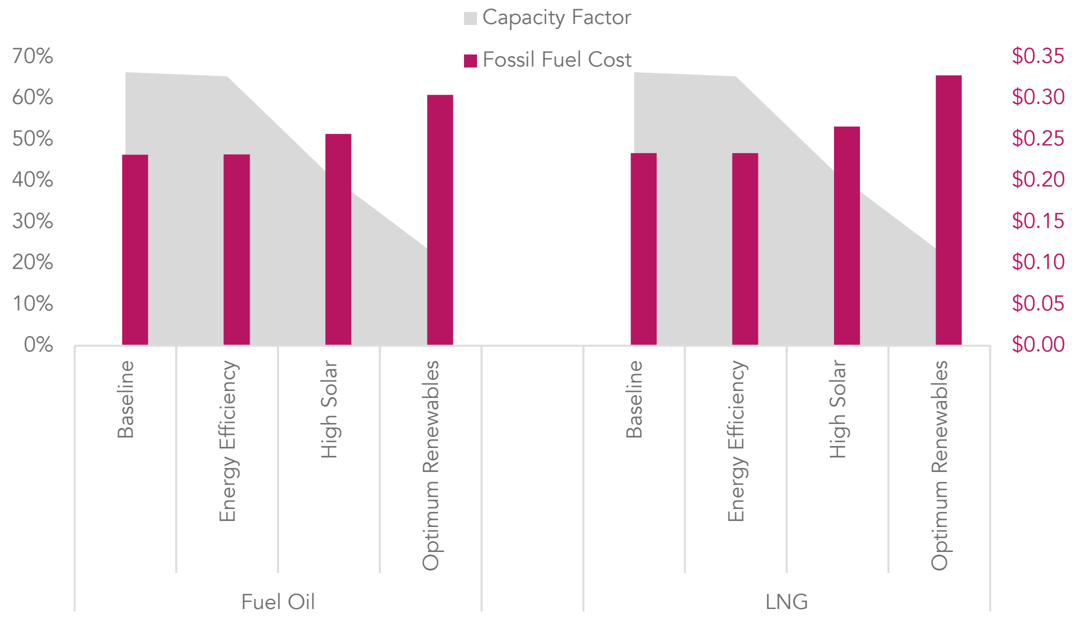


Figure 22 – Fossil fuel cost variation with capacity factor

8.1.5 Energy mix

The capacity factor for fossil fuels decreases significantly in the high solar and preferred renewables scenarios. The Bermuda energy industry needs to work together to ensure the TD&R licensee is able to maintain profitability as its primary role shifts from electricity generation to delivery and balancing.

LNG regasification at the scale proposed in Bermuda is uncommon. While LNG has a long history of use for electricity generation, small scale regasification plant at the scale proposed for Bermuda is a developing concept. Dispatch modelling indicates demand for LNG will range from 4 to 12MMcfd.

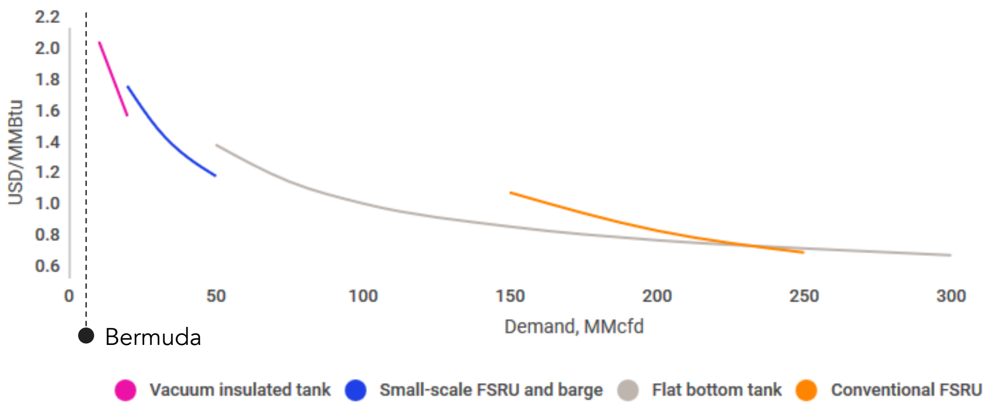


Figure 23 – Regasification cost based on daily demand (©McKinsey[41])

LPG avoids the capital costs and risk associated with LNG infrastructure yet achieves similar carbon reductions for a similar fuel cost. Although not compared in the scenarios investigated in this study, LPG appears to offer a low risk route to reduce the carbon content of fossil fuel generation in Bermuda while integrating renewable energy.

Renewable energy does not significantly reduce annual peak demand, without substantial amounts of energy storage, though the frequency of demand peaks does reduce.

Electric vehicles offer significant potential for demand response, and potentially also energy storage. By 2038, there could be over 145MWh of combined storage capacity in electric vehicles across Bermuda. Smart charging of these vehicles represents an opportunity to make better use of intermittent renewable energy.

[41] McKinsey Energy Insights (2017) *Will a gas market develop in the Caribbean?*

APPENDIX A – INTEGRATED RESOURCE PLANS FROM OTHER JURISDICTIONS

Barbados

Barbados' IRP (2014) considers three 'worlds' to set the demand context, and five scenarios of future supply options were selected using criteria including plausibility, uniqueness from other scenarios, and consistency with regulatory and policy requirements. Two of the five scenarios include a target of 29% renewable energy generation by 2029, based on the indicative target identified in the Sustainable Energy Framework for Barbados (SEFB), whereas the recommended scenario reaches between 16.6% and 27.8% renewable energy generation depending on the demand context.

Hawaii

Hawaii's IRP (2013) combines proposals for five Hawaiian Islands and states clear priorities as: accelerating the deactivation of older oil-fired steam generators; procuring or developing low-cost, fast track utility-scale renewable energy resources; and converting existing generating units to cost effective renewable and lower carbon fuels, including biomass, biofuels, and liquefied natural gas. Renewable energy generation is targeted at over 80% by 2030 in the most ambitious scenario.

The islands start from a baseline of 13.9% renewable energy generation in 2012, in line with interim targets set by Hawaii's Renewable Portfolio Standard (RPS) towards a final 40% renewable energy generation target by the end of 2030. The report states that rooftop and utility-scale solar photovoltaic facilities on all islands, along with wind energy geothermal energy production are contributing to the high baseline. "By the end of 2013, we expect to achieve 18% renewable energy, twice the percentage of just five years ago and well ahead of the 2015 Renewable Portfolio Standard goal of 15%. Correspondingly, the Companies have cut oil use by 500,000 barrels a year, avoiding spending $69 million for oil in 2012."

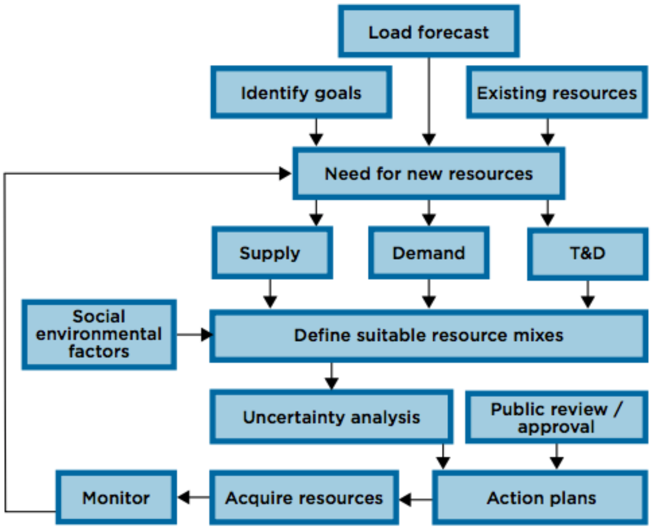
St. Lucia

St Lucia is one of the Small Island Developing States (SIDS) that submitted a climate action plan to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015 and ratified the Paris Agreement on Climate Change in 2016. The island also set targets for renewable energy penetration and reduction in energy consumption in the public sector in 2014 (20% and 35% respectively by 2050). The Government of Saint Lucia and St. Lucia Electricity Services (LUCELEC) have worked together to develop the Saint Lucia National Energy Transition Strategy and Integrated Resource Plan (NET-IRP), and they commissioned RMI-CWR and Clinton Climate Initiative (CCI) to support this development.

Building upon the standard IRP methodology, the NET-IRP followed a participatory and collaborative approach, engaging stakeholders in the energy sector (RMI, 2016). The NETS-IRP presents five scenarios balancing total cost to operate over 20 years against percentage renewable penetration. The recommended scenario, considered cost optimal while protecting against fuel price volatility and providing continued reliability, targets 38.9% renewables penetration by 2025, which represents a mix of centrally owned solar, wind, energy storage, energy efficiency, and existing diesel generation. The optimal scenario for renewable penetration is 75.3% by 2025, which includes geothermal energy.

APPENDIX B – INTEGRATED RESOURCE PLAN BEST PRACTICE

Regulatory Assistance Project: Best practices in electric utility integrated resource planning
The regulatory assistance project is a global non-profit established to promote regulatory best practice. This Alternative Proposal has considered key recommendations for developing integrated resource plans from their guidance[42]. Key components of their recommended approach are illustrated by IRENA[43]:



Source: Wilson and Biewald, 2013

Siemens: Next Generation Integrated Resource Planning
A white paper issued by Siemens[44] describes the need for integrated resource plans to consider transmission and distribution during IRP development. The model for integrated resource plans must consider the impact of increasing levels of distributed energy resources, the necessary investments to bring renewables to load centres and intra-hour assessments to evaluate the system's ability to reliably serve load with intermittent renewables. Optimum solutions should be developed through multiple iterations and simulations. While this Alternative Proposal only fulfils part of this recommendation, Etude supports their approach and suggests that this document be used as a starting point for a more thorough technical evaluation.

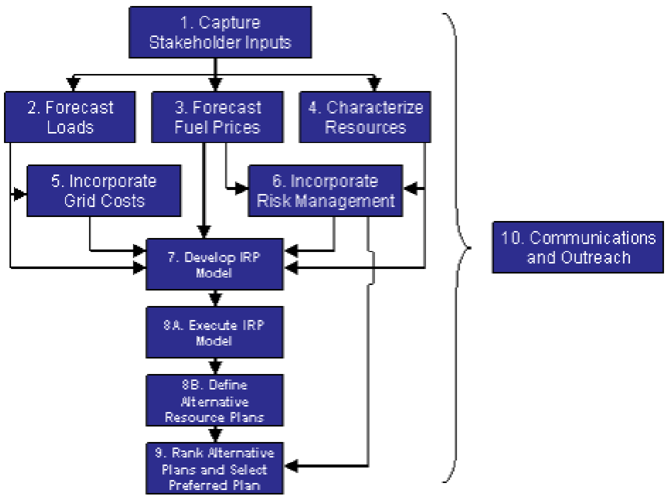
[42] Regulatory Assistance Project (2013) *Best practices in electric utility electric resource planning*
[43] IRENA (2017) *Planning for the renewable future*
[44] Siemens (2015) *Next Generation Integrated Resource Planning*

IRENA: Insights on planning for power system regulators

IRENA identify the key elements of an integrated resource plan in their recently released guidance on power system planning[45]. These have been considered in the development of this Alternative Proposal.

Rocky Mountain Institute: Valuation of renewable resources: Implications for the IRP process

This report[46], based on Dr. Joel Swhisher's 1997 textbook on integrated resource planning, outlines 10 fundamental tasks which should be accomplished by an integrated resource plan. The report also considers previous work by the Rocky Mountain Institute[47].



[45] IRENA (2018) *Insights on Planning for Power System Regulators*

[46] Rocky Mountain Institute (2006) *Valuation of Renewable and Distributed Resources: Implications for the Integrated Resource Planning Process*

[47] Rocky Mountain Institute (2001) *Small is Profitable: Hidden Economic Benefits of Making Electrical Resources the Right Size*

APPENDIX C – LEVELISED ENERGY COST ASSUMPTIONS

Solar Photovoltaics

	Bulk Solar	Distributed Solar Commercial	Distributed Solar Residential
Capital Cost	Low: $1,000 High: $2,000 Based on system prices in Europe and North America. Sense checked against airport solar contract price.	Low: $3,249 High: $4,131 Based on actual prices for systems installed in Bermuda adjusted for 2022 using IRENA projections.	Low: $3,600 High: $4,491 Based on actual prices and quotations for systems installed in Bermuda adjusted for 2022 using IRENA projections.
WACC	Low: 5% based similar projects achieving as low as 2% High 8% based on IRP	Low 6.25% based on local green loan High 8% based on IRP	Low 5.75% based on local mortgage rates High 8% based on IRP
Lifetime	Low: 25 years High: 30 years Based on power output warranties of these lengths for commercially available solar modules.	Low: 25 years High: 30 years Based on power output warranties of these lengths for commercially available solar modules.	Low: 25 years High: 30 years Based on power output warranties of these lengths for commercially available solar modules.
O&M Costs	Low: $10 /kW/year High: $20 /kW/year Based on EPRI[48]. Some maintenance associated with larger ground mounted systems.	Low: $5 /kW/year High: $10 /kW/year Nominal sum as systems are effectively maintenance free.	Low: $0 High: $10 /kW/year Nominal sum as systems are effectively maintenance free.
Capacity Factor (annual energy generation)	Low: 17% High: 19% Based on several years operational data from dozens of systems. Accounts for tilt, orientation, inverter type and losses.		
Degradation	Low: 0.4% High: 0.8% Low figure based on commercially available solar modules. High end based on typical conservative industry estimate.		

[48] EPRI (2015) Budgeting for Solar PV Plant Operations & Maintenance: Practices and Pricing

Offshore Wind

	TD&R licensee IRP	Etude Low Case	Etude High Case
Capital Cost	$6,500	$4,000 Based on Bren wind study, IRENA projections and industry experts	$5,600 Based on Bren wind study and industry experts
WACC	10%	7.5% Based on IRENA reports, and offshore wind industry experts	10% Conservative assumption
Lifetime	Unknown	30 Based on offshore wind industry experts. Reflects turbines currently coming onto the market	25 Based on stated turbine design life
O&M Costs	$41 per MWh	$21 per kW fixed $40 per MWh variable Based on Bren wind study and confirmed by industry experts	
Capacity Factor (annual energy generation)	Unknown	46% Based on larger 5MW turbines, Bren study and Etude analysis of Bermuda wind speed data	44% Based on smaller 3MW turbines, Bren study and Etude analysis of Bermuda wind speed data
Losses	Unknown	11.53% Based on reduced turbulence wake losses, line losses and increased availability	20.84% Based on increased turbulence wake losses, line losses and reduced availability

Fuel Oil

	TD&R licensee IRP	Etude Low Case	Etude High Case
Capital Cost	Not specifically stated. Assumed to be $1,994	$1,994 Based on TD&R licenses's IRP Appendix II.D2	
WACC	8% Based on TD&R licenses's IRP		
Lifetime	30 years Based on TD&R licenses's IRP		
O&M Costs	$36.16 per kw fixed $6.30 per MWh variable Based on TD&R licenses's IRP for new engines in North Power Station		
Capacity Factor (annual energy generation)	Not specifically stated. Assumed to be 65.7%	65.7% Based on dispatch modelling for Etude baseline scenario	25% Based on initial dispatch modelling for Etude optimum renewables scenario.
Total Fuel Cost: Consisting of:	$14.76 / mmBtu Blended cost based onTD&R licensee's IRP	$12.70 / mmBtu Blended cost	$32.15 / mmBtu Blended cost
1. Commodity Price	$6.98 / mmBtu for #6 residual fuel oil $14.09 / mmBtu for #2 distillate fuel oil	$4.93 / mmBtu for #6 residual fuel oil $11.12 / mmBtu for #2 distillate fuel oil Based on EIA AEO 2018: Low Oil Case for 2022	$24.37 / mmBtu for #6 residual fuel oil $32.80 / mmBtu for #2 distillate fuel oil Based on EIA AEO 2018: Low Oil Case for 2022
2. Through-put	$1.19 / mmBtu for #6 residual fuel oil $1.00 / mmBtu for #2 distillate fuel oil Based on TD&R licensee's IRP		
3. Freight and supply	$1.44 / mmBtu for #6 residual fuel oil $0.92 / mmBtu for #2 distillate fuel oil Based on TD&R licensee's IRP		
7. UNESCO Tax	$0.06 / mmBtu Based on TD&R licensee's IRP		
6. Customs Duty	$5.37 / mmBtu Based on TD&R licenses's IRP		
Efficiency	Not specifically stated. Assumed to be 41% based on back-calculating from the TD&R licenses's IRP	41% Based on back-calculating from the TD&R licenses's IRP	

Liquified Natural Gas

	TD&R licensee IRP	Etude Low Case	Etude High Case
Capital Cost	Not specifically stated. Assumed to be $2,737	$2,737 Based on TD&R licenesss's IRP Appendix II.D4	
WACC	8% Based on TD&R licenesss's IRP		
Lifetime	30 years Based on TD&R licenesss's IRP		
O&M Costs	36.16 per kw fixed 6.30 per MWh variable Based on TD&R licenesss's IRP for new engines in North Power Station		
Capacity Factor (annual energy generation)	Not specifically stated. Assumed to be 65.7%	65.7% Based on dispatch modelling for Etude baseline scenario	25% Based on initial dispatch modelling for Etude optimum renewables scenario.
Total Fuel Cost: Consisting of:	$17.56 / mmBtu	$17.65 / mmBtu	$20.24 / mmBtu
1. Commodity Price	$4.37 / mmBtu Based on EIA AEO 2017: High Oil Case or LNG High Resource Case for 2022	$3.97 / mmBtu Based on EIA AEO 2018: Low Oil Case for 2022	$5.84 / mmBtu Based on EIA AEO 2018: Low Oil & Gas Resource & Technology for 2022
2. Liquifaction	$6.22 / mmBtu Includes 'margin'. + $0.37 Listed as 'commodity adder'	$3.00 / mmBtu Based on Oxford Institute for Energy Studies[49]	$3.50 / mmBtu Based on Wartsila[50] and McKinsey
3. Shipping		$1.85 / mmBtu Based on Wartsila paper on LNG for small tropical locations	$0.60 / mmBtu Based on Oxford Institute for Energy Studies. Conservative figure as this scenario assumes Bermuda invests $75M in its own ship.
4. Terminal Capital Costs	$1.93 / mmBtu Based on $117M facility CAPEX	$2.30 / mmBtu Based on $117M facility CAPEX from TD&R licensee's IRP. Accounts for reduced energy demand in Etude energy efficiency scenario	$3.77 / mmBtu Based on $117M facility CAPEX from TD&R licensee's IRP and $75M ship from Castalia study[51]. Accounts for reduced energy demand in Etude energy efficiency scenario
5. Terminal OPEX	$0.55 / mmBtu	$1.05 / mmBtu	$1.57 / mmBtu
7. UNESCO Tax	$0.11 / mmBtu Based on TD&R licensee's IRP		
6. Customs Duty	$5.37 / mmBtu Normalised to maintain government revenue neutrality. Based on TD&R licensee's IRP.		
Efficiency	34% Based on TD&R licenesss's IRP		

[49] Oxford Institute for Energy Studies (2018) *The LNG Shipping Forecast: costs rebounding, outlook uncertain*
[50] Wartsila (2014) *Small and Medium size LNG for Power Production*
[51] Castalis (2014) *Viability of Liquified Natural Gas in Bermuda*

APPENDIX D – KEY REFERENCES

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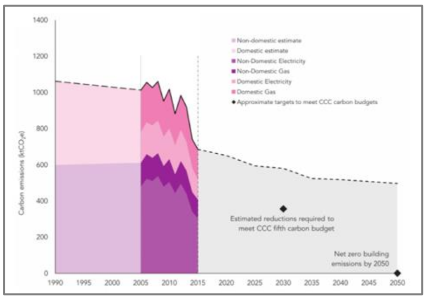
About Etude

Etude is a team of consulting engineers based in London and specialised in energy efficiency, energy modelling, renewable energy, strategic energy policy and research. Our current projects include a 1,500-home zero carbon development in the London Olympic Park and the £70m Sir Henry Royce Institute for Advanced Materials at the University of Manchester. Etude have provided assistance to local authorities in the United Kingdom on numerous occasions. These include the following.

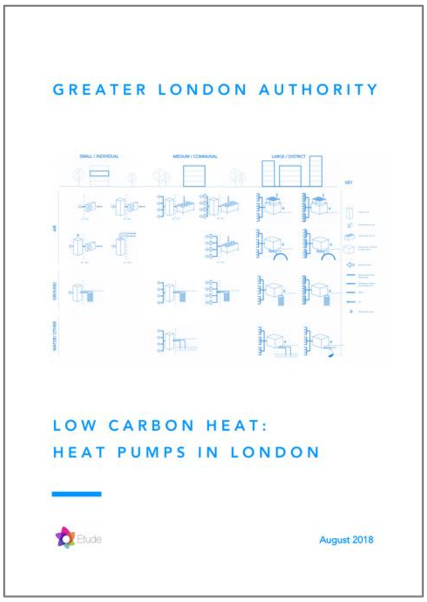


Islington energy and carbon evidence base
Client Islington Council
Year 2017

The borough of Islington is one of the most populated boroughs in London with more than 215,000 inhabitants. Etude have been commissioned by Islington Council to develop carbon pathways and suggest the required improvements in terms of energy efficiency, low carbon heat and low carbon electricity in order to achieve their carbon targets over the period 2019-2034.

Tower Hamlets Carbon Offset Fund
Client Tower Hamlets Council
Year 2015

Etude were appointed to assist the borough (population of 270,000) in the design and development of their carbon offset fund. We also developed a comprehensive energy database linked to a GIS tool. This tool can be used to identify the least energy efficient schools or cluster of social housing properties and how much carbon could potentially be saved. The multi-million LBTH carbon offset fund has now been successfully operating for three years.



Low carbon heat: heat pumps in London
Client Greater London Authority
Year 2018
The Mayor of London has set a target for the city and its 7-million inhabitants to become zero carbon by 2050. Etude have been commissioned by the Greater London Authority to to undertake a study into the implications of a more widespread uptake of heat pump technologies in London’s new developments. As the electricity grid continues to decarbonise and building design becomes more efficient, a move towards heat pump led solutions could potentially help to address both the carbon and air quality challenges of future decades. The work has been summarised in a 120-page report