HIGH PENETRATION RENEWABLE ENERGY ROADMAP FOR THE REPUBLIC OF MAURITIUS

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Carnegie CLEAN ENERGY

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Abbreviations and Definitions

AC	Alternating Current
CEB	Central Energy Board
CPV	Concentrating Photo Voltaics
CSP	Concentrated Solar Power
CST	Concentrating Solar Thermal
CWA	Central Water Authority
DC	Direct Current
DFIG	A type of wind turbine generator known as a Doubly-Fed Induction Generator
DG	Distributed Generation (also known as embedded generation)
DNSP	Distribution Network Service Provider
DSM	Demand Side Management
EEMO	Energy Efficiency Management Office
EU	European Union
EV	Electric Vehicle
FiT	Feed-if Tariff. A price paid to generators of renewable energy for a guaranteed time period for
GHG	Greenhouse Gas
IEP	Integrated Electricity Plan
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
IRS	Integrated Resource Schemes
ktoe	Kilo-Tonnes of oil equivalent
LCOE	Levelised Cost of Energy
LNG	Liquid Natural Gas
LTES	Long-term Energy Strategy 2009-2025
LWT	Large Wind Turbines
MARENA	Mauritius Renewable Energy Agency
MEPU	Ministry of Energy and Public Utilities
MID	Maurice Ile Durable
MMS	Mauritius Meteorological Services
MRC	Mauritian Research Council
MSDG	Medium Scale Distributed Generation
MSW	Municipal Solid Waste
PECR	Public Educational Charitable and Religious Institution
PSAP	MID Policy, Strategy and Action Plan
PV	Photo-Voltaic
RE	Renewable Energy
RE	Renewable Energy
REMMPAP	Renewable Energy Management Master Plan and Action Plan
RES	Real Estate Schemes

RoMRE	Republic of Mauritius Renewable Energy
RPA	Radiation Protection Authority
SHW	Solar Hot Water
SIDS	Small Island Developing States
SME	Small-Medium Enterprise
SSDG	Small Scale Distributed Generation
SSWT	Small Scale Wind Turbines
SWT	Small Wind Turbines
SWT RoM	Small wind turbine. Refers to wind generators with a nameplate rating of less than 100 kW
UHT	Ultra-High Temperature
UNDP-GEF	United Nations Development Programme - Global Environment Finance
VRESWT	Variable Renewable Energy Small wind turbine. Refers to a wind generators with a nameplate
WMA	Wastewater Management Authority
WRU	Water Resources Unit
WtE	Waste To Energy
WTG	Wind Turbine Generator
WTGVRE	Wind Turbine Generator Variable Renewable Energy

REPORT ISSUE AUTHORISATION

PROJECT: High Penetration Renewable Energy Roadmap for the Republic of Mauritius

REVISION: Released

DOCUMENT: CP117-0011-1_REP-High Penetration Renewable Energy Roadmap for the Re public of Mauritius

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Date	Purpose of Issue/Nature of Revision	Rev	Prepared by	Issue Authorised by
22/07/2016	Interim Report	-	DH, SM, WB	NdT
14/11/2016	Draft Report	1	SM, WB	NdT
9/8/2017	Released Report	2	SM, WB	NdT

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EXECUTIVE SUMMARY

The Republic of Mauritius has excellent renewable energy resources, including solar, wind and wave, however, this report finds that the proportion of the nation's electricity requirements currently met from renewable energy resources is moderate, with 22.7% on the island of Mauritius and 6.7% on the island of Rodrigues for the full year 2015. The nation has set a target for a 35% share of electricity production to be generated from renewable energy by 2025. Many island nations with similar resources, particularly in the Pacific and Caribbean, have established plans to reach 100% renewables, some as early as 2020.

The country's major source of renewable energy – bagasse, which currently accounts for 16% of Mauritian electricity generation and 80% of renewable electricity generation – is intrinsically unscaleable (due to land constraints and its seasonal availability). Diversifying the mix of energy sources by using more locally produced renewable energy from solar, wind, and wave is a clear pathway for island nations such as the Republic of Mauritius to reduce their reliance on imported energy and at the same time reduce the environmental impact of fossil fuels.

This report, a renewable energy roadmap, provides the data and a list of specific recommendations to assist governing bodies in Mauritius to develop a plan to reach a target of 60% renewable contribution or more as early as 2030-35.

In creating the renewable energy roadmap, consideration has been given to the availability of renewable energy resources, the costs of converting to renewable energy, the policies and programs that are in place to support investment in renewable energy, feasible renewable energy technologies, future energy demand, and various factors that serve to constrain investment in renewable energy.

The report analyses electricity demand and consumption information from a baseline year of 2015 and determines the likely share of renewables in the energy generation mix in 2025 to achieve the 35% target, and the extent to which the nation's reliance on its renewable energy resources may be increased. The outcome of this report is a list of recommended strategies for increasing the uptake of the nation's renewable energy generation.

SUMMARY OF FINDINGS

- Mauritius is on track to achieve the 35% locally produced renewable energy target by 2025.
- Without large quantities of energy storage, solar photovoltaic (solar PV) and onshore wind technologies are limited in their ability to achieve the 60% renewable target mainly due to mismatch of generation to load profile. Modelling indicates adding solar PV and onshore wind to the existing generation mix will only achieve a target of approximately 45% renewable energy.
- It is evident that to reach a 60% target offshore renewable technologies need to be considered and these include:
  - Offshore Wind
  - Wave Energy
- By diversifying the mix of renewable energy technologies, it is possible to achieve a 60% target as early as 2030-35.
- Power system modernisation using battery systems is key to achieving grid stability with a high penetration of renewables in Mauritius.

2015 ENERGY GENERATION MIX

The total renewable energy generation for the Republic of Mauritius is calculated by summing the total electricity generation from both Mauritius and Rodrigues, see Table 1. For the baseline year, the percentage is 22.7% of total electricity generation. The energy generation mix of Mauritius represents approximately 99% of all electricity generation for the Republic of Mauritius.

Table 1: Total electricity generated and renewable energy split for the Republic of Mauritius

Electricity Source		Units Generated (GWh)	%
Renewable	Mauritius	676	22.6%
	Rodrigues	2.7	0.1%
Non-renewables	Mauritius	2,280	76.1%
	Rodrigues	37	1.2%
Total Electricity Generation		**2,956**	**100.0%**
Total Renewable Generation		**679**	**22.7%**
Total Non-renewable Generation		**2,317**	**77.3%**
Renewable	Mauritius	2,956	98.7%
	Rodrigues	40	1.3%

ENERGY GENERATION MIX TO 2025

Modelling carried out for this report utilising information from multiple sources including the Long-term Energy Strategy and CEB, demonstrated that provided the Republic of Mauritius continued with the current and proposed schemes then the 35% renewable energy target would be met in 2025, see Figure 1.

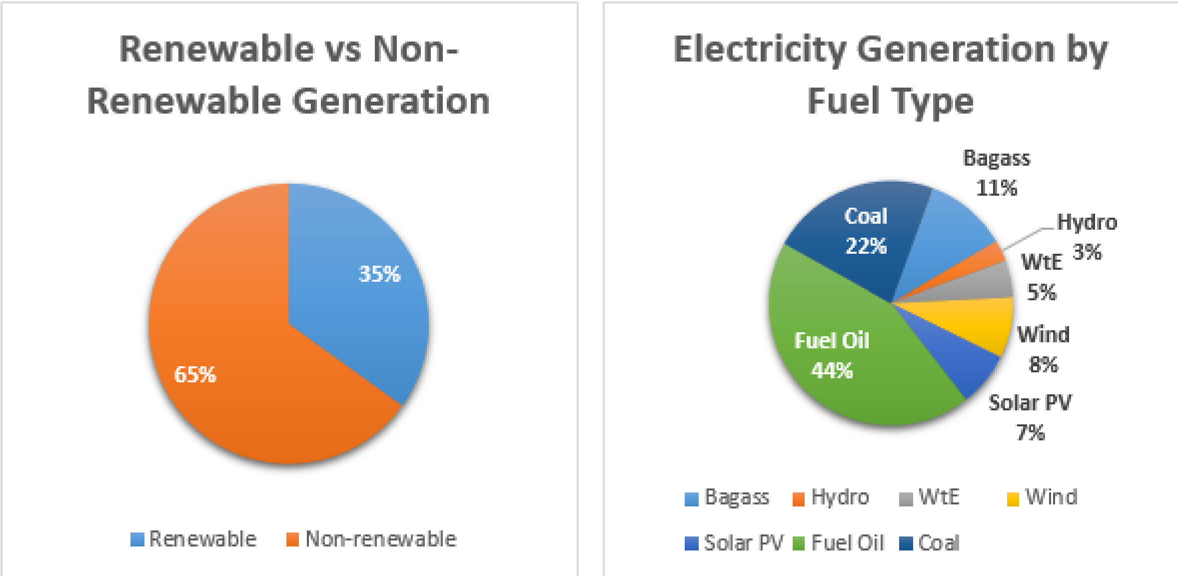


Figure 1: Electricity sources for Mauritius as modelled for 2025

VIABLE RENEWABLE ENERGY TECHNOLOGIES

Based on the candidate renewable energy technologies as assessed in this report, the following list of technologies will likely need to be used to reach a 60% Renewable Energy target. The opportunities for utilising renewable energy sources on Mauritius are a function of the nature of the resources that are available, the stage of commercial development of the associated conversion technologies, and the costs. The recommended renewable energy technologies for deployment in Mauritius are summarised in Table 2 below.

Table 2: Summary of renewable energy technologies and applicability to Mauritius

Technology	Resource	Sub-category	Recommended for region	Technology Risk	Challenge
Solar energy	Very good	Small scale distributed generation (SSDG) – solar PV	✓	Low (fixed, non-tracking)	Land and roof availability
		Medium scale distributed generation (MSDG) – solar PV	✓	Low (fixed, non-tracking)	Land and roof availability
		Utility scale solar PV	✓	Low (fixed or single-axis tracking)	Land availability, grid node capacity limit
Onshore Wind energy	Good	Large wind turbine (LWT)	✓	Low but need to consider cyclone risk	Amenity, finding potential sites, grid node capacity limit, land availability and cyclone risk
Offshore Wind Energy	Very good	Shallow Water	✓	Medium – cyclone risk to be resolved	Amenity, finding potential sites, network connection and integration, water depth and cyclone risk
		Transitional Depth	✓ (long term)		
Hydropower Pumped Storage	Limited	Conventional Pumped Storage	✓ (potential resource)	Low	Cost, environmental impact, available/ reliable water source, and network connection and integration
		Seawater Pumped Storage	✓ (potential resource)	Medium	Cost, environmental impact particularly with the use of salt water, land availability, and network connection and integration
Wave energy	Good	Point absorbers	✓ (medium term)	High – until fully commercialised around 2025	Environmental impact
		Linear attenuators			
		Terminators			

Note that biomass generation from bagasse is not expected to add any significant increase in generation capacity or annual output into the future. This industry is affected by climate change and coupled to the import of coal. Coal generation accounts for 40% of total electricity generation for the island and will need to be reduced to meet a higher renewable energy target and the goals of the MID initiative.

The Levelised Cost of Energy (LCOE) was devised to provide a metric to allow comparison of the cost to produce energy ($/kWh) for different energy generation technologies. The LCOE is calculated over the lifetime of the technology by assessing a combination of capital costs, O&M, generator performance and fuel costs. Note that the LCOE for solar PV will vary by location as a system installed near the equator will produce more energy than one located near the Antarctic. A summary table has been produced looking at the LCOE calculated from various sources and provides a typical range for that technology and estimated installation costs, see Table 3. Note that it has been found that the calculated LCOE values have been reducing faster than forecast for many of the renewable technologies considered in this report.

Table 3: Summary of renewable energy technologies LCOE (Unsubsidised, US$)

Technology	Sub-category	LCOE 2016/17 (US$/ MWh)	LCOE 2025-30 (US$/MWh)	LCOE 2035-50 (US$/MWh)	Installed Cost 2016/17 (US$)	Estimated O&M
Solar energy	SSDG/ MSDG – solar PV	$100 to $350	$80 to $300	$60 to $250	$1.2 to $4.0 per W_{dc}	Low
	Utility scale solar PV	$50 to $200	$40 to $120	$40 to $80	$1.5 to $1.75/$W_{AC}$ Fixed-tilt $1.75 to $2.0/$W_{AC}$ Tracking (single-axis)	Low
	Utility scale solar PV with Storage	$150 to $300	$140 to $220	$140	$3.9/$W_{AC}$	Low
Onshore Wind energy	Large wind turbine (LWT)	$70 to $150	$60 to $75	$50	$1.25 to $1.70/W	Low-medium
Offshore Wind Energy	Shallow Water	$164 to $185	$100 to $150 (Floating up to $165)	$80 to $130 (Floating up to $140)	$2.75-$4.5/W	Medium
	Transitional Depth					
Hydropower Pumped Storage	Conventional Pumped Storage	$25 to $150 (lifetime for calculating LCOE can vary from 40 to 80 years)			$1.0 to $4.0/W (CAPEX can be high, for example 30 MW facility could be as high as $120 Million)	Low-medium
	Seawater Pumped Storage					Medium
Wave energy	Point absorbers	Non-commercial	$270 to $300	$100 to $270	Non-commercial	Medium
	Linear attenuators	Non-commercial				Medium
	Terminators	Non-commercial				Medium

ENERGY GENERATION MIX FOR A 60% RENEWABLE ENERGY TARGET

The analysis of energy generation beyond 2025 showed that without significant energy storage capacity, solar PV and even onshore wind will be limited in the amount they can contribute towards the renewable energy target. This is because solar PV is limited to generating energy only when the sun shines. Complicating the energy production from solar PV is the addition of significant amounts of onshore wind. Wind energy is often being generated at the same time as solar production resulting in one or both sources needing to be curtailed.

In addition, there are also electricity network constraints to be considered. The CEB has identified these constraints and has listed them in the Integrated Electricity Plan 2013-2022. Analysis has shown that the limits set have relied on a conservative approach and have only considered onshore technologies. Future onshore solar and wind need to come with a requirement to “firm” capacity to mitigate the reduction in power quality of the grid.

Due to these issues, future planning needs to consider complementing renewable energy sources that can work together to provide a more consistent supply of energy to the grid and contribute towards a higher renewable energy target. To achieve higher levels of renewable contribution other renewable resources and the associated conversion technologies need to be considered. Several offshore technologies are considered in this report which are close to commercialisation and could be integrated into future planning. These technologies included offshore wind and wave energy, both of which have higher capacity factors, are more predictable and provide a more constant output throughout a 24-hour period.

All scenario analysis for potential energy generation beyond 2025 has considered both future annual growth in electricity demand in line with demand growth scenarios used by the World Bank and commitments for PPA off-take agreements currently in place. The four scenarios considered in this report are described in Figure 2.

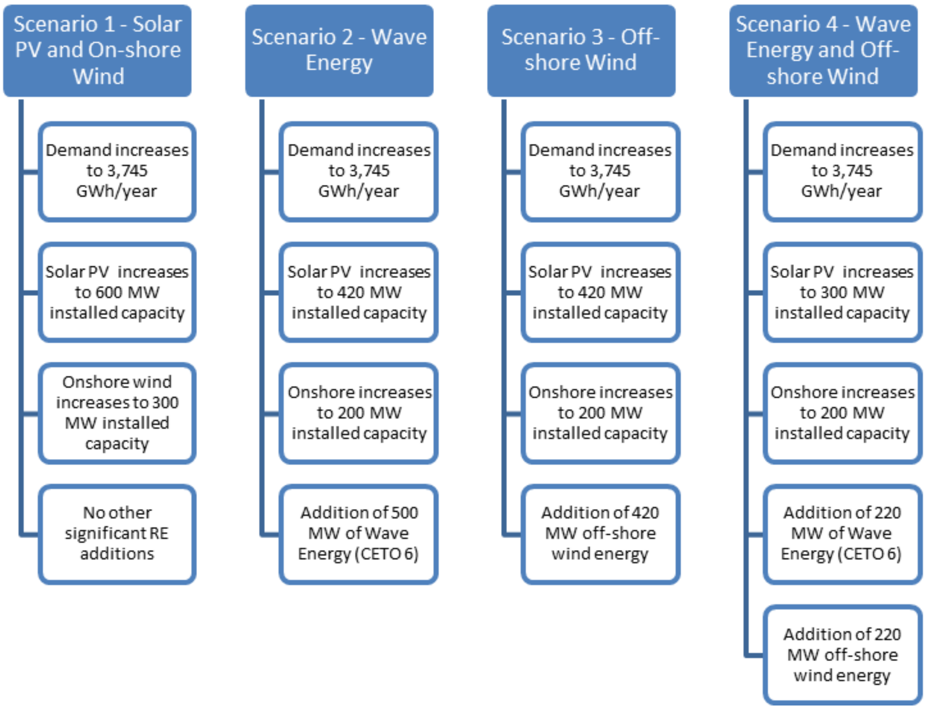


Figure 2: Proposed generation scenarios to reach a target of 60% beyond 2025

Modelling Assumptions

- Business as usual (BAU) growth in electricity continues to 2030-35 leading to a yearly demand of 3,745 GWh
  - The daily profile of the Mauritius load is assumed to remain the same
  - See Chapter 3 for further details of the projected growth forecast
- Existing IPP contracts are accounted as being permanently dispatched as required by the off-take agreements. The dispatch of the off-take is optimised to improve the penetration of solar and wind energy contribution.
- Network upgrades have been carried out to support the integration of intermittent renewable energy sources
  - Energy storage is assumed to be used in conjunction to the new installed renewable generation to balance the effects on voltage and frequency on the Mauritius grid
  - Network strengthening has occurred in some areas to support increased distributed generation
  - Prioritisation of SSDG and MSDG contracts to mitigate the effects to the power system
- Wave energy is commercialised around 2025 and CAPEX cost projection provided by Carnegie Clean Energy
- Offshore wind is commercialised around 2025 for areas subject to cyclonic conditions
  - Some form of storage has been integrated into the grid
  - Possible network strengthening in some areas to support increased distributed generation

The analysis for scenario 1, a proposal for 300 MW of onshore wind with 600 MW of solar PV, demonstrated that these installed capacities are close to the limit for a mix of wind and solar PV without significant storage capacity and that the combination could only help Mauritius reach a target of around 45% renewable energy. Further analysis showed that you could get close to the 60% target by increasing both wind and solar PV generation but this resulted in a significant amount of excess energy that could not be used. Again, further analysis with additional pumped hydro storage did not decrease the amount of excess energy significantly. To shift 15% of the annual generation from would require a storage system with sufficient capacity to shift at least 1.5 GWh per day. Note that storage would provide other energy smoothing and network stabilization benefits which are beyond the scope of this study. The report discusses the benefits of residential solar systems and distributed utility scale projects. The geographic spread acts as a natural dampener of solar generation variability with up to 90% reduction in effects compared to a central utility scale project. This has not been studied in detail in Mauritius and this is one of the recommendations of this report.

Although solar PV and onshore wind have a significant part to play in the future energy mix for the Republic of Mauritius, other scenarios where developed to consider offshore wind and wave energy, both of which are more predictable and provide a more constant output throughout the day.

Of the scenarios considered in this report, Scenario 4 as detailed in Table 4 has been determined as the most appropriate for Mauritius. The scenario meets the renewable energy target of 60% with low excess energy production while offering a diverse mix of renewable energy generation sources. This scenario includes an increase in both solar PV and onshore wind beyond the 2025 target of 160 MW and 101.2 MW respectively plus the addition of 220 MW of offshore wind and 220 MW of wave energy.

This scenario is reliant on the ability of the CEB to expand the solar PV schemes and increase the total solar PV from an estimated 140 MW in 2025 to 300 MW around 2030. Similar, onshore wind energy needs to expand from an estimated 100 MW in 2025 to 200 MW around 2030. With the right incentives in place along with falling prices for both solar PV and onshore wind, these targets should be easily achievable within a 10-year timeframe out to 2030.

The most significant generation change will require the installation of 220 MW of both offshore wind and wave energy. As the installation is due to occur sometime after 2025, there is sufficient time for the technology to mature and for Mauritius to play a part in the development of these technologies by participating in research and development. This could involve the deployment of offshore wind and/or wave energy technology as demonstration projects over the next 5-year period prior to the full roll-out of both offshore wind and wave energy to meet the 60% renewable energy target.

Table 4: Scenario 4 - explanation of electricity generation technology mix

Technology	Changes to capacity	Capacity	Comments
Onshore Wind energy	Increase	200 MW (up from 98 MW in 2025)	New onshore wind farms, will be limited by amenity and need to consider tourism industry. May help some farmers with additional income stream.
Solar PV	Increase	300 MW (up from 140 MW in 2025) Utility scale – 110 MW SSDG – 130 MW MSDG – 60 MW	Significant increase in SSDG solar PV with additional capacity from utility scale and MSDG, solar PV has good potential for local job development
Offshore Wind energy	Installation of wind turbines in shallow depth areas	220 MW	Under this scenario, offshore wind becomes cost competitive with fossil fuel generation
Wave energy	Installation of CETO 6 or equivalent	220 MW (equivalent to 220 x 1 MW_e units)	Under this scenario, wave energy conversion technologies become cost competitive with fossil fuel generation

RECOMMENDATIONS

Mauritius has good solar and wind resources. Onshore technologies such as solar PV and wind are the cheapest forms of renewable energy and at utility scale are lower in cost than new build fossil fuel generation. The number of buildings on Mauritius would indicate that there is significant potential for roof mounted solar PV beyond what has already been installed through the CEB SSDG scheme. Therefore, solar PV along with onshore wind should be considered the best renewable energy sources for the short term. However, as mentioned above, without energy storage to shift energy generated by these sources to times when they are not generating, there remains a limit to the amount these sources can contribute. Our analysis indicates that the limit of this contribution from solar and onshore wind to be approximately 45% depending on the generation mix employed.

Recommendation 1:

Develop and implement a plan to significantly expand the SSDG and MSDG solar PV scheme beginning early 2020's with a target to increase the total install base to 130 MW and 60 MW respectively by 2030.

- Investigate incentives for landlords to invest in solar PV for rental properties.
- Investigate the feasibility of selling electricity behind the meter, thereby eliminating the need for consumers to provide capital upfront for small and medium-scale solar PV projects.

Recommendation 2:

Commission a detailed study to evaluate the roof top potential for solar and the impact of this distributed solar on the overall power systems in Mauritius and Rodrigues.

- Investigate the feasibility of home energy storage systems to lessen the impact of distributed solar generation

Recommendation 3:

Develop and implement a plan to significantly expand the utility scale solar PV scheme beginning early 2020's with a target to increase the total install base to at least 110 MW of firm capacity using energy storage by 2030.

- Provide incentives for the CEB to perform detailed power systems studies to allow for more distributed solar across the entire electricity network and to identify locations for utility scale solar PV farms.

Recommendation 4:

Develop and implement a plan to significantly expand the onshore wind farms beginning around 2020 with a target to increase the total installed base to 200 MW of firm capacity using energy storage by 2030.

To achieve higher levels of renewable contribution, offshore technologies need to be considered. Mauritius has very good offshore wind and wave resources with the potential to provide a greater portion of generation over a full 24-hour period. Several offshore technologies where considered in this report being close to commercialization with offshore wind and wave energy being the most promising. These technologies could provide a path toward a 60% target over the medium to long term meaning any future planning should consider the integration of these technologies.

Recommendation 5:

Commission a study to develop an offshore wind farm industry beginning around 2025 with a target to install 220 MW by 2030.

- Study to consider potential electricity network connection points for future offshore development.

Recommendation 6:

Develop and implement a plan to create a wave energy industry beginning around 2025 with a target to install 220 MW by 2030 including Rodrigues island being used as a trial site to test wave units in Mauritius.

Given the good to very good solar, wind and wave resources in Mauritius region, a program to release resource mapping for Mauritius should be undertaken. Where necessary resource mapping could be carried out in conjunction with local university and research organisations. Governing bodies around the world have found that this can provide a boost for local research programs while at the same time reducing the risk for potential investors in renewable energy infrastructure without providing direct subsidies. In addition, Governing bodies around the world are finding that releasing specific non-private data sets for free can enable innovative problem solving.

Recommendation 7:

Allocate MID fund/MARENA funding for research to identify and map potential onshore and offshore wind sites and offshore wave energy sites including:

- Resources for both onshore and offshore wind monitoring
- Bathymetry data generation for offshore wind and wave energy sites (this can be integrated with mapping for other marine research activities)
- Make all resource data gathered public domain

The costs of generation management solutions are high and those investing in renewable energy generation (centralised or distributed) in CEB's supply areas should not be required to invest in high cost solutions unless it is absolutely necessary for them to do so. It should also be important to develop the lowest cost possible renewable energy generation management solutions. This will include for example, understanding the appropriate energy storage capacities required to be incorporated into renewable energy generation management systems.

Recommendation 8:

Prioritise renewable generation within the Ministry of Energy and Public Utilities (MEPU) and the Central Electricity Board (CEB) - all new generation to be RE were possible.

- Commission studies to perform detailed assessments of grid infrastructure including the ability to accept greater renewable generation and to establish preferred locations for energy storage and renewable generation.
- Expand the CEB Integrated Electricity Plan (IEP) 2013-2022 to target 60% RE contribution integrating the outcomes of the proposed study above including the locations where renewable energy can be connected for lowest levelised cost.
- Commission a study to assess the benefits of residential solar systems and distributed utility scale projects as geographic spread has been shown in other locations to reduce generation variability by up to 90% compared to a central utility scale project.
- Fast track RE connection applications that propose connection in areas designated high priority.

Recommendation 9:

Set up a dedicated research organisation funded by government to review the technologies and methods of achieving higher levels of renewable generation. Research mandate to include a mechanism to trial advanced technology projects to achieve the higher contribution of renewables in Mauritius and Rodrigues.

- The organisation should facilitate research and demonstration projects with research partners (such as CEB, university research groups, and industry) to develop and trial low cost renewable energy generation management solutions.
- Policy for renewable energy is the subject of multiple government departments, creating significant coordination and continuity challenges. The Mauritius government should aim to reduce the number of departments involved in renewable energy policy.

There are legal, regulatory and cultural barriers that may hamper the progress of renewable energy projects in Mauritius. These barriers can be described as “Institutional” barriers. The following recommendation should be considered to ensure the successful transition to a higher renewable energy target. As previously noted in recommendation 7, making all resource data gathered public domain, particularil for offshore wind and wave renewable energy resources, is an import step in reducing “information” barriers.

Recommendation 10:

Update the Electricity Act 1939 as a priority and ensure that it covers future smart grid applications.

- Investigate the impact from the deployment of smart meters, additional distributed generation and small behind the meter battery storage systems.

Recommendation 11:

To achieve acceptable payback periods for renewable energy and encourage investment in the industry, consider implementing reverse auctions for the procurement of utility scale renewable energy at least cost.

Recommendation 12:

To overcome inefficient pricing barriers for renewable energy and to level the playing field between polluting generators and renewable energy, organise an independent review with the objective to determine the best method of implementing a price on carbon for Mauritius.

- Methods such as a carbon tax are efficient to implement, have a low to moderate impact on consumers and can provide additional revenue to fund the transition to a higher renewable energy target (i.e. funds can be used to help low income consumers, fund improvements in the electricity network, and fund research and development).
- The review could be conducted by a dedicated research organisation, see recommendation 9.

Recommendation 13:

To overcome opposition to renewable energy, consider the implementation of and/or priority for community renewable energy projects. This provides local community members with some ownership in the transition to a higher renewable energy target. These projects can take many forms, for example:

- a community owned generator (co-operative model);
- private utility scale projects gifting a small part of the project to the local community; and
- private utility scale projects providing funds directly to local communities for the installation of solar PV on the local hall, school or church.

Renewable energy employment in Mauritius could be a great driver for jobs creation and these jobs can be exported to neighbouring countries (e.g. Madagascar) to support the development of renewable energy projects in the region.

Recommendation 14:

Commission a study to evaluate the potential job and economic benefits of a more aspirational renewable energy target, such as the 60% target proposed.

The 2011 Mauritius census logged 1,700 households that did not have electricity. There are several options available to provide standalone power systems to homes without access to electricity, however, the circumstances behind why these households do not have an electricity connection needs to be investigated before a comprehensive solution can be proposed.

Recommendation 15:

Commission a study to evaluate why these households do not have an electricity and the costs for connecting them to the grid versus utilising standalone power systems where applicable.

- This is an ideal project to be conducted by universities and/or other not-for-profits organisations as part of humanitarian efforts in Mauritius.

As countries look to meet future energy mix requirements in a rapidly growing and changing world, trying to achieve sustainable transportation is emerging as a key mission. Electric vehicles (EVs) are one of the most beneficial ways to improve energy security and at the same time reduce greenhouse gases and other pollutants. For a geographically small country like Mauritius, EV technology is well suited as the driving ranges are short.

Recommendation 16:

Commission a study to evaluate the full impact of an expansion and deployment of EVs across Mauritius and Rodrigues, particularly the impacts on future energy demand growth (electricity production).

- This is an ideal project to be conducted by local universities and/or other research organisations.

1. Introduction

1.1. Purpose of the High Penetration Renewable Energy Roadmap

The document will provide information on current electricity demand and consumption in the Republic of Mauritius, the share of renewable energy in the current energy generation mix, the expected share of renewables in the energy generation mix in 2025 to achieve the 35% target, the extent to which the nation's reliance on its renewable energy resources may be increased, and recommended strategies for increasing the uptake of the nation's renewable energy generation to a target of 60% or more. The study will focus more closely on the energy generation mix of Mauritius as it represents over 98% of all electricity generation for the Republic of Mauritius.

The strategies detailed in this report will reduce the island nations reliance on fossil fuels, increase energy security, decrease emissions associated with the electricity sector while at the same time meeting Central Electricity Board's (CEBs) obligations to provide reliable and secure electricity services to Mauritius and Rodrigues, at the least possible cost and in a socially responsible manner.

It should be noted that throughout this document reference to the Republic of Mauritius is referring to the country as a whole, reference to Mauritius is to the island of Mauritius, reference to Rodrigues is to the island of Rodrigues.

1.2. Roadmap process, Content and Structure

This roadmap was developed with inputs from diverse stakeholders representing the wave industry, the power sector, R&D institutions and government institutions. The first step in that process is to provide a comprehensive outline of the existing energy and renewable energy policy environment as an understanding of current policies is critical to explaining current renewable energy generation and the opportunities for increasing the Republics reliance on renewable energy.

This is followed in Chapter 3 with a comprehensive outline of the current electricity supply and demand and predicted future situation – how much energy is used, by whom, for what purposes and in what locations, and when the energy is supplied. This will rely on reports commissioned by the CEB such as the *Assessment of electricity demand forecast and generation expansion plan with focus on the 2015-2017 period* (The World Bank 2015). This is important to understand the amount of renewable energy required to meet future targets.

Chapter 4 is used to outline current energy generation mix in the Republic of Mauritius – what forms of electricity generation are used, and in what locations, what percentage comes from renewable generation and what will be the likely energy generation mix in 2025. A baseline year, 2015, will be used to assess the current energy generation mix for comparison with the likely future mix in 2025.

The next step in that process is to describe the currently available commercialised renewable energy conversion technologies and the nation's associated renewable energy resources that could be harnessed by these technologies is provided in Chapter 5. A summary list is provided of the commercialised technologies that could be used to harness the associated renewable energy resources.

A description of the renewable energy conversion technologies under development and the nation's associated renewable energy resources that could be harnessed by these technologies is provided in Chapter 6. A summary list is provided of the viable technologies that could be used to harness the associated renewable energy resources.

Based on both the viable commercialised and emerging renewable energy conversion technologies, Chapter 7 presents several energy generation mixes to meet a 60% renewable energy target. Each energy generation mix will be modelled to determine the likely contribution from each renewable energy source and likelihood of producing 60% or more energy from the most suitable renewable energy sources for Mauritius.

To determine the maximum renewable contribution to the Mauritius power system the capacity limits for the Mauritius grid to accept large amounts of Variable Renewable Energy (VRE) needs to be determined. Chapter 8 looks at the strategies currently being implemented by the CEB to manage the 35% renewable contribution by year 2025 and its success. The chapter addresses potential grid enhancement strategies that would need to be implemented with advanced control systems, battery storage and strategic location of renewable power plants to avoid future network reliability issues.

Investing in renewable energy generation infrastructure, however, faces many challenges – technical, environmental, social and economic – that serve to constrain the potential for a nation to rely on its renewable energy resources. These challenges are considered in Chapter 9 to arrive at those viable opportunities.

How the identified opportunities could be married with the Government's Long-Term Energy Strategy are outlined in Chapter 10 including a list of high level recommendations and a summary of the report's findings.

1.3. Renewable Energy Strategy for the Republic of Mauritius

The Central Electricity Board (CEB) and its contributions are seen to be a key component of a successful High Penetration Renewable Energy Roadmap for Mauritius.

The Central Electricity Board (CEB) is a body that is wholly owned by the Government of Mauritius and reporting to the Ministry of Energy and Public Utilities. Established in 1952 and empowered by the Central Electricity Board Act of 25 January 1964, the CEB's business is to "prepare and carry out development schemes with the general object of promoting, coordinating and improving the generation, transmission, distribution and sale of electricity" in Mauritius.

The CEB produces around 40% of the country's total power requirements from its 4 thermal power stations and 8 hydroelectric plants; the remaining 60% being purchased from Independent Power Producers. Currently, it is the sole organisation responsible for the transmission, distribution and supply of electricity to the population.

The Central Electricity Board (CEB), by adhering to its corporate mission, as defined in the CEB Act 1964, and its Corporate Plan 2003–04, undertakes to pursue its development as a technically viable business partner. The main objective of the CEB remains to deliver, at all times, reliable and quality electricity supply in Mauritius and Rodrigues.

With this strategic objective high on its corporate agenda, CEB has prepared an Integrated Electricity Plan (IEP) covering the period 2013 to 2022. Like the previous IEP, it focuses primarily on the CEB's obligations to provide reliable and secure electricity services to Mauritius and Rodrigues, at the least possible cost and in a socially responsible manner.

The CEB reviewed the integration of further renewable sources to increase the total contribution. The need to promote the development of renewable energy was additionally addressed in Government's Long-Term Energy Strategy (LTES) 2009-2025 for Mauritius. The Republic of Mauritius through the Ministry of Renewable Energy and Public Utilities has set a target for the share of renewables in the energy mix of 35% by 2025 as part of the LTES (Republic of Mauritius 2009). As part of this strategy, the CEB has put in place the mechanisms to facilitated the construction of several large scale renewable energy projects, primarily wind projects and solar farms, to meet the 2025 target.

1.4. How much renewable energy?

The central question raised by any renewable energy roadmap is how far a nation's renewable energy strategy should go? There are two extremes and the question is at what point between those two extremes would be sensible to aim for. The answer to that question is determined by several factors, including the renewable energy resources that are available, the availability of commercialised renewable energy conversion technologies, the availability of emerging renewable energy technologies, and the cost competitiveness of renewable energy compared to conventional forms of energy.

At one extreme is a ‘business as usual’ approach. In such an approach, renewable energy take-up rates or penetration targets are not set nor actively pursued, but are left to ‘the market’. That is, investment in renewable energy is left to individuals (households and businesses) and while there may be barriers that serve to reduce investment in renewable energy to levels that are suboptimal from a social and/or from an economic perspective, no effort is made to overcome those barriers.

The primary example of such a policy approach is the Australian government’s policy, or lack of policy, regarding Australia’s supply and use of petroleum products. The Australian government’s policy, labelled by some as ‘complacent’ and described by others as a ‘She’ll be right’ attitude, has been criticised because the total reliance on the market and global supply chains holds very significant risks for individuals, for businesses and for the Australian economy as a whole (Blackburn 2013, 2014). While the major risks are generally regarded to relate particularly to the transport sector and to inflationary pressures on the economy, in regional areas of Australia where there is a high degree of reliance on diesel to generate electricity, those risks are amplified as they relate to both the transport sector and to stationary energy generation sector.

At the other extreme in terms of a renewable energy strategy is an aim or target of achieving energy self-sufficiency. Such an aim is described by Abegg (Abegg 2010, Abegg 2011) as ‘a regional declaration of independence’ and ‘a promising strategy for dealing with both climate change and energy crisis—to the benefit of the regional economy’. While complete energy self-sufficiency is the extreme, an increasing number of communities around the world are setting themselves energy self-sufficiency targets. Eigg Island in Scotland with a population of approximately 65 people sources up to 90 percent of its energy requirements from renewable sources, including solar PV systems, wind turbines and micro hydroelectric schemes to meet the energy requirements of almost all its residents (Grozdanic 2014).

The town of Bolzano in the Italian Alps has adopted a target of carbon-neutrality by 2030 and Wildpoldsried, a village in Germany, has embarked on a 10-year transition plan to achieve self-sufficiency based on renewable energy resources (wind, solar, biogas and hydro). Even larger communities, such as Westlausitz, a region in Germany that consists of 4 cities and 9 municipalities, is implementing a strategy for moving toward energy self-sufficiency (Stump 2013) using wind turbines, a woodchip-fired heating plant and a biogas plant (Glücksman 2013). In fact, more and more areas are declaring themselves “energy self-sufficient regions” (Abegg 2010) and although they differ in many ways, they all pursue a single, ambitious vision: to become independent of fossil fuel imports.

Achieving energy sufficiency is not without its challenges (Abegg 2011) and the challenges vary in their nature and degree between regions and communities. Nations with large hydroelectric, bioenergy (crops, waste), solar and wind resources will be able to move far more quickly and easily towards energy independence than will most other communities. And the ease or difficulty of moving toward energy self-sufficiency is determined not only by the availability of renewable energy resources, but also by the nature of their energy end uses and residential and business energy requirements.

The Republic of Mauritius current approach is more forward-thinking than a cautious, wait-and-see, ‘business-as-usual’ approach having already set a renewable energy target of 35% by 2025 along with a long-term vision set in 2008 known as Maurice Ile Durable (MID) or Mauritius a sustainable island. The main objective of the MID concept is to make the Republic of Mauritius a world model of sustainable development, particularly in the context of SIDS (Small Island Developing States). In addition, Mauritius was one of the first fifteen countries to have signed and ratified the Paris Agreement adopted at the 21st Meeting of the Conference of Parties (COP 21) to the United Nations (UN) Framework Convention on Climate Change in a ceremony held on 22 April 2016 at the UN Headquarters in New York.

The question for the Republic of Mauritius that this strategy attempts to answer is to what extent it would be possible for Mauritius to meet its own energy demand by using its renewable energy resources. Meeting a higher target will require a shift away from ongoing spending on fossil fuels and toward up-front capital investments in renewable energy technologies. Many of these renewable energy technologies, such as wind and solar, have little or no fuel cost once built, similar to the existing hydropower facilities on Mauritius.

The purpose of the roadmap is not to provide a roadmap for energy self-sufficiency for the Republic of Mauritius, it does detail that there are several strong benefits to be gained by using local energy resources to meet the region's energy requirements to the extent that it is technically and economically feasible to do so. The benefits detailed include greater diversification in energy supply and, therefore, greater economic resilience; a reduction in the outflow of money from the region for the purchase of energy by the members of the local community; augmentation of the region's tourism strategy based on its natural landscape attractions and clean environment; and reducing the costs of energy for members of the community and local businesses.

The roadmap assesses the extent to which it is technically and economically viable to for the Republic of Mauritius to increase its generation from renewable energy to 60% or more and in doing so reduce its reliance on imported fossil fuels.

1.5. Project Partners

The Mauritius Research Council acts as a central body to advise Government on Science and Technology issues and to influence the direction of technological innovation by funding research projects in areas of national priority and encouraging strategic partnerships.

In November 2015, The Mauritius Renewable Energy Council approved a specialist study to expand the contribution of renewable sources in Mauritius, perform a Wave Generation assessment and Microgrid Development for Mauritius.

The study will be conducted by Carnegie Wave and EMC as strategic partners.

Carnegie Clean Energy Limited is an Australian, ASX-listed (ASX:CCE) wave energy technology developer. Carnegie is the 100% owner and developer of the CETO Wave Energy Technology intellectual property. Carnegie is focussed on commercial opportunities in key target markets including UK, Europe and remote islands.

EMC provides a range of services to the clean energy industry in Australia, such as providing contract engineering services, smart meters, remote monitoring, industrial energy efficiency, designing solutions for the installation of renewable energy, such as wind, solar PV, geothermal, heat pumps, water pumping, and hybrid systems. Its current pipeline of active projects includes the Alkimos energy storage project with Synergy and Square Kilometre Array project with CSIRO in Western Australia.

2. Current Policy Environment

This Chapter of the roadmap provides a comprehensive outline of the existing energy and renewable energy policy environment in the Republic of Mauritius, see Figure 3. Understanding of current policies is critical to explaining current renewable energy generation and the opportunities for increasing the Republics reliance on renewable energy. Note that the use of the term energy in the policy documents includes all forms such as electricity and transport energy unless otherwise noted.

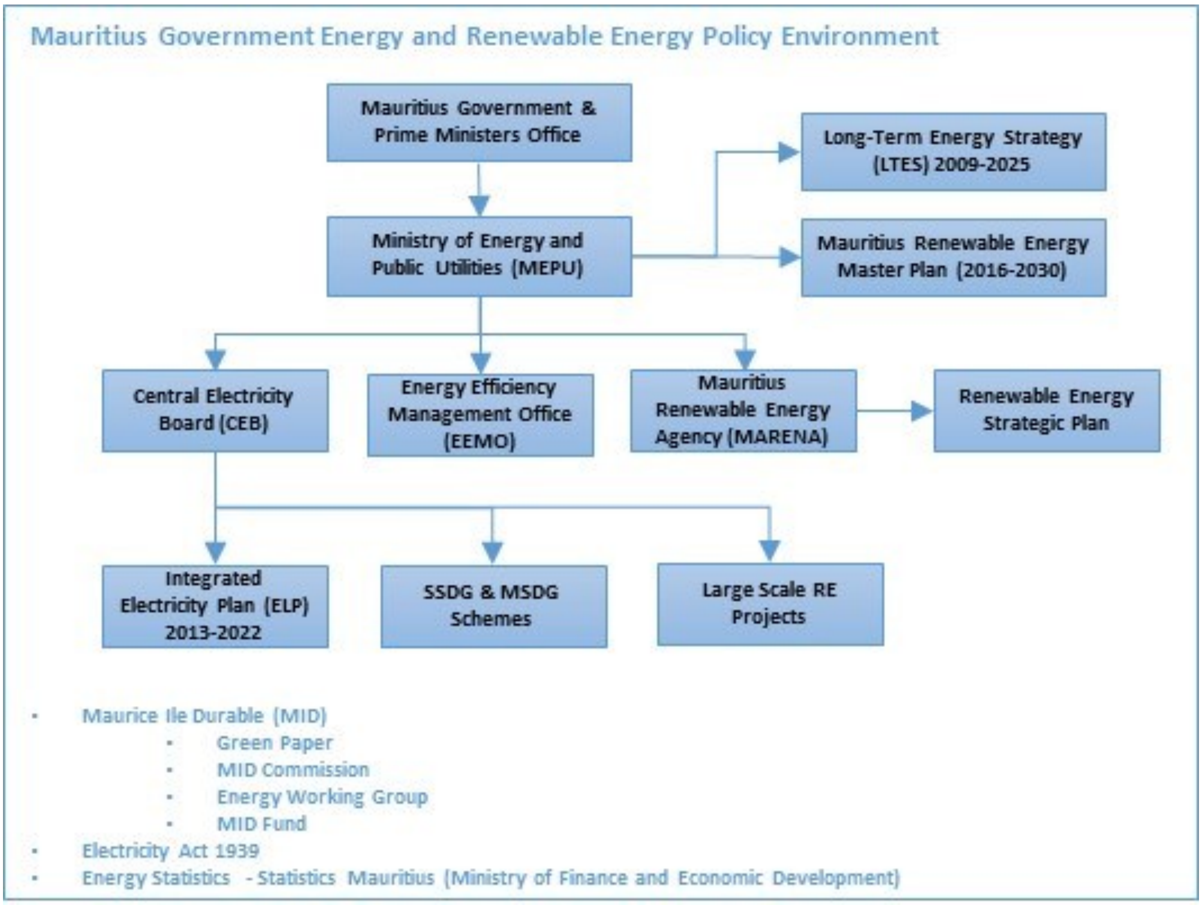


Figure 3: Mauritius government energy and renewable energy policy environment

2.1. Mauritius a Sustainable Island/Maurice Ile Durable (MID)

The price of oil rose significantly from around \$40 a barrel to reach a peak of around \$147 during 2007/2008. This resulted in the petroleum import cost for Mauritius increasing from Rs 6.5 billion in 2000 to around Rs 25 billion in 2008. Partly in response to the global oil price spike and the fact the country relies on approximately 80 percent of its energy being imported, the Government of Mauritius became aware of the islands challenges and looked towards alternatives such as renewable energy to reduce its dependence on imported energy.

In 2008, the Prime Minister, Navinchandra Ramgoolam announced the Maurice Ile Durable (MID) concept, as being the new long term vision for making Mauritius a sustainable island. The main objective of the Maurice Ile Durable concept is to make the Republic of Mauritius a world model of sustainable development, particularly in the context of SIDS (Small Island Developing States) (MID Commission 2016). Although the initial concept was based around reducing dependency on fossil fuel imports through the uptake of renewable energy and energy efficiency, the MID concept expanded to include a large scope in the quest for a sustainable Republic of Mauritius. This scope included the greater economy, society and the environment, commonly referred as the three pillars of sustainability or the triple bottom line.

A key concept for the MID was to facilitate a participatory approach towards elaborating a national strategy for sustainable development aiming to both listen to and include feedback from the wider Mauritian society in the implementation of this ambitious project.

2.2 Green Paper

After a consultation period a Green Paper was produced for the MID project to capture the key proposals of a sustainable Republic of Mauritius. According to the Green Paper on MID, Energy is considered a high priority theme as far as the sustainable development of Mauritius is concerned. In view of the risks associated with the global price of fossil fuel and the known ecological impacts, there is an urgency to move towards a sustainable energy future.

> "Maurice Ile Durable (MID) is essentially a vision that seeks to transform the environmental, economic and social landscape of our country. It belongs to each and every one of us. MID seeks to build up capital, not only for our generation but for generations to come. The MID vision is embedded in a strategic framework embracing five development pillars, namely Education, Environment, Energy, Employment and Equity."
> (Dr. The Honourable Navinchandra Ramgoolam, Opening Ceremony of the Workshop on MID, 01 December 2010) (7).

2.2.1. MID Commission

A steering committee was initially established comprising representatives from various Ministries and government departments to coordinate the efforts of the MID project. The committee was converted to a Commission in 2011 which operates under support of the Prime Minister's Office in collaboration with the Ministry of Environment and Sustainable Development and other stakeholders. The main objective of the MID Commission is to produce and implement an Action Plan every 5 years to realise the MID vision.

2.2.2. MID Strategic Committee

Around the same time as the Commission was established the MID Strategic Committee was formed comprising representatives of the Public sector, the private sector, the academia, civil society and the chairpersons of the six MID Working Groups (MID Commission 2016). The purpose of the MID Strategic Committee was to advise the Mauritian Government of the second phase of the MID initiative.

The Committee operates in close collaboration with the MID Commission and reports to the Prime Minister's Office. Its mandate is as follows (MID Commission 2016):

- To monitor the content, orientation and time frame for the MID 5E action plan currently being implemented at the level of all Ministries; and
- To engage stakeholders and the community with a view to ensuring that the MID 5E is inclusive and widely accepted by the community.

The six working groups were established to cover the five development pillars of Education, Environment, Energy, Employment and Equity:

1. Energy
2. Environment – Biodiversity
3. Environment – Pollution
4. Employment
5. Education
6. Equity

2.2.3. MID Policy, Strategy and Action Plan (PSAP)

The MID policy, strategy and action plan (PSAP) is to be delivered through 4 main programmes:

1. Green Economy
2. Ocean Economy
3. Cleaner, Greener and Pollution Free Mauritius
4. Energy (a summary of the energy action plan is provided in Table 5)

The Mauritius cabinet approved the MID PSAP in June 2013.

Table 5: Summary of Energy Action Plan (Republic of Mauritius 2013)

	Action	Short/ Medium/ Long term	Cost Estimate	Monitoring and Evaluation	Implementing Agencies
1	Consolidation of the Energy Efficiency Management Office	On-going	Rs 3m / year	Operationalisation of the Office	Ministry of Energy and Public Utilities
2	Setting up of the Utilities Regulatory Authority	On-going	Rs 10-15m	Establishing core regulatory capacities and functions as prioritised by Prime Minister and Government	Ministry of Energy and Public Utilities
3	Renewable Energy Plan	Short	Rs 4.5 - 6.5m	Implementation of the Renewable Energy Plan	Ministry of Energy and Public Utilities
4	Renewable Energy Deployment Plan	Short	Rs 5 Billion*	Publication	Ministry of Energy and Public Utilities
a.	*29.4 MW Plaine Sophie Wind Farm (PPP Project)*	Short	*Rs 75m/year subsidy*	Operational	*Ministry of Energy and Public Utilities*
b.	*9 MW Wind Farm atPlaine des Roches (PPP Project)*	*Short*	*Rs 32m/year subsidy*	*Operational*	*Ministry of Energy and Public Utilities*
c.	*Several solar PV farms (PPP Projects)*	*Short*	*Rs 49m/year subsidy*	*Operational*	*Ministry of Energy and Public Utilities*
d.	*2 mini-hydro Plants by CEB (La Nicoliere and Midlands)*	*Commissioning stage*	*Midlands benefitted from a financial support of Rs 30m from MID Fund*	*Operational*	*Ministry of Energy and Public Utilities*
e.	*Small Scale Decentralized Generation (SSDG),3MW - Rs 48m annually being limited to 3MW SSDG project on LV 240/415V grid (CEB) - PPP Project*	*Short*	*Rs 48m/year subsidy*	*Operational*	*Ministry of Energy and Public Utilities*

Table 5: Summary of Energy Action Plan (Republic of Mauritius 2013)

	Action	Short/ Medium/ Long term	Cost Estimate	Monitoring and Evaluation	Implementing Agencies
f.	*Landfill Gas to Energy (3MW) - PPP Project*	*Short*	*Rs 20m/year subsidy over 5 years*	*Operational*	*Ministry of Energy and Public Utilities*
5	Solar PV projects in 10 schools	Short	Rs 7m	Operational and feeding into grid	Ministry of Education and Human Resources
6	Pre-feasibility study on geothermal power in Mauritius	Short	Rs 20m	Report delivered with recommendations	Ministry of Energy and Public Utilities
7	Energy Auditors – Accreditation and Certification	Short	Rs 11m	Fully qualified auditors and undertaking audits	Ministry of Energy and Public Utilities Ministry of Industry, Commerce and Consumer Protection

2.2.3.1 MID Energy Targets as deliverables of PSAP

The following MID energy related targets were adopted by the Mauritian government:

- Achieve the national target of 35% renewable energy by 2025; and
- Reduce energy consumption in non-residential and public sector buildings by 10% by 2020.

2.2.4 MID Fund

The MID Fund was set up by regulations under the Finance and Audit Act in June 2008, with the objectives to finance projects, schemes or programmes (MID Commission 2016):

a. for the conservation of local natural resources with a view to achieving sustainable development;
b. for mitigation against, adaptation to, and increase of resilience to, climate change;
c. for the promotion of sustainable consumption and production, including efficient use of resources, cleaner production, sustainable public service practices and increase in the use of sustainable products;
d. to explore and harness potential sources of renewable energy and to reduce dependency on imported fossil fuels;
e. to foster research, development and innovation with a view to promoting sustainable development;
f. for the promotion of energy conservation and energy efficiency;
g. to encourage the production of energy from renewable energy sources on a small scale by any individual, household, business or group and for the sale of any surplus to the national grid;
h. for sustainable transportation, which promotes environment friendly and low emitting fuel-efficient motor vehicles, including buses under the Bus Modernisation Programme;
i. to encourage and promote sustainable waste management through waste reduction, reuse and recycling;
j. to educate people and raise awareness on sustainable development;
k. to encourage efficient and responsible use of water resources;
l. which are incidental to or conducive to the attainment of any of the above objects.

2.3. Government Structure and Energy Responsibilities

The Republic of Mauritius is a constitutional republic with three tiers of government: central, local and village. The central government has a multiparty and parliamentary democracy like the British system. The Republic of Mauritius government has about 27 different ministries or government organisations that manage a specific sector of public administration. For example, local government in the Republic of Mauritius is governed by the Local Government Act 2011 (Act No. 36 of 2011) and the Ministry of Local Government and Outer Islands (MLGOI) is responsible for overseeing those local authorities (CLGF 2016).

2.3.1. Ministry of Energy and Public Utilities (MEPU)

The Ministry of Energy and Public Utilities has the responsibility to formulate both policy and strategy and provided oversight related to the sectors of water, wastewater, energy, radiation safety, and renewable energy.

The following organisations fall under the purview of the Ministry (Republic of Mauritius 2016):

1. Central Water Authority (CWA) – Treatment and Distribution of potable water;
2. Central Electricity Board (CEB) – Prepare and carry out development schemes with the general object of promoting, coordinating and improving the generation, transmission, distribution and sale of electricity;
3. Wastewater Management Authority (WMA) – Collection, Treatment, Disposal of wastewater;
4. Energy Efficiency Management Office (EEMO);
5. Radiation Protection Authority (RPA);
6. Water Resources Unit (WRU) – Mobilization and Development of water resources; and
7. Mauritius Renewable Energy Agency (MARENA - Operational as from 2016)

A recent change to the ministry as part of the government's commitment to the Long-term Energy Strategy (LTES) 2009-2025 was the implementation of MARENA to coordinate the rapid deployment of renewable energy.

2.3.2 Electricity Act 1939

The Electricity Act 1939 governs electricity generation, distribution and sales in the Republic of Mauritius and establishes the Central Electricity Board (CEB) with the power to oversee the implementation of the Act in conjunction with the MEPU.

The core energy policy framework is implemented by the Central Electricity Board (CEB) which oversees the operation of the electricity generation, transmission, distribution and sale of electricity in the Republic of Mauritius.

2.3.2.1 Limitations on the ownership of power generation

The current Act has several limitations on the ownership of power generation that could impact on the deployment of additional renewable energy sources and battery storage, particularly small-scale systems. Section 27 of the Act (see Figure 4) has potential implications for someone purchasing a home with an existing permit for generation. This section restricts the "undertaker" from purchasing or acquiring the supply of electricity to any area with an entity which already has a permit to supply unless authorised by the CEB. This implies that the sale of a home with a solar PV system installed requires the permission of the CEB to authorise the transfer of the permit for solar generation at the premises. In addition, section 11 of the Act (see Figure 4) also restricts "undertakers" from altering the form or amount of capital without the consent of the CEB. Should a household take out a 'green' loan to purchase a solar PV system and then opt to change the form or amount of the loan, then per the Act, they must obtain permission from the CEB.

Some of these conditions may not be enforced by the CEB, however, these could be challenged in court by a disgruntled third party resulting in an order to the CEB to follow the Act. This would result in additional unnecessarily paperwork and delay for small-scale renewable projects. It could be argued that large-scale projects must continue to follow the Act and if this is the case the Act should be modified to make a distinction between small and large-scale projects.

Another potential issue, is contained in section 8 of the Act (see Figure 4), where it states that a permit shall not be granted to another to supply electricity within the area for which a permit has already been granted. It is unclear by this definition what would happen should another party wish to supply electricity within an area where a permit has already been granted. It may be that the area can support both generators or if the original permit holder does not install the generation does the new party need to wait for the original permit to expire?

Furthermore, it is also unclear how these sections would affect company(s) that install generation (solar PV or battery storage) behind the meter and then sell the electricity from the system to the occupants or if this is allowed under the act.

8. Permit not to be granted to another

Subject to this Act, a permit shall not be granted to any other authority, company, body or person to supply electricity within the area for which a permit has already been granted and has not expired.

11. Restriction on undertakers' capital

The undertakers shall not alter the form or amount of their loan or share capital, or fix the terms of issue of new capital proposed to be raised, without the consent in writing of the Board, and undertakers requiring such consent shall furnish to the Board particulars of the amount, purposes, nature and circumstances of such additions, alterations, and such other particulars, as the Board may require.

27. Undertakers not to purchase other undertakings

(1) The undertakers shall not purchase or acquire the undertaking of, or associate themselves with, or make any arrangements with regard to, the supply of electricity to any area, except as otherwise provided, with any authority, company, body or person supplying energy under a permit, unless the undertakers are authorised by the Board to do so.

(2) Where the undertakers, in contravention of this section, purchase or acquire any such undertaking, or associate themselves with or make any arrangement with regard to the supply of electricity to any area with any such authority, company, body or person, the Board may, if it thinks fit, revoke the permit upon such terms as it thinks just.

Figure 4: Sections of the Electricity Act that may place limitations on the ownership of generation

It is clear from the above examples that the Electricity Act 1939 requires a significant update for the operation of a future smart electricity system in Mauritius. This has been attempted with the proposed Electricity Act 2005, however, since the proposed Act was issued, changes in future grid operation have evolved and an additional review of the proposed Act is required to ensure it will meet with future requirements.

2.3.2.2. Proposed Electricity Act 2005 and Utility Regulatory Authority Act 2008

Originally proposed as part of the Water Sector Reform, a new Utility Regulatory Authority was to be established by the Utility Regulatory Authority Act 2008. This authority would oversee all utility regulation including water and electricity and it is assumed would take over the regulation component of electricity from the CEB. Under the LTES action plan these acts are still referenced, however, it indicates that the Water Sector Reform and the Electricity Act 2005 have been delayed. It is not clear now if there are still plans to proceed with these Acts or not.

2.3.3. *Central Electricity Board (CEB)*

The Central Electricity Board (CEB) is a body that is wholly owned by the Government of Mauritius and reporting to the Ministry of Energy and Public Utilities. Established in 1952 and empowered by the Central Electricity Board Act of 25 January 1964, the CEB's business is to "prepare and carry out development schemes with the general object of promoting, coordinating and improving the generation, transmission, distribution and sale of electricity" in the Republic of Mauritius. The CEB's corporate vision is: *"A world class, commercial electricity utility enabling the social and economic development of the region."*

The CEB produces around 40% of the country's total power requirements from its 4 thermal power stations and 8 hydroelectric plants; the remaining 60% being purchased from Independent Power Producers. Currently, it is the sole organisation responsible for the transmission, distribution and supply of electricity to the population.

The CEB, by adhering to its corporate mission, as defined in the CEB Act 1964, and its Corporate Plan 2003–04, undertakes to pursue its development as a technically viable business partner. The main objective of the CEB remains to deliver, at all times, reliable and quality electricity supply in Mauritius and Rodrigues.

With this strategic objective high on its corporate agenda, CEB has prepared an Integrated Electricity Plan (IEP) covering the period 2013 to 2022. Like the previous IEP, the current one also focuses primarily on the CEB's obligations to provide reliable and secure electricity services to Mauritius and Rodrigues, at the least possible cost and in a socially responsible manner.

The CEB reviewed the integration of further renewable sources to increase the total contribution. The need to promote the development of renewable energy was additionally addressed in the Government's LTES for Mauritius. As part of this strategy, the CEB has put in place the mechanisms to facilitate the construction of several large scale renewable energy projects, primarily wind projects and solar farms, to meet the 2025 target.

2.3.4. *Energy Efficiency Management Office (EEMO)*

The Energy Efficiency Management Office (EEMO) was established under section 4 of the Energy Efficiency Act 2001. The primary objective of the office is to promote awareness of the efficient use of energy to reduce carbon emissions and protect the environment. The key office functions include (Republic of Mauritius 2016):

- The implementation of strategies and programmes for the efficient use of energy;
- Establishing links with regional and international institutions;
- Participating in programmes pertaining to the efficient use of energy;
- Highlighting the initiatives in energy efficiency in the domestic, industrial, transport and services sectors; and
- Creating a synergy around the effective management of energy.

2.3.5. *Mauritius Renewable Energy Agency (MARENA)*

As part of the Government's drive to reduce fossil fuel use it put in place the LTES. Under this Strategy, the Government announced the establishment of a dedicated Renewable Energy Agency, MARENA, to coordinate the rapid deployment of renewable energy. The institutions main task will be the creation of an enabling environment for the development of renewable energy while working closely with international organisation such as the International Renewable Energy Agency (IRENA) and the Mauritius governments Energy Efficiency Management Office (EEMO) to promote renewable energy on Mauritius.

This dedicated body, MARENA, was founded in 2016 and is governed by the Mauritius Renewable Energy Agency Act 2015 (Act No. 11 of 2015). The agency setup is due to be completed in 2017. The Act specifies that the functions of the agency shall be:

a. advise the Minister on all matters relating to renewable energy policy and strategy;
b. every 5 years, elaborate a renewable energy strategic plan;
c. establish the necessary mechanism and framework to increase the use of renewable energy;
d. assess the feasibility and competitiveness of renewable energy projects and make recommendations;
e. encourage and support studies and research on the renewable energy technologies and their implementation;

f. compile and analyse data on use and benefits of renewable energy;
g. develop guidelines and standards for renewable energy projects and for evaluation and approval of on-grid and off-grid renewable energy projects;
h. devising incentive mechanisms, including subsidisation mechanisms based on principles of competitiveness and specific technologies;
i. define a funding strategy for renewable energy projects;
j. assess the requirements for the improvement of skills for the implementation of renewable energy projects;
k. establish linkages with the International Renewable Energy Agency and regional and international institutions with similar objectives;
l. share information and knowledge on renewable energy technologies;
m. carry out sensitisation programmes on renewable energy technologies;
n. devise such criteria as may be necessary for the accreditation of operators in the renewable energy sector; and
o. do such acts and things as may be necessary for the purposes of this Act.

2.4. Government Energy Policy

The government has had some significant success with policies for the promotion of solar hot water heating systems and small-scale solar PV on Mauritius. The challenge for the government will be to build on this success and to accelerate the deployment of renewable energy generation.

2.4.1 Long-Term Energy Strategy (LTES) 2009-2025

The LTES is a white paper, which outlines in broad terms the development of the energy sector, including energy in the transport sector, to the year 2025. The LTES was produced by the MEPU in October 2009. The Republic of Mauritius through the MEPU has set a target for the share of renewables in the energy generation mix of 35% by 2025 as part of the LTES, see Figure 5.

Fuel Source		Percentage of Total Electricity Generation			
		2010	2015	2020	2025
Renewable	Bagasse	16%	13%	14%	17%
	Hydro	4%	3%	3%	2%
	Waste to energy	0	5%	4%	4%
	Wind	0	2%	6%	8%
	Solar PV	0	1%	1%	2%
	Geothermal	0	0	0	2%
	Sub-total	20%	24%	28%	35%
Non-Renewable	Fuel Oil	37%	31%	28%	25%
	Coal	43%	45%	44%	40%
	Sub-total	80%	76%	72%	65%
	Total	100%	100%	100%	100%

Figure 5: Renewable energy targets for Mauritius as outlined in the LTES

As the white paper was produced in 2009, it is now somewhat out of date in terms of potential renewable energy sources that will compose the 2025 target of 35%. For example, the plan assumed that geothermal energy would be available in Mauritius and a plant generating electricity by 2025. This is now very unlikely as preliminary reports indicate that there is no easily accessed geothermal resource available on Mauritius while the associated costs of the technology, such as drilling, remain high. In addition, the report underestimated the likely role that solar PV would likely play in the future energy mix as costs have reduced significantly.

This report calculates that renewable energy component for the 2015 energy generation mix was 22.9%, see Table 6, which is behind the target of 24% set in the LTES for 2015. No onshore wind farms were operational in 2015 and WtE plants only contributed 0.7%. Bagasse generation was the largest renewable energy component representing 17.3% of total generation or 12.9% of electricity transmitted via the grid. Hydro power generation was 4.1% or 121.9 GWh which was higher than the long-term average of approximately 90 GWh per annum.

Table 6: Electricity exported to the grid and self-consumed by IPP generators in 2015

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse (crop season)	381.0	12.9
	Hydro	121.9	4.1%
	WtE	20.4	0.7%
	Onshore Wind	0.0	0.0%
	Solar PV	23.8	0.8%
Sub Total (Renewable)		**547.1**	**18.5%**
Non-Renewables	Fuel Oil	1096.5	37.1%
	Coal(non-crop season)	1047.0	35.4%
Total Electricity Exported to CEB Grid		**2690.6**	**91.0%**
IPP Self-consumption	Renewable—Bagasse (crop season)	128.8	4.4%
	Non-renewables—Coal (non-crop season)	136.8	4.6%
Total Electricity Generation		**2956**	**100.0%**
Total Excess Electricity Generation		**0**	**0.0%**
Total Grid Load/Demand Serves		**1659**	**100.0%**
Total Renewable Generation		**676**	**22.9%**
Total Non-renewable Generation		**2280**	**77.1%**

2.4.1.1. Energy Strategy Action Plan

As part of the LTES an action plan was established and updated in April 2014. This included the update of the Electricity Act 1939 to the proposed Electricity Act 2005, however, this has been postponed. This change to the Electricity Act was originally part of Water Sector Reform were a new Utility Regulatory Authority was to be established to oversee all utility regulation.

The action plan also includes sections on the Institutional, Renewable Energy, Transport, Power Sector, Conventional Fuels, and Public Sector broad initiatives which appears to set the high-level goals for each sector. For example, the Renewable Energy initiatives are then incorporated into the CEBs Integrated Electricity Plan.

2.4.2. CEB – Integrated Electricity Plan (ELP) 2013-2022

CEB produced and released the first Integrated Electricity Plan (IEP) in 2002 with the objective of increasing stakeholders' confidence in its capability to ensure reliable, affordable and sustainable electricity supply for Mauritius and Rodrigues (CEB 2016). CEB release the second Integrated Electricity Plan (IEP) in 2013, a summary of the energy related action items is provided in Table 7.

[4] Note that the Hydro Electricity contribution for the baseline year was higher than the annual average of around 90 GWh.

[5] Electricity that is generated by the IPP companies that is used onsite and not exported to the CEB grid

Table 7: - Summary of Energy Generation Related Action items form the IEP 2013-2022

PROJECT	DESCRIPTION
POWER GENERATION PROJECTS	
New Thermal Power Stations	Construction of the CT Power 100 MW coal-based power plant at Pointe aux Caves. The coming into operation of the CT Power is expected in 2015/2016.
Renewable Energy	Already in the pipeline, the 29.4 MW Curepipe Point Wind Farm, the first of its kind in Mauritius, will start operation in 2014.
	In line with the Government strategy to promote renewable energy projects, 10 MW distributed Solar PV Farms are expected to be operational by the end of 2014.
	The Aerowatt Wind Farm at Plaine des Roches is also in the pipeline. The revised 9 MW Wind Energy Project will further boost the share of renewable capacity in the generation mix. The project is also planned for 2014.
	Construction of a mini-hydro power plant at the Bagatelle Dam Project is being contemplated in the short term.
	A large-scale Solar PV Farm of 15 MW is also under consideration for implementation in the short term.
Future Power Plants	To meet forecasted demand, additional capacity of 50 MW is planned for 2017.
	A further addition of 50 MW is also planned for 2021.
SYSTEM PLANNING STUDIES	
MSDG Grid Code	Establish a Grid Code including the Feed-in tariff and model ESPA for the Medium Scale Distributed Generation, as stipulated in the ESAP 2011-2025 of the MEPU.
Renewable Energy	Continue research work/studies in view of increasing the level of integration of renewable energy.
Smart Grid	Study the feasibility for the implementation of a *Mauritius Smart Grid*.

The key objectives of the latest ELP are:

- To optimise the use of the existing power system;
- To keep electricity prices as low as possible through least-cost capacity expansion
- To encourage our customers to participate in Demand-Side Management (DSM); and
- To provide for continued Private Sector opportunities in the electricity sector.

2.4.2.1. Small-scale Distributed Generation (SSDG) Scheme

The small-scale distributed generation (SSDG) scheme was developed as a key element to promote the uptake of renewable energy generation by citizens on Mauritius in line with the governments long-term vision of promoting a sustainable island. The scheme was devised by the Central Electricity Board (CEB), in collaboration with Ministry of Energy and Public Utilities (MEPU) with help from two UNDP-GEF projects. The scheme covers the deployment of small-scale wind, solar PV and hydro of less than 50 kW.

The first of the UNDP-GEF projects covered Feed-in Tariffs (FiT) to promote small-scale solar PV and wind energy in Mauritius for up to a total of 5 MW of capacity for systems smaller than 50 kW (phases 1 & 2 of the SSDG scheme). The second UNDP-GEF project covered the deployment of individual solar PV systems over 50 kW in capacity through additional FiT policy support and initial funding for direct incentive payments. A key objective of the second UNDP-GEF project was to support the Maurice Île Durable (MID) vision. The projects were run by the UNDP between October 2009 to February 2010.

Under the small-scale distributed generation (SSDG) scheme the CEB plans to integrate a total of 10 MW in capacity from multiple projects using renewable energy (RE) technologies, of which the majority is expected to be solar PV, in the Mauritian grid (Central Electricity Board 2016):

- SSDG Phase 1 was opened for 2MW.
- SSDG Phase 2 was opened for an additional of 1MW.
- SSDG Phase 2 was opened for PECR (Public Educational Charitable and Religious Institution) for a total capacity of 2MW.
- SSDG Phase 3 – CEB 2015 SSDG Net Metering Scheme:
    - Launch of 5 MW net-metering scheme on 24 August 2015.
    - 4 MW is reserved for single-phase domestic customers.
    - 1 MW for three-phase domestic customers and others having declared load below 20 kVA.

Close to 3 MW of capacity has been installed and commissioned under the SSDG scheme at the end of 2015.

2.4.2.2. SSDG Phase 3 – CEB 2015 SSDG Net Metering Scheme

The CEB plans to integrate a total of 5 MW of new SSDG using either solar PV or wind technologies into the Mauritian grid under this scheme. The scheme will use net-metering and will allow the offset of any monthly energy imported from the grid with the energy generated by the solar PV or wind installation and exported to the grid in the form of kilowatt-hour (kWh) credits. The credit can then be used to cover future monthly electricity imports from the grid when the solar PV or wind system is not generating electricity.

2.4.2.3. Medium-scale Distributed Generation (MSDG) Scheme

CEB currently has the following medium to large scale schemes and projects underway or planned:

- Plan to launch a 10 MW net-metering medium-scale distributed generation (MSDG) scheme.
- Plan to launch a 30 MW net-metering Prosumers MSDG scheme.

The CEB has set a maximum permissible capacity per customer of 2 MW.

2.4.2.4. Grid Codes Established

As a stepping stone for the SSDG and MSDG schemes, the Government and the CEB, with the help of the UNDP, established grid codes. The first SSDG grid codes for the SSDG phase 1 were introduced in May 2009. The grid codes were updated and new codes published for the SSDG phase 3 – CEB 2015 SSDG Net Metering Scheme in August 2015.

The purpose of the grid codes is to assist the public/private sector to better understand the procedure for application, the requirements for interconnection, the Feed-in-Tariffs and other related issues regarding the schemes and each can be summarised as (CEB 2010) (CEB 2015):

- The SSDG set of Grid Codes describe the technical criteria and requirements for interconnection of SSDG with CEB's low voltage (230/400V) network systems.
    - Caters for the production of electricity from Photovoltaic (PV) and Wind Turbine renewable technologies.
    - Defines two categories of customers:
        - Category 1: Domestic Customers excluding IRS, RES and 3-phase Domestic Customers
        - Category 2: Domestic Customers with 3-phase supply including IRS, RES Customers and Other Customers having a declared load less than 20 kVA.
    - The maximum allowable capacities per installation for the above two categories are as follows:
        - Category 1: 3.5 kWp
        - Category 2: 5.0 kWp
    - The 5 MW in Mauritius is allocated to the two customer categories as follows:
        - Category 1: 4MW
        - Category 2: 1MW
- The MSDG set of Grid Codes describe the technical criteria and requirements for the connection of distributed generation plant of capacity greater than 50kW and not exceeding 2MW to the CEB's 22kV distribution network.

2.5. Funding and Policy Support

Funding and policy support has been provided through the following projects:

- UNDP-GEF projects
    - Feed-in Tariffs (FiT) to promote small-scale solar PV and wind energy in Mauritius for up to a total of 5 MW of capacity
    - Deployment of individual solar PV systems over 50 kW in capacity through additional FiT policy support and initial funding for direct incentive payments
- Mauritius government has recently become the 137th member of the International Renewable Energy Agency (IRENA)
- MID Fund
    - Funding to develop grid codes
    - Feasibility study for a wind farm at Curepipe Point, wind power projects in Rodrigues, a hydro power project at Midlands, a Landfill Gas to Energy project and a Waste to Energy project.
    - Feasibility study for geothermal energy
    - Mauritius Renewable Energy Master Plan 2016-2030

3. Demand and Supply Beyond 2025

Reviewing the current growth trends over the last decade in the Republic of Mauritius, this chapter attempts to project the electricity supply growth over the next 15 years and beyond. It is feasible to assume that the moderate economic growth the Republic of Mauritius has experienced over the last 20 years will continue over the next 10 years driving the country to a higher social status when the country is looking to achieve 35% renewable energy target. Beyond that, Mauritius is setting ambitious targets to achieve a continued increase in social status and more aggressive increases in renewable energy generation. The renewable energy industry has become an industry that drives local employment and social growth.

Scenario planning in Australia led to additional employment in the electricity sector, resulting from both the construction of new electricity generating infrastructure, and from the operation of existing and new generating capacity. Even with some job losses due to reduced coal/oil fired electricity generation, these losses are more than compensated for by additional jobs created in the construction and operation of renewable energy plants. With a target of 50% renewable energy contribution by 2030 it is expected that the electricity industry will create an additional 28,000 jobs. This chapter also looks at the jobs potential in the renewable energy sector by targeting a more aggressive 60% plus renewable energy target for the Republic of Mauritius.

3.1. Population Distribution in Mauritius

The population on Mauritius is distributed around the capital, St Louis. Data sourced from the national census in 2011 indicates the percentage change in population is also concentrated around the Port Louis area. Figure 6 shows the population density (right) and the percentage of population change (left) for Mauritius.

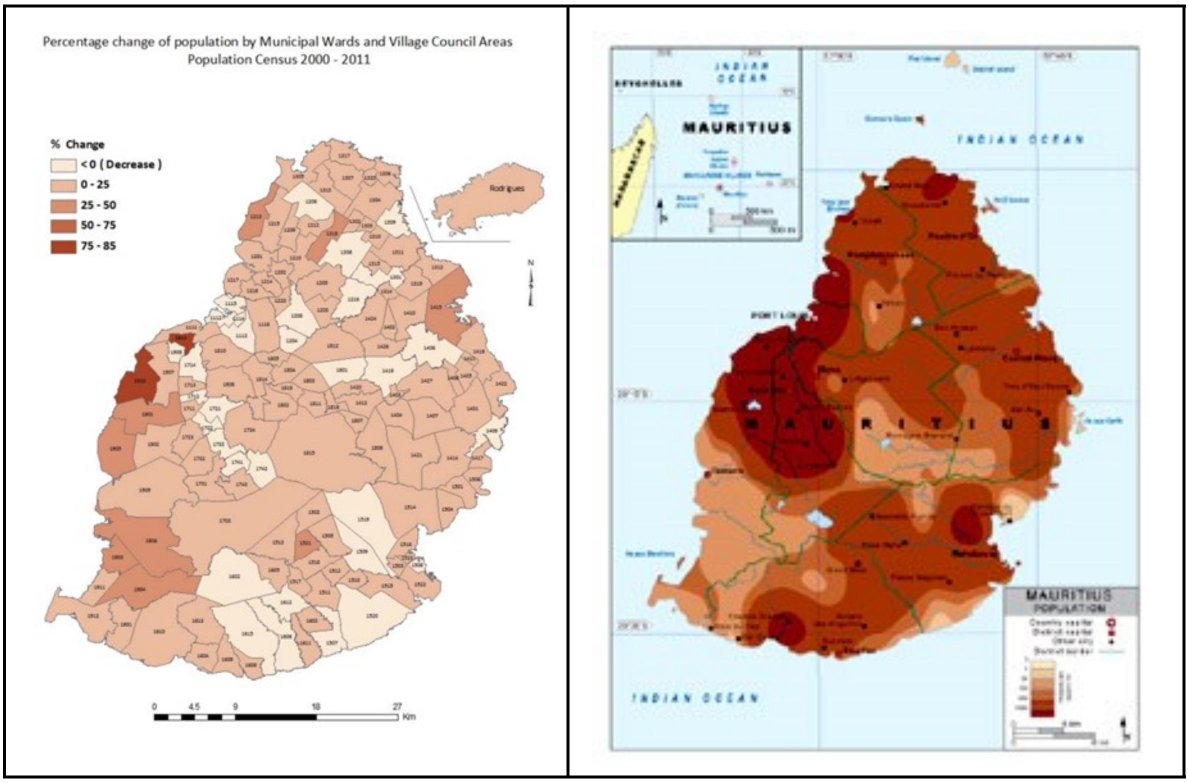


Figure 6: Population change and population density for Mauritius[6]

Figure 7 shows the proportion of the population by gender. Figure 8 shows the overall population of Mauritius for the period 1952 – 2016.

[6] Source: WHO (2003). Report on Mauritius http://www.who.int/healthinfo/survey/whsmus-mauritius.pdf

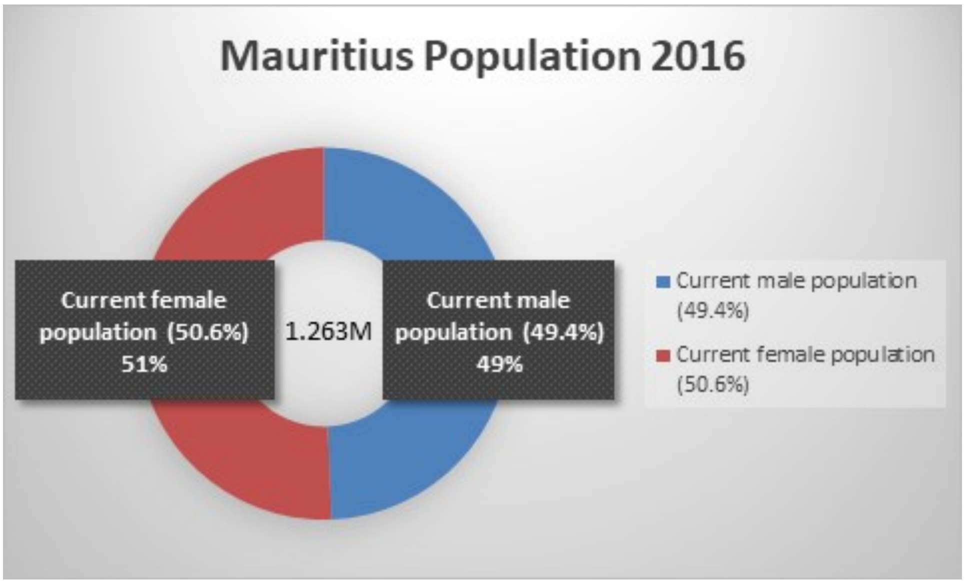


Figure 7: Population proportion by gender

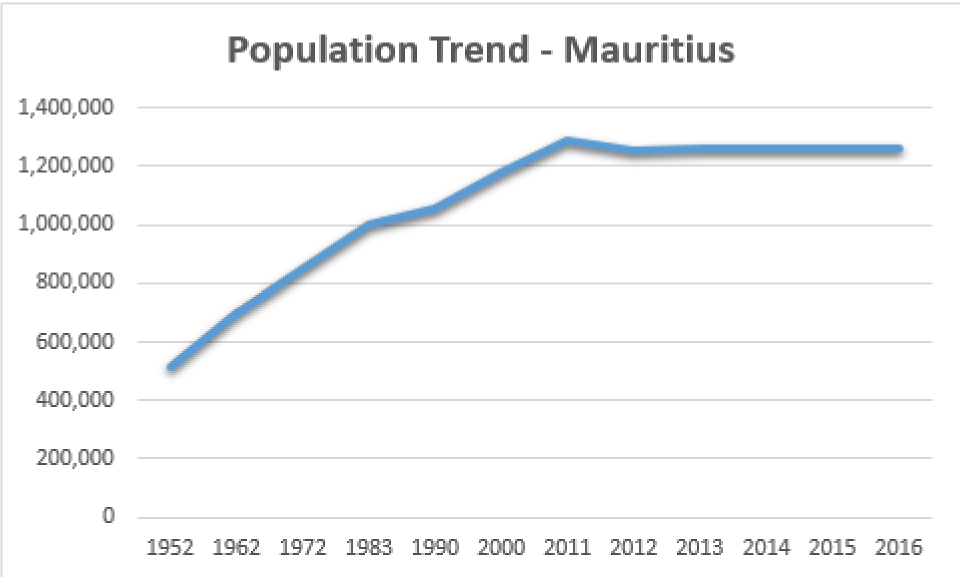


Figure 8: Overall population for Mauritius

The population of Mauritius has been quite stable during the past few years and has not seen the same growth rate that occurred during recent decades.

The 2011 Housing Census counted 311,500 buildings, 356,900 housing units and 341,000 households in the Republic of Mauritius as shown in Figure 9.

	Buildings	Housing units	Private households	Population[1]
Republic of Mauritius	**311,500**	**356,900**	**341,000**	**1,257,900**
Island of Mauritius	297,500	344,700	329,950	1,217,175
Island of Rodrigues	13,900	12,115	10,971	40,440
Agalega	100	85	79	285

[1] Population in both private and communal households

Figure 9: 2011 Housing Census Data

Out of the 311,500 buildings in the Republic of Mauritius in 2011, the majority (264,100 or 84.8%) were wholly residential buildings. Between 2000 and 2011, the housing stock grew by 19.9% from 297,700 to 356,900 housing units. Out of all housing units recorded in 2011, 90.5% were used as a principal residence, 1.7% as a secondary residence and 7.8% were vacant. The number of private households increased by 14.5% from 297,900 in 2000 to 341,000 in 2011 while the average number of people per household decreased from 3.9 to 3.6.

Housing and living conditions improved from 2000 to 2011 with higher proportions of households:

- owning their houses (from 86.5% to 88.9%);
- having access to electricity (from 99.0% to 99.4%);
- with piped water inside their house (from 83.7% to 94.2%).

Of particular interest for household electricity access is those housed on Mauritius without electricity. The census logged 1,700 households that did not have electricity. There are several options available to provide standalone power systems to homes without access to electricity. As part of the humanitarian efforts in Mauritius, this roadmap will address the access of electricity to these homes.

The 2011 Housing Census counted 311,500 buildings in the Republic of Mauritius, Table 8. Most of them (264,100 or 84.8%) were wholly residential buildings used by private households though their share of total buildings declined from 2000 to 2011 at the expense of partly residential buildings, hotels, tourist residence and guest houses as well as non-residential buildings.

Table 8: Number of building by type, Republic of Mauritius, 2000 and 2011 Housing Censuses

Building Type	Number		%	
	2000	2011	2000	2011
Under Construction	12,100	13,100	4.5	4.2
Wholly Residential	229,000	264,100	85.4	84.8
Partly Residential	11,400	14,500	4.2	4.7
Hotels, Tourist Residence & Guest Houses	400	1,100	0.1	0.3
Institutions	100	200	0.1	0.1
Non-residential	15,300	18,500	5.7	5.9
All Buildings	268,300	311,500	100.0	100.0

As in 2000, concrete is the main type of construction material used for housing, see Table 9. It is becoming even more predominant over time with the proportion of wholly concrete residential and partly residential buildings rising from 86.3% to 92.0%. Conversely, the proportion made of iron/tin walls and roof declined from 8.1% to 4.5% with 6,700 fewer such buildings in 2011.

Table 9: Distribution of residential and partly residential buildings[7] by construction material, Republic of Mauritius, 2000 and 2011 Housing Censuses

Type of Construction Materials	Number		%	
	2000	2011	2000	2011
Concrete walls & roof	206,200	255,700	86.3	92.0
Concrete walls & iron/tin roof	9,400	7,400	3.9	2.7
Iron/tin walls & roof	19,300	12,600	8.1	4.5
Wood walls & iron/tin/shingle roof	2,200	1,000	0.9	0.4
Other	1,800	1,200	0.8	0.4
Total	238,900	277,900	100.0	100.0

3.2. Employment in the RE sector

The following data is from the International Renewable Energy Agency (IRENA).

In its 2015 Renewable Energy and Jobs Annual Report, the International Renewable Energy Agency (IRENA) estimated there were 7.7 million direct and indirect jobs in the renewable energy sector in 2014. The nine sectors of renewable energy covered by the report are shown in Figure 10 along with a breakdown of jobs per technology. The report revealed that China leads global employment in renewable energy with roughly 3.4 million direct and indirect jobs, followed by Brazil, the United States, India, and Germany.

Across the globe, solar PV has the highest employment in the renewable energy sector, with roughly 2.5 million jobs. Liquid biofuels trail closely behind with 1.8 million jobs, followed by wind power at approximately one million jobs.

[7] Figure excludes detached rooms (1,500 for 2000 and 700 for 2011), used as part of household

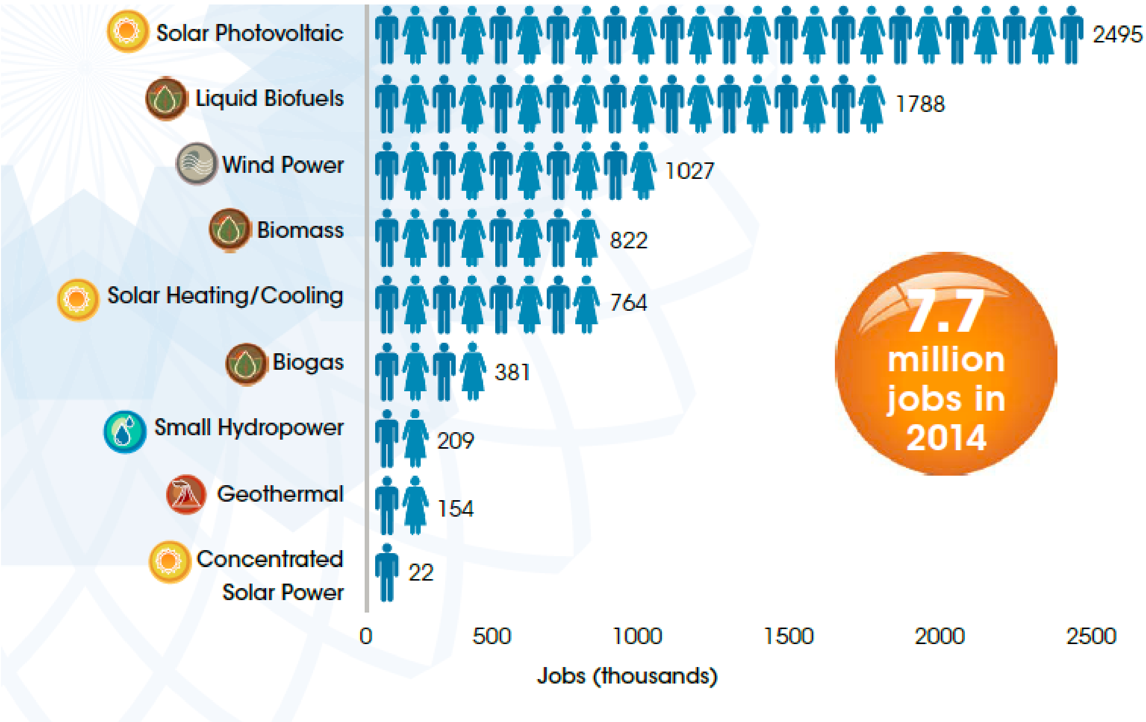


Figure 10: Renewable energy employment by technology. (1)

It is estimated that the renewable energy industry in Mauritius could support more than 1,000 jobs by 2025. This estimate is based on applying a similar percentage of employment to countries such as United Kingdom (UK). Mauritius could follow the UK's lead in the renewable energy space as the two countries have similar offshore wind and wave energy resources. The European Commission forecasts that low-carbon generation and energy efficiency could generate five million jobs across the EU by 2020. The wind, wave and tidal energy sector directly employs 18,465 people full time. The sector also supports 15,908 indirect jobs, making a total of over 34,300 employees. The number of employees in offshore wind has doubled since 2010.

More than 80% of all employers in the wind, wave and tidal industries employ fewer than 250 people and 56% employ fewer than 25 people, showing that SMEs are at the heart of the sector, and are driving the growth in employment, reflecting the depth and diversity of the industry.

More than 30,000 jobs could be created in the next decade in offshore wind. The scale of the opportunity is massive, but success is not guaranteed. To harness the economic benefits of these renewable technologies the UK must ensure that there is certainty for industry - a plentiful and skillful workforce of renewable energy engineers is crucial - the country must invest in the right people and develop the right skills.

US labour statistics show that 373,807 full-time equivalent (FTE) employees (shown in Figure 11 below) are working in the solar industry in 2016 (DOE Report Jan 2017) with a population of 326.5 million. Interestingly much of the jobs in the traditional fuels is the production of the fuel itself and not the power generation sector. This would mean that there is a greater potential for growth in Mauritius with the advancement of the solar industry.

	Electric Power Generation	Fuels	Total
Solar	373,807	-	373,807
Wind	101,738	-	101,738
Geothermal	5,768	-	5,768
Bioenergy/CHP	26,014	104,663	130,677
Corn Ethanol	-	28,613	28,613
Other Ethanol/Non-Woody Biomass, incl. Biodiesel	-	23,088	23,088
Woody Biomass Fuel for Energy and Cellulosic Biofuels	-	30,458	30,458
Other Biofuels	-	22,504	22,504
Low Impact Hydroelectric Generation	9,295	-	9,295
Traditional Hydropower	56,259	-	56,259
Nuclear	68,176	8,595	76,771
Coal	86,035	74,084	160,119
Natural Gas	52,125	309,993	362,118
Oil/Petroleum	12,840	502,678	515,518
Advanced Gas	36,117	-	36,117
Other Generation/Other Fuels	32,695	82,736	115,431

Figure 11: USA Generation and Fuels Employment by Sub-Technology. (DOE Report Jan 2017)

Renewable energy employment in Mauritius could be a great driver for jobs creation for the country and these jobs can be exported to neighbouring countries (e.g. Madagascar) to support the development of renewable energy projects in the region. The merits of renewable energy employment are not part of the scope of this study and it is recommended a specific study be commissioned to evaluate the benefits of a more aspirational renewable energy target.

3.3. Mauritius Energy Demand – All Sources

The energy users in Mauritius can be categorized into five sectors:

1. Transport
2. Commercial
3. Distributive trade
4. Manufacturing and
5. Households.

As shown in Figure 12, the transport sector is currently the largest consumer of energy accounting for 50.9% of the total energy demand in 2015. Transport represented over 50% of diesel use on the island and is continuing to increase annually. The Manufacturing and Household sector make up for about 23.8% and 14.3% of the total energy consumption respectively.

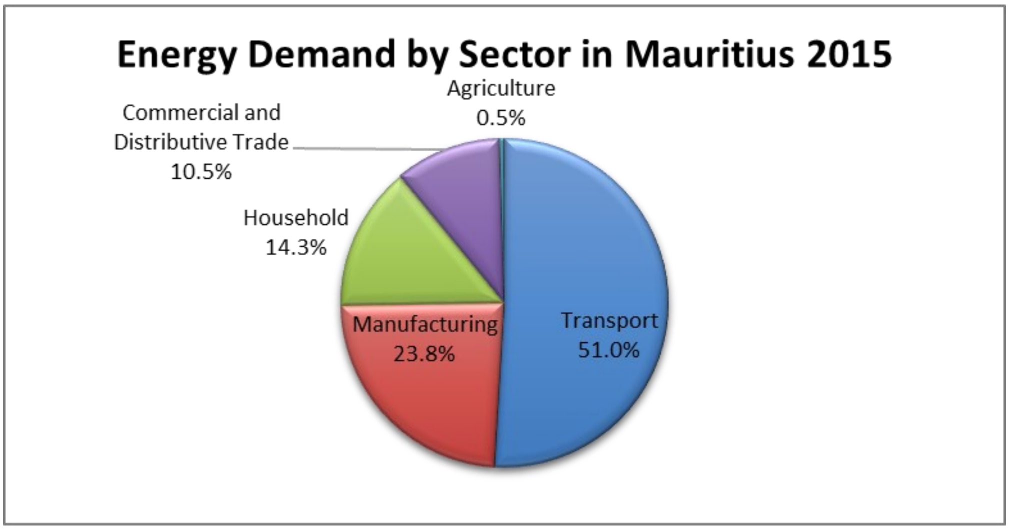


Figure 12: Mauritius Energy Usage by Sectors 2015.

Over the period 1993 to 2015, the growth in demand has mainly come from the transport industries that grew from 39.8% to 50.9%. The second highest increase was accounted in the household sector (excluding transport) from 1997 to 2015 with an increase from about 7% to 14.3% of the total energy demand. The two main sources of energy for households were electricity and LPG, representing 55% and 41% respectively of the household total. Between 2014 and 2015, household consumption of electricity and LPG rose by 3.2% and 3.1% respectively. Air-conditioning and other household appliances accounted for most of the increase in household electricity consumption.

The main sectors are predicted to decline over the next decade with tourism being more consistent in regards to growth prospects. Below are published data currently available in the website (FAO Corporate Document Reposotory n.d.).

3.3.1. Agriculture

It is envisaged that the land area used for sugar production would continue to decline, and profitability would likely come under pressure from stagnant, or even falling world sugar prices and increasing competition from the EU. However, it is expected that output and profitability would be maintained because of improvements in productivity.

While there is a continuing loss of sugarcane fields of some 500 hectares a year because of residential and industrial development, the effect of this will be partially offset by a gradual increase in area of the 5,000 hectares under irrigation and a further 1,000 hectares brought under cultivation due to de-rocking. There is also increasing productivity due to the grouping of small planters, increased mechanisation, more efficient irrigation systems, the introduction of higher yielding varieties, and the adoption of lower cost methods in field, factory and marketing operations.

Thus, sugar will continue to account for the majority of land under cultivation and will still represent an important sector within the economy of Mauritius via export earnings. However, it will still account for a declining proportion of total GDP and sharply declining share of total employment as other sectors expand and labour productivity rises. There should be scope for reducing the cost of imported food by increasing Mauritian production of fruit, vegetables, meat and dairy products, and of processed food and drinks, which should benefit from the TDS (Tax Deductions at Source). There may also be greater scope for exports of flowers, spices, palm kernel and other products, provided international standards can be met.

3.3.2. Manufacturing

The rapid build-up of the manufacturing industry in Mauritius has been mainly in the Export Processing Zone and based predominantly on the export of clothing and textiles to Europe, where Mauritius has enjoyed free access under the Lomé Convention. Moreover, with the Multi fibre Agreement due to be phased out by 2005, Mauritius will face sharply increased competition from low-cost, large-volume producers. Some of the smaller firms are much less advanced and will require the Export Processing Zones Development Authority to help them adopt best practices by improving training opportunities, establishing industrial parks and encouraging the use of information technology in design, production, marketing and communication.

The country's membership of the Common Market for Eastern and Southern Africa, the Indian Ocean Commission, the Indian Ocean Rim – Association for Regional Cooperation and the Southern African Development Community, will provide favoured access to these newly growing regional markets and will reduce the dependence on Europe as a destination for exports.

3.3.3. Tourism

Mauritius has considerable natural advantages as a holiday destination – beautiful coral beaches, warm clear lagoons, colourful reefs, picturesque mountains, a subtropical climate, a southern hemisphere location, an atmosphere that is exotically different, yet safe and stable, and people who are friendly and welcoming. These advantages have been exploited with attractive well run hotels with good amenities, direct and reliable air services, efficient supporting infrastructure and effective marketing as an up-market quality destination. It is therefore hardly surprising that tourist arrivals have been rising by more than 8 percent a year and the tourism industry has become one of the most dynamic sectors of the economy, accounting for 19 per cent of gross export earnings and providing employment directly and indirectly for about 50,000 people .

Infrastructure constraints have developed in the form of congestion at peak times at the airport and inadequate effluent treatment leading to deterioration in water quality in some of the lagoons. In the longer term, there will be more general environmental constraints, in the form of limits to the capacity for absorbing ever increasing numbers of visitors in a small densely populated country with a finite length of beaches and a sensitive coastal ecology.

The development of Mauritius as a regional centre should give scope for the growth of business tourism and the holding of conferences, exhibitions and other special events.

It will be necessary to improve the infrastructure on which tourism depends as well as environmental management to guarantee the quality of the environment on which the tourism industry and the country depends.

3.4. Historical Annual Electricity Usage for Mauritius

Electricity consumption accounts for approximately 26% of the total energy demand for Mauritius. As shown in Figure 13, the total electricity demand can be separated into different sectors with manufacturing being the largest consumer of electricity accounting for 35.2% in 2015. The Commercial and Distributive Trade and the Household sector made up 33.6% and 30.4% of the total energy consumption respectively.

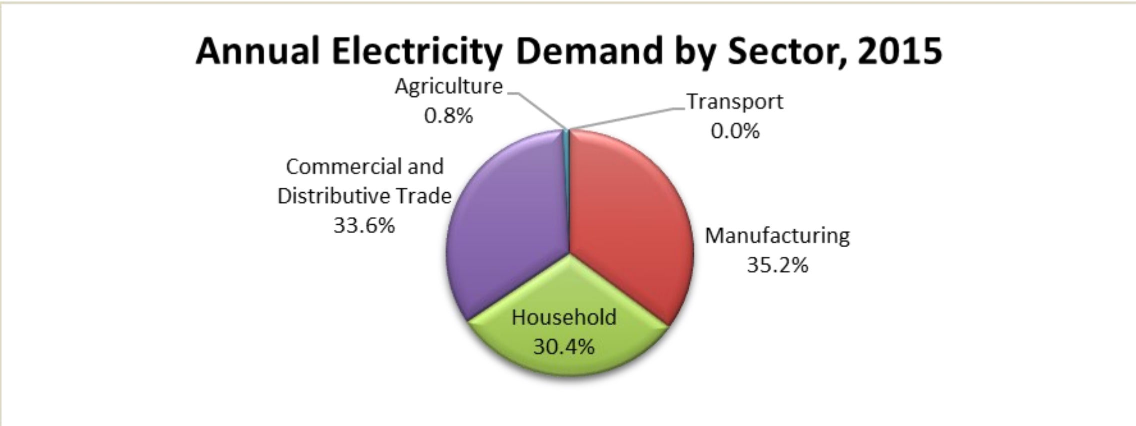


Figure 13: Mauritius Electricity Usage by Sectors 2015.

The Mauritius daily electricity demand profile is represented by the sample data in Table 10. It shows that the electricity load is higher in summer than in winter and that the summer peaks occur between 10 am to 4 pm and 7 pm to 9 pm.

Table 10: Annual load profile for Mauritius showing peak electricity consumption during Dec-Jan.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	301,256.05	288,559.10	275,862.15	263,165.20	250,468.25	237,771.30	225,074.35	237,771.30	250,468.25	263,165.20	275,862.15	288,559.10
01:00	280,534.46	268,780.73	257,026.99	245,273.26	233,519.53	221,765.79	210,012.06	221,765.79	233,519.53	245,273.26	257,026.99	268,780.73
02:00	269,092.27	258,985.52	248,878.77	238,772.02	228,665.26	218,558.51	208,451.76	218,558.51	228,665.26	238,772.02	248,878.77	258,985.52
03:00	262,181.64	252,639.62	243,097.60	233,555.57	224,013.55	214,471.53	204,929.50	214,471.53	224,013.55	233,555.57	243,097.60	252,639.62
04:00	260,729.48	251,651.77	242,574.06	233,496.35	224,418.64	215,340.93	206,263.22	215,340.93	224,418.64	233,496.35	242,574.06	251,651.77
05:00	264,128.15	256,268.30	248,408.45	240,548.59	232,688.74	224,828.89	216,969.03	224,828.89	232,688.74	240,548.59	248,408.45	256,268.30
06:00	269,988.29	267,502.79	265,017.30	262,531.81	260,046.32	257,560.83	255,075.33	257,560.83	260,046.32	262,531.81	265,017.30	267,502.79
07:00	299,814.19	296,307.38	292,800.57	289,293.76	285,786.95	282,280.14	278,773.33	282,280.14	285,786.95	289,293.76	292,800.57	296,307.38
08:00	359,146.73	350,950.44	342,754.15	334,557.87	326,361.58	318,165.29	309,969.00	318,165.29	326,361.58	334,557.87	342,754.15	350,950.44
09:00	408,757.01	395,174.35	381,591.68	368,009.02	354,426.35	340,843.69	327,261.02	340,843.69	354,426.35	368,009.02	381,591.68	395,174.35
10:00	433,659.99	418,843.17	404,026.34	389,209.51	374,392.68	359,575.85	344,759.03	359,575.85	374,392.68	389,209.51	404,026.34	418,843.17
11:00	434,844.38	420,331.37	405,818.36	391,305.36	376,792.35	362,279.34	347,766.33	362,279.34	376,792.35	391,305.36	405,818.36	420,331.37
12:00	433,273.78	417,197.90	401,122.02	385,046.14	368,970.26	352,894.38	336,818.50	352,894.38	368,970.26	385,046.14	401,122.02	417,197.90
13:00	429,004.85	413,940.84	398,876.84	383,812.83	368,748.83	353,684.83	338,620.82	353,684.83	368,748.83	383,812.83	398,876.84	413,940.84
14:00	440,400.69	423,812.43	407,224.18	390,635.92	374,047.66	357,459.41	340,871.15	357,459.41	374,047.66	390,635.92	407,224.18	423,812.43
15:00	437,717.80	421,333.81	404,949.81	388,565.82	372,181.83	355,797.84	339,413.84	355,797.84	372,181.83	388,565.82	404,949.81	421,333.81
16:00	428,654.68	414,143.39	399,632.10	385,120.81	370,609.52	356,098.22	341,586.93	356,098.22	370,609.52	385,120.81	399,632.10	414,143.39
17:00	400,270.64	387,896.39	375,522.14	363,147.89	350,773.64	338,399.39	326,025.14	338,399.39	350,773.64	363,147.89	375,522.14	387,896.39
18:00	394,096.38	386,874.21	379,652.04	372,429.86	365,207.69	357,985.52	350,763.34	357,985.52	365,207.69	372,429.86	379,652.04	386,874.21
19:00	433,531.26	425,778.68	418,026.11	410,273.54	402,520.97	394,768.39	387,015.82	394,768.39	402,520.97	410,273.54	418,026.11	425,778.68
20:00	435,441.72	423,403.05	411,364.37	399,325.70	387,287.03	375,248.36	363,209.68	375,248.36	387,287.03	399,325.70	411,364.37	423,403.05
21:00	412,979.60	399,140.32	385,301.04	371,461.76	357,622.48	343,783.19	329,943.91	343,783.19	357,622.48	371,461.76	385,301.04	399,140.32
22:00	383,524.46	366,749.96	349,975.47	333,200.97	316,426.48	299,651.98	282,877.48	299,651.98	316,426.48	333,200.97	349,975.47	366,749.96
23:00	344,372.81	329,386.05	314,399.29	299,412.53	284,425.77	269,439.01	254,452.24	269,439.01	284,425.77	299,412.53	314,399.29	329,386.05
	8,817,401	8,535,652	8,253,902	7,972,152	7,690,402	7,408,653	7,126,903	7,408,653	7,690,402	7,972,152	8,253,902	8,535,652

Year on year, the increase in consumption has averaged between 2-3% over the last decade, see Table 11 and Figure 14. Most of this increase has come from the manufacturing and trade sectors. With the population profile being generally flat, much of the increase in the Household sector has come from increased wealth and the upgrade of facilities with air conditioners and other appliances.

Table 11: Total annual electricity generation for Mauritius (Statistics Mauritius 2016, Statistics Mauritius 2014)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Rodrigues	30	31	31	31	32	32	33	34	36	37	40
Mauritius	2242	2319	2434	2526	2546	2657	2706	2764	2850	2900	2956
Total Generated Electricity (MWh)	2272	2350	2465	2557	2577	2689	2739	2797	2885	2937	2996

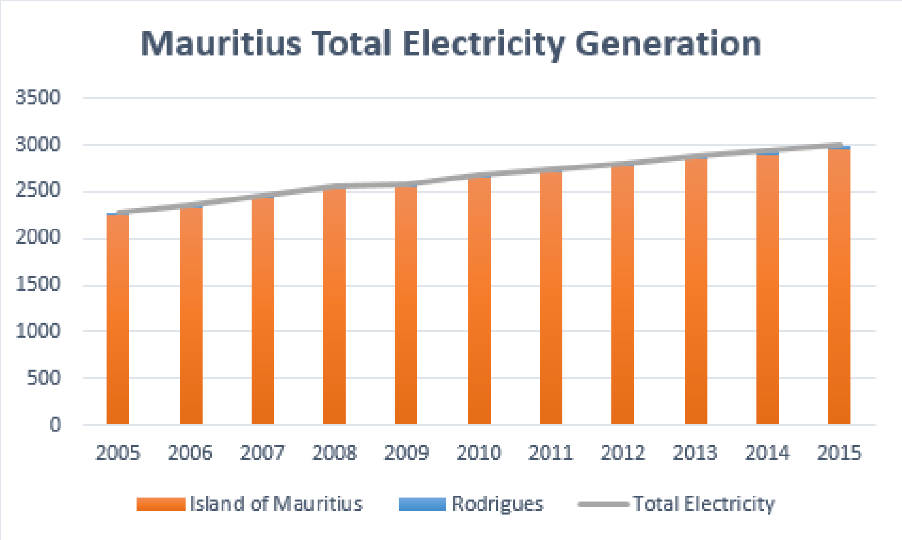


Figure 14: Total annual electricity generation for Mauritius (Statistics Mauritius 2016, Statistics Mauritius 2014)

3.4.1. Predicted Future Electricity Demand

The projections assume a base case average annual growth in electricity demand for Mauritius of around 1.9%, meaning the base case peak demand is estimated to reach 632 MW by 2030. This indicates that Mauritius will need to add significant new capacity over the next 15 years to secure demand during peak periods. Figure 15 and Table 12 convey the demand growth scenarios used by the World Bank. Figure 16 conveys the generation growth scenarios that match the demand growth used by the World Bank.

Table 12: Electricity Demand Growth (The World Bank 2015)

Year	Low Scenario		Base Scenario		High Scenario	
	Electricity (GWh)	% annual growth	Electricity (GWh)	% annual growth	Electricity (GWh)	% annual growth
2015	2,686		2,687		2,688	
2016	2,733	1.7	2,744	2.1	2,777	3.3
2017	2,779	1.7	2,802	2.1	2,866	3.2
2018	2,826	1.7	2,859	2	2,955	3.1
2019	2,872	1.6	2,917	2	3,044	3
2020	2,919	1.6	2,974	2	3,133	2.9
2021	2,960	1.4	3,027	1.8	3,226	3
2022	3,002	1.4	3,080	1.8	3,319	2.9
2023	3,043	1.4	3,134	1.7	3,413	2.8
2024	3,085	1.4	3,187	1.7	3,506	2.7
2025	3,126	1.3	3,240	1.7	3,599	2.7
2026	3,164	1.2	3,291	1.6	3,699	2.8
2027	3,201	1.2	3,343	1.6	3,799	2.7
2028	3,239	1.2	3,394	1.5	3,900	2.6
2029	3,276	1.2	3,446	1.5	4,000	2.6
2030	3,314	1.1	3,497	1.5	4,100	2.5
2031	3,347	1	3,549	1.5	4,198	2.4
2032	3,377	0.9	3,599	1.4	4,295	2.3
2033	3,404	0.8	3,650	1.4	4,389	2.2
2034	3,428	0.7	3,697	1.3	4,482	2.1
2035	3,449	0.6	3,745	1.3	4,571	2

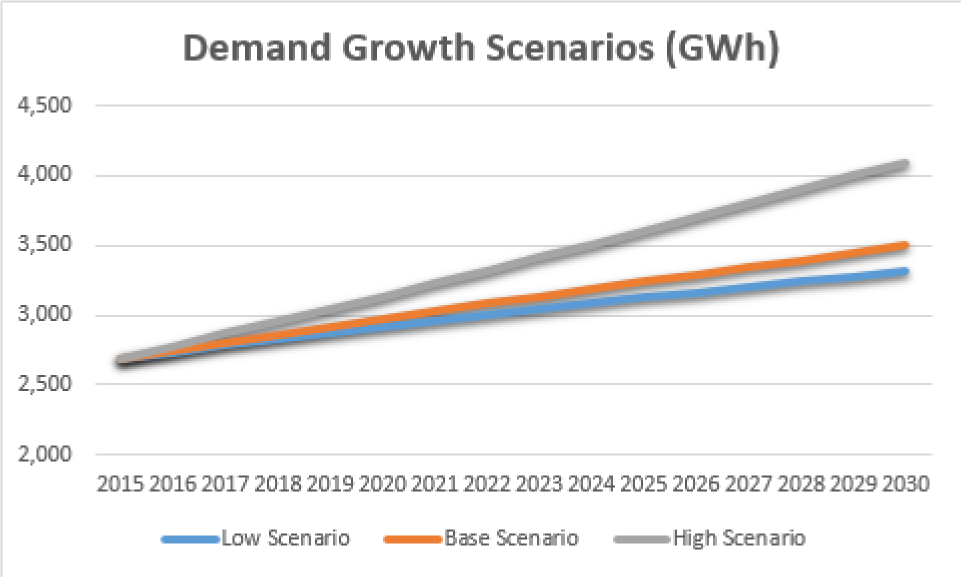


Figure 15: Demand growth scenarios (The World Bank 2015)

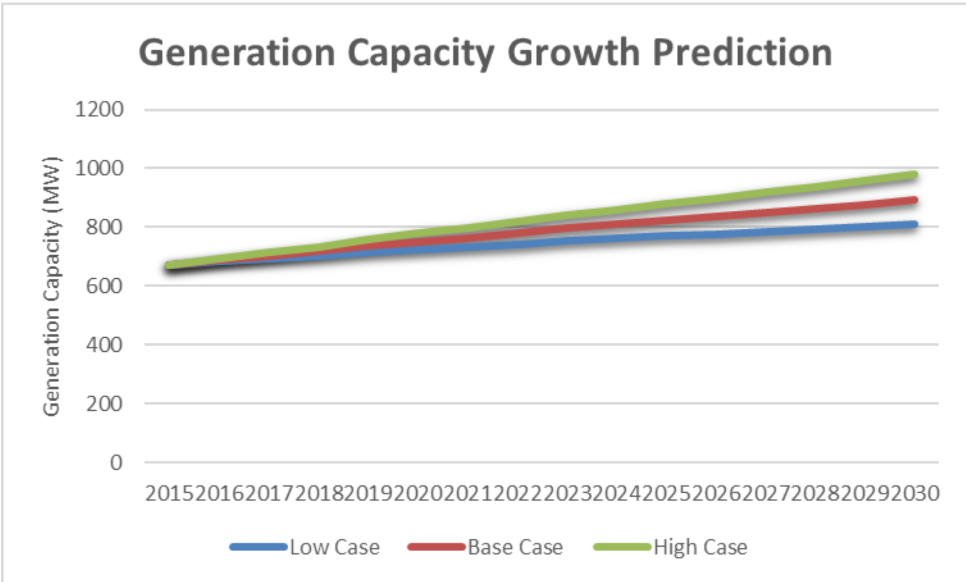


Figure 16: Generation Capacity Increase based on 4% median growth to 2030.

3.5. Electric Vehicles

As countries look to meet future energy mix requirements in a rapidly growing and changing world, trying to achieve sustainable transportation is emerging as a key mission. Electric vehicles (EVs) are one of the most beneficial ways to improve energy security and at the same time reduce greenhouse gases and other pollutants.

There have now been more that 540,000 EVs sold in the US alone. Annual worldwide sales of EVs are expected to increase from practically nothing in 2010 to over 1,000,000 in 2017. The leaders of this revolution are China, US, Japan, and France who are striving to achieve a high number of EV integration into the national transport models.

The EV transformation is undoubtedly a long-term ambition. The EV market represents less than 1% of total vehicle sales in most major markets, due partly to higher upfront costs, range limitations (improving), and a lack of real education. Currently, there has been considerable progress in the global market, which suggests a relatively positive outlook. Mauritius like other modern societies are conscious of the impact of climate change and are looking to increase their own independence and energy security by considering studies on to uptake of EVs in Mauritius. For a small country like Mauritius, EV technology is well suited as the driving ranges are short, however, this goes beyond the scope of this study and it is suggested that further detailed studies need to be performed to evaluate the full impact of a rapid expansion in EV technology.

3.6. Mauritius LNG Bunkering

Mauritius Ports Authority has hired Royal HaskoningDHV to consider possibilities for Port Louis to be converted into a bunkering and petroleum/LNG hub. The analysis would be conducted within the scope of the Port Masterplan studies for Port Louis (the gateway port of Mauritius) and for Port Mathurin on the Island of Rodrigues. Having in mind the growing popularity of LNG as marine fuel among shipowners, the port authority is interested in exploring the opportunity. The studies, to be completed by August 2016, will also examine the challenges associated with future development of the ports, including:

- exploring the potential of Port Louis for container transhipment, increasing performance of the Mauritius Container Terminal, and maintaining and improving market share in a competitive market;
- unlocking land outside the port boundaries for port expansion, and related challenges in terms of interactions between the port, city and land owners;
- adapting existing port infrastructure such as quay walls, jetties, port basins and tank farms to handle a wider range of trades; finding a balance between trade development, waterfront development, cruise facilities, marina development, and preservation of the islands' sensitive ecological system.

This opportunity provides an avenue to replace the current mix of energy use in Mauritius with a lower priced LNG for both transportation and electricity generation. The evaluation of this study and the impact it may have on electricity production in Mauritius is beyond the scope of this report.

3.7. Energy Efficiency Strategies for Mauritius

The Government of Mauritius has placed emphasis on sustainable development through the adaptation of green building concepts. Challenges in the areas of energy and the environment can be met, not by doing without technology but rather by continuing to develop and deploy advanced technology to save energy and protect the environment. One way for us to save energy is to use it more intelligently and therefore more efficiently. A paper released in 2010 provided a holistic approach to develop and retrofit buildings to be energy efficient. It provides an overview of energy audits and the steps required to implement energy management systems. Important standards related to the energy efficiency in buildings and energy audits are discussed. Energy efficiency is a key aspect of developing a sustainable energy portfolio and further studies are required to expand on the findings of the 2010 paper. A link to the paper is provided below:

http://www.iemauritius.com/upload/files/
towards_energy_efficient_buildings_for_a_sustainable_mauritius.pdf

Although energy efficiency is beyond the scope of this report, it should be noted that previous studies commissioned by the Mauritius Government, such as the Renewable Energy Management Master Plan and Action Plan (2), cover energy efficiency. In addition, this study provides some background information on two specific emerging energy efficient technologies of relevance to Mauritius, see:

APPENDIX C | Technology Overview – Deep Seawater Air Conditioning

APPENDIX D | District Cooling System Case Studies

4. Assessment of the Energy Generation Mix to 2025

This Chapter of the roadmap provides a summary of the current supply and use of electricity in the Republic of Mauritius. The total electricity supply includes that generated on both Mauritius and Rodrigues, however, this study will concentrate on Mauritius only as it *accounts for over 98% of the total electricity supply. The study will highlight the current energy generation mix in Mauritius – what forms of electricity generation are used, and in what locations, what percentage comes from renewable* generation and what will be the likely energy generation mix in 2025.

A baseline year, 2015[8], will be used to assess the current energy generation mix. The assessment will consider the baseline energy generation mix in 2015 and the potential changes that are likely to take place during the period up to 2025 based on the proposals and plans underway by the Central Electricity Board (CEB) to meet the 35% renewables target. This will provide the basis to determine the likely energy generation mix in 2025 and whether the 35% target is likely to be achieved. The assessment will assume an average annual growth in electricity demand of around 1.9% between 2015 and 2025, in line with demand growth scenarios used by the World Bank. The information obtained for use in the assessment of the energy generation mix is listed in Table 13.

Table 13: Summary of reports used to determine the energy generation mix in 2015 and beyond

Reports	Reference	Citation
CEB Presentation on Electricity Infrastructure Development	Presentation given to the Southern Africa Energy and Infrastructure Summit 2016 in Maputo Mozambique.	(Mukoon 2016)
CEB Presentation July 2016	Presentation given to Carnegie Wave Energy (CWE) and Energy Made Clean (EMC) on 11 July 2016 on the Central Electricity Board and current development plans.	(Central Electricity Board 2016)
Long-Term Energy Strategy	This document is a blue print for the development of the energy sector up to year 2025. It lays emphasis on the development of renewable energy, reduction of our dependence on imported fossil fuel and the promotion of energy efficiency in line with Government's objective to promote sustainable development in the context of the Maurice Ile Durable vision.	(Republic of Mauritius 2009)
Assessment of electricity demand forecast and generation expansion plan with focus on the 2015-2017 period	The objective of this document is to assess the ability of the generation system in Mauritius to meet the demand for electricity, and to recommend measures to ensure the adequacy of supply in this island in the short and long terms.	(The World Bank 2015)
Renewable Energy Management Master Plan and Action Plan (REMMPAP)	This Master Plan identifies opportunities to accelerate creation of a clean and affordable energy matrix. It assesses Mauritius' technical potential for RE, and grid improvements; analyses socioeconomic costs and benefits of different electricity development pathways; identifies barriers and opportunities for financing sustainable energy projects; and recommends policy, regulatory, and institutional changes.	(Maxwell Stamp PLC 2016)
Digest of Energy and Water Statistics – 2015	The Digest of Energy and Water document is published annually by Statistics Mauritius and presents statistics on energy and water. It includes data on imports of energy fuels, generation and sales of electricity, consumption of energy by sectors, rainfall, storage level of reservoirs and water sales.	(Statistics Mauritius 2016)
Digest of Energy and Water Statistics – 2014		(Statistics Mauritius 2015)
Digest of Energy and Water Statistics – 2013		(Statistics Mauritius 2014)

[8] The year 2015 is the most recent for which complete electricity generation information is available for each generation type.

4.1. 2015 Energy generation mix – Republic of Mauritius

The total electricity generated is used to determine the total renewable energy generation for the Republic of Mauritius by summing the total electricity generation from both Mauritius and Rodrigues, see Table 14. For the baseline year, the percentage is 22.7% of total electricity generation, see Figure 18. The energy generation mix of Mauritius represents approximately 99% of all electricity generation for the Republic of Mauritius.

Table 14: Total electricity generated and renewable energy split for the Republic of Mauritius

Electricity Source		Units Generated (GWh)	%
Renewable	Mauritius	676	22.6%
	Rodrigues	2.7	0.1%
Non-renewables	Mauritius	2,280	76.1%
	Rodrigues	37	1.2%
Total Electricity Generation		**2,956**	**100.0%**
Total Renewable Generation		**679**	**22.7%**
Total Non-renewable Generation		**2,317**	**77.3%**
Renewable	Mauritius	2,956	98.7%
	Rodrigues	40	1.3%

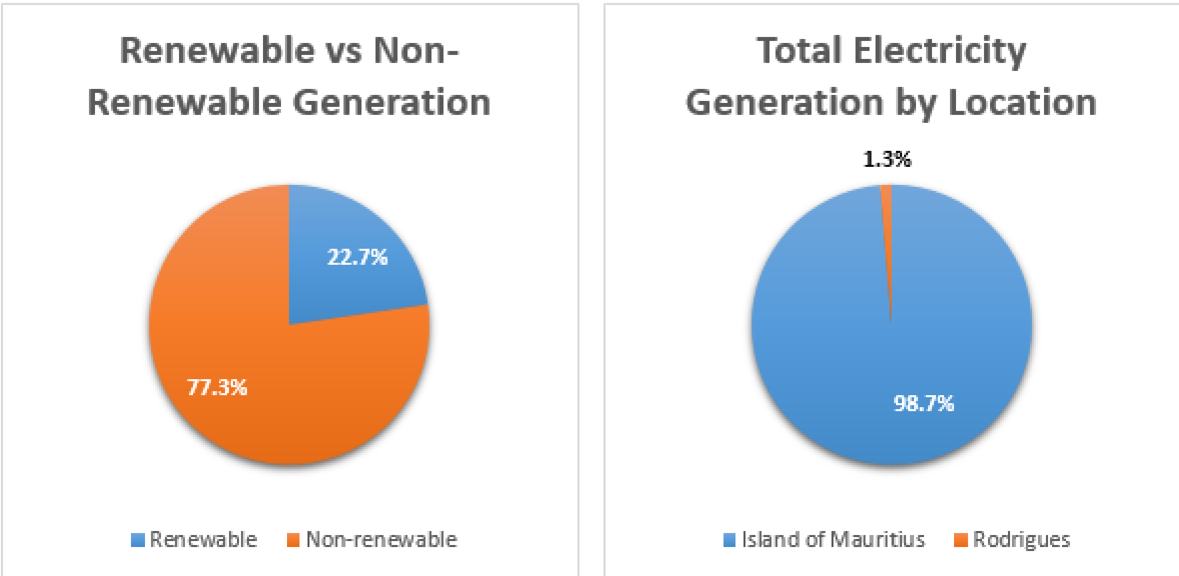


Figure 18: Electricity sources for Republic of Mauritius (2015)

4.1.1. 2015 Energy generation mix – Mauritius

The electricity breakdown by fuel type for the baseline year, 2015, is given in Table 15. On Mauritius, there are several electricity generation plants that run from both bagasse, a by-product obtained from sugar cane processing, and coal. These plants use a portion of the electricity that they produce which is referred as self-consumption (i.e. the portion of electricity that is generated at the site but not exported to CEB grid), see Table 16. The total electricity generated, including the self-consumption total, is used to determine the total renewable energy generation for Mauritius. For the baseline year of 2015 the percentage of generation produced by renewable energy sources is 22.9% of total electricity generation, see Table 15.

Rainfall was higher than average in 2015 which resulted in a higher contribution to the total electricity generation from Hydro generation sources above the annual average of approximately 90 GWh.

Table 15: Total electricity generated by type in 2015

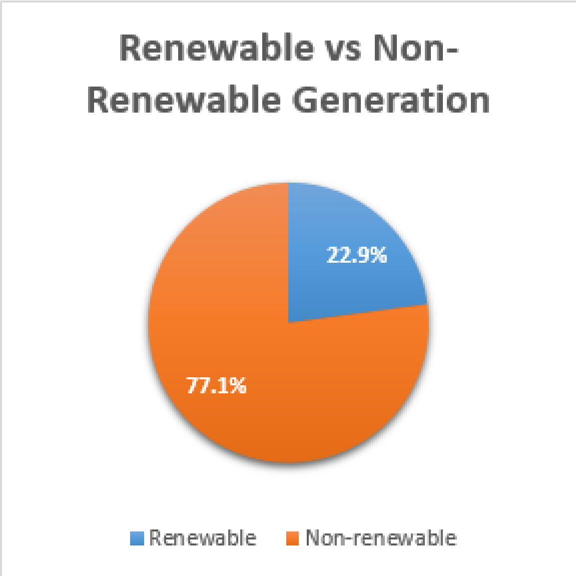
Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse	509.8	17.2%
	Hydro	121.9	4.1%
	WtE	20.4	0.7%
	Onshore Wind	0.0	0.0%
	Solar PV	23.8	0.8%
Sub Total (Renewable)		**675.9**	**22.9%**
Non-renewables	Fuel Oil	1096.5	37.1%
	Coal	1183.8	40.0%
Total Electricity Exported to CEB Grid		**2956.2**	**100%**

Table 16: Electricity exported to the grid and self-consumed by IPP generators in 2015

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse (crop season)	381.0	12.9
	Hydro[10]	121.9	4.1%
	WtE	20.4	0.7%
	Onshore Wind	0.0	0.0%
	Solar PV	23.8	0.8%
Sub Total (Renewable)		**547.1**	**18.5%**
Non-Renewables	Fuel Oil	1096.5	37.1%
	Coal(non-crop season)	1047.0	35.4%
Total Electricity Exported to CEB Grid		**2690.6**	**91.0%**
IPP Self-consumption [11]	Renewable—Bagasse (crop season)	128.8	4.4%
	Non-renewables—Coal (non-crop season)	136.8	4.6%
Total Electricity Generation		**2956**	**100.0%**
Total Excess Electricity Generation		**0**	**0.0%**
Total Grid Load/Demand Serves		**1659**	**100.0%**
Total Renewable Generation		**676**	**22.9%**
Total Non-renewable Generation		**2280**	**77.1%**

[10] Note that the Hydro Electricity contribution for the baseline year was higher than the annual average of around 90 GWh.

[11] Electricity that is generated by the IPP companies that is used onsite and not exported to the CEB grid



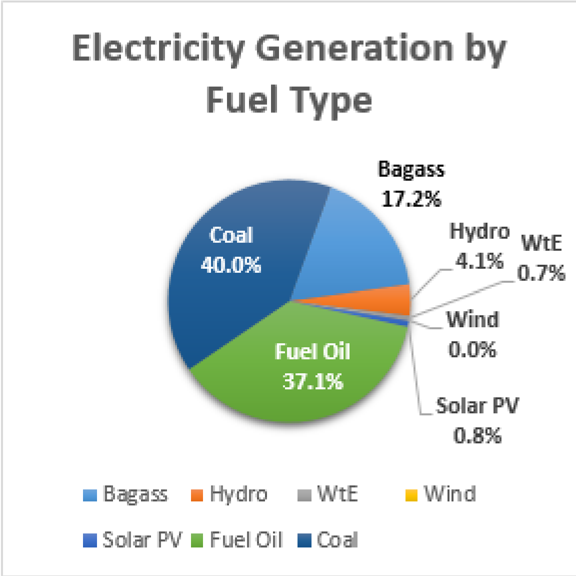


Figure 19: Electricity sources for Mauritius in 2015

4.2. 2015 Installed Generation Capacity and Type – Mauritius

The energy generation mix for 2015 is presented in Table 17. Note that generation from Bagasse sources only occurs during the crop season, for the rest of the year the generators use coal. The crop season typically occurs from June through to December each year, see Figure 20.

Table 17: Total installed generation capacity by type for Mauritius in 2015

Fuel Type		Effective Capacity – Crop Season[12] (MW)	Effective Capacity – Off-crop Season (MW)
Renewable	IPP Thermal - Bagasse	142.5	0
	CEB Hydro	56.3	56.3
	WtE	3	3
	Onshore Wind	0	0
	Solar PV	17.8	17.8
Sub Total (Renewable)		**220**	**77**
Non-Renewables	CEB Thermal - Fuel Oil	380	380
	IPP Thermal - Coal	52	215
Total Electricity Generation Capacity		**652**	**672**

[12] The crop season typically occurs from June through to December each year.

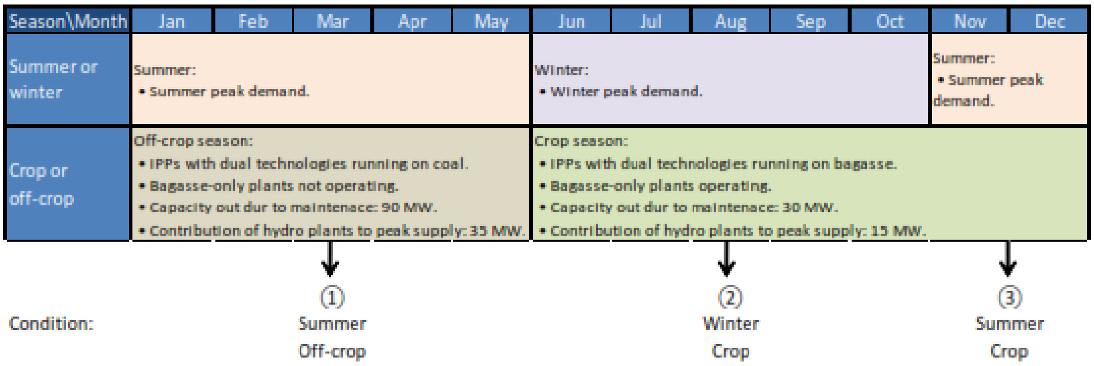


Figure 20: Seasonal changes in demand and energy generation mix based on crop seasons (The World Bank 2015)

The following sections provide a list of current generators for each fuel type. Electricity generation plant is typically owned either by the Central Electricity Board (CEB) or a private third party known as an Independent Power Producer (IPP) whom has an agreement with the CEB to purchase their electricity. A map showing the location of CEB Thermal and Hydro plants along with IPP Thermal plants on Mauritius is provided in Figure 21. The map also shows the location and voltage of electricity transmission lines used on the island.

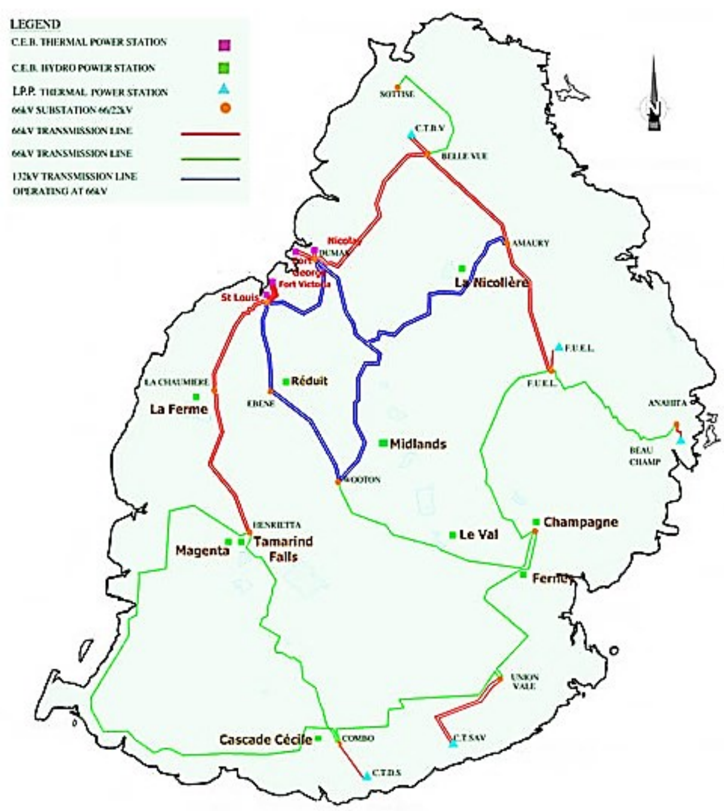


Figure 21: Location of installed CEB Thermal/Hydro and IPP Thermal electricity plants (CEB 2016)

4.2.1. IPP Bagasse/Coal

A list of all currently operating IPP Bagasse/Coal or IPP Coal only plants is provided in Table 18.

Table 18: IPP Bagasse/Coal plants

Name of Power Station	Location	Year of Operation	Installed capacity (MW)	Effective capacity – bagasse (MW)	Effective capacity – coal (MW)	Energy Source Used
Consolidated Energy Limited (CEL)[13]	Beau Champ	1997	24.5	12	22	Coal/ Bagasse (to 2015)
Alteo Energy Limited (ex FSPG)	FUEL	1998	36.7	20	27	Coal/ Bagasse
Terragen Ltd (ex CTBV)	Mapou	2000	71.2	46	62	Coal/ Bagasse
OTEOSA (ex CTDS)	Saint Aubin	2005	34.5		30	Coal
OTEOLB (ex CTSav)	L'escalier	2007	90	65.5	74	Coal/ Bagasse
MSML (ex Medine)[14]	Bambous	2015	21.7	11		Bagasse
Total			**278.6**	**142.5**	**215**	

4.2.2. CEB Hydro

A list of all currently operating CEB Hydro plants is provided in Table 19.

Table 19: CEB Hydro plants

Name of Power Station	Location	Year of Operation	Installed capacity (MW)	Effective capacity (MW)
Champagne	Mahebourg	1984	30	28
Ferney	Mahebourg	1971	10	10
Tamarind Falls	Henrietta	1945	11.7	9.5
Magenta	Henrietta	1960	0.94	0.9
Le Val	Riche en Eau	1961	4	4
Cascade Cecile	Surinam	1963	1	1
A.I.A (Reduit)	Reduit	1984	1.2	1
La Ferme	La Ferme	1988	1.2	1.2
La Nicoliere F.C	Nicoliere	2010	0.35	0.35
Midlands	Midlands	2013	0.35	0.35
Total			**60.74**	**56.3**

[13] CEL's first PPA was extended in 2015 up to 2018 for operation on coal only (33)
[14] Effective Capacity of MSML for first two months of Crop Season is 9 MW and 11 MW for the rest of the Crop Season (33)

4.2.3. Waste to Energy (WtE)

A list of all currently operating WtE plants is provided in Table 20. Note that these plant(s) are operated under an IPP agreement similar to the Bagasse/Coal plants.

Table 20: List of WtE projects installed in 2015

Name of Power Station	Location	Year	Installed Capacity (MW)	Effective capacity (MW)
Sotravic Ltee	Mare Chicose	2011	3.3	3.0
Total			**3.3**	**3.0**

4.2.4 Onshore Wind

At the end of 2015 there were no operating wind farms on Mauritius. Two wind farms have been constructed on Mauritius with a total capacity of 38.8 MW and are expected to be commissioned and operational during 2016.

4.2.5. Solar PV

A list of all currently operating solar PV plants is provided in Table 21. Note that the solar PV farms are operated under IPP agreements.

Table 21: List of Solar PV projects installed in 2015 and proposed out to 2025 (Central Electricity Board 2016)

	Name of Solar PV Scheme or Power Station	Location	Proposed Capacity (MW)	2015 Installed Capacity (MW)
1	IPP - Sarako	Bambous		15
2	SSDG	Mauritius	3.8	2.06
3	SSDG - PECR	Mauritius	2.14	0.84
	Total			**17.9**

In 2010, the Central Electricity Board (CEB), in collaboration with the Ministry of Energy and Public Utilities, launched the Small Scale Distributed Generation (SSDG) project. Under the SSDG project the CEB plans to integrate a total of 5 MW projects using renewable energy (RE) technologies in the Mauritian grid (Central Electricity Board 2016):

- Phase 1 was opened for 2MW
- Phase 2 was opened for an additional of 1MW
- Phase 2 was opened for PECR (Public Educational Charitable and Religious Institution) for a total capacity of 2MW.

Although the SSDG project is open to solar PV, hydro, and wind up to a maximum capacity of 50 kW per customer, the majority of the project is expected to be fulfilled by solar PV as it is the least cost small renewable energy technology out of the technologies specified under the scheme.

4.2.6. CEB Thermal

A list of all currently operating CEB Thermal power stations is provided in Table 22. A breakdown of the individual generation units by power station in given in Table 23. Note that there are some minor discrepancies regarding capacity between the different reports.

Table 22: CEB Thermal power stations (CEB 2016)

Name of Power Station	Location	Year of Operation	Installed capacity (MW)	Effective capacity (MW)	Energy Source Used
St.Louis	Pailles	1954	89	66.6	Heavy Fuel Oil (HFO)
Fort Victoria	Cassis	1964	109.6	107	Heavy Fuel Oil (HFO)
Fort George	Mer Rouge	1993	138	134	Heavy Fuel Oil (HFO)
Nicolay	Port Louis	1988	78.4	72	Jet A-1 / Kerosene
Total			**415**	**380**	

Table 23: Breakdown of individual CEB generation units by power station (The World Bank 2015, WorleyParsons RSA (Pty) Ltd. 2014)

Power station	Unit	Fuel	Technology	Manufact.	Date commis.	Capacity [MW]		
						Rated	Effective	Injectable[15]
Fort George	G1	HFO 380 cSt (heated)	Thermal, plant, diesel engine, slow speed	Sulzer	1992	24	22	127
	G2				1993	24	22	
	G3			Mitsui/ Hyundai	1997	30	30	
	G4				1999	30	30	
	G5				2000	30	30	
Saint-Louis	G1	HFO 180 cSt	Thermal, plant, diesel engine	Pielstick[16]	1978	11.9	5	25
	G2				1978	11.9	5	
	G3				1979	11.9	5	
	G4				1979	11.9	5	
	G5				1981	11.9	5	
	G6				1981	Decommissioned 2012		
	G7	HFO 180 cSt	Thermal, plant, diesel engine, medium speed	Wartsila	2006	13.8	13.8	40
	G8				2006	13.8	13.8	
	G9				2006	13.8	13.8	
Fort Victoria	G1	HFO 180 cSt	Thermal, plant, diesel engine, medium speed	Wartsila	2010	15	15	28
	G2				2010	15	15	
	G3				2012	15	15	56
	G4				2012	15	15	
	G5				2012	15	15	
	G6				2012	15	15	
	G11			MAN	1989	9.8	8.5	16
	G12				1989	9.8	8.5	
Nicolay	G1	Jet A1 (kerosene)	Thermal, plant, open-cycle gas turbine	GE	1988	21.8	21	72
	G2				1991	22.7	21	
	G3				1995	33.9	33	
Total						**426.9**	**381.4**	**364**

[15] Injectable capacity refers to capacity that can be injected into the electricity grid and contribute to peak power supply.
[16] G6 has been decommissioned in July 2012 with G1 through G5 scheduled for decommissioning beginning 2016.

4.3. 2025 Installed Generation Capacity and Type – Mauritius

Based on the Long-term Energy Strategy and information from the CEB, there are several ways that the CEB will reach the 35% target for renewable energy for Mauritius. The likely energy generation mix for 2025 is presented in Table 24. Note that generation from Bagasse sources only occurs during the crop season, for the rest of the year the generators use coal. The crop season typically occurs from June through to December each year.

Table 24: Total likely installed generation capacity by type for Mauritius in 2025

Fuel Type		Effective Capacity – Crop Season (MW)	Effective Capacity – Off-crop Season (MW)
Renewable	IPP Thermal - Bagasse	142.5	0
	CEB Hydro	56.3	56.3
	WtE	33.0	33.0
	Onshore Wind	98.8	98.8
	Solar PV	140	140
Sub Total (Renewable)		**471**	**328**
Non-Renewables	CEB Thermal - Fuel Oil	510	510
	IPP Thermal - Coal	30	193
Total Electricity Generation Capacity		**1,011**	**1,031**

The following section lists the proposed changes and/or potential for changes to each generation type. A summary of the likely energy mix in 2025 is provided in Figure 22. The study assumes that the CEB will make the necessary network and control system upgrades to support the expansion of intermittent renewables out to 2025.

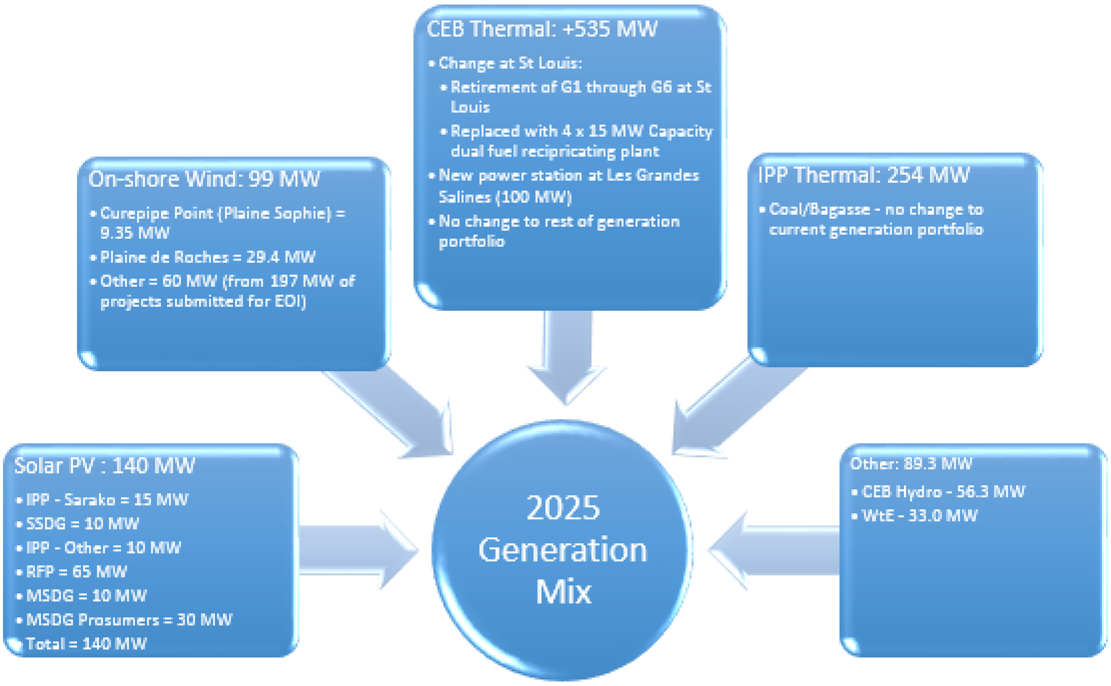


Figure 22: Summary of the likely installed capacity in 2025

4.3.1. IPP Bagasse/Coal

The LTES indicates that through more efficient use of Bagasse resources and more energy efficient generation equipment, annual average generation from Bagasse could increase from approximately 300 GWh in 2009 up to 600 GWh by 2025. In 2015, the generation from Bagasse had reached an annual total 510 GWh, with 380 GWh exported to the CEB grid on Mauritius.

As there are no substantial plans in place for the addition of or changes to Bagasse generation, this study will assume that there will be no change in Bagasse generation prior to the 2025 target apart from the single contract termination that was scheduled for 2015 and has now been extended to 2018, see Table 25. The estimated Bagasse/Coal power stations in operation in 2025 is listed in Table 26.

Table 25: IPP Bagasse/Coal power stations contract terminations/closures between 2015 and 2025

Name of Power Station	Location	Year of Operation	Installed capacity (MW)	Effective capacity – bagasse (MW)	Effective capacity – coal (MW)	Energy Source Used
Consolidated Energy Limited (CEL)[18]	Beau Champ	1997	24.5	n/a	22	Coal

Table 26: Estimate IPP Bagasse/Coal power stations is operation in 2025

Name of Power Station	Location	Year of Commis.	Installed capacity (MW)	Effective capacity – bagasse (MW)	Effective capacity – coal (MW)	Energy Source Used
Alteo Energy Limited (ex FSPG)	FUEL	1998	36.7	20	27	Coal/ Bagasse
Terragen Ltd (ex CTBV)	Mapou	2000	71.2	46	62	Coal/ Bagasse
OTEOSA (ex CTDS)	Saint Aubin	2005	34.5		30	Coal
OTEOLB (ex CTSav)	L'escalier	2007	90	65.5	74	Coal/ Bagasse
MSML (ex Medine)	Bambous	2015	21.7	11		Bagasse
Total			**254.1**	**142.5**	**193**	

4.3.2. CEB Hydro

Apart from an evaluation of low capacity gate systems by CEB, it is expected that there will be no change in the hydro capacity or annual generation in 2025.

4.3.3. Waste to Energy (WtE)

The REMMPAP indicated the establishment of a 30 MW WtE plant before 2025, the CEB have indicated they are preparing to launch a Request-For-Proposal (RFP) for a WtE project of 30 MW. The REMMPAP also indicated a limited volume of waste and that potential beyond 30 MW was limited. Therefore, this study will assume that there is no further WtE projects beyond that already planned as listed in Table 27.

Table 27: List of WtE generation in 2025

Name of Power Station	Location	Year	Installed Capacity (MW)	Effective capacity (MW)
Sotravic Ltee	Mare Chicose	2011	3.3	3.0
CEB RFP Process	As per RFP	Before 2025	30.0	30.0
Total			**33.3**	**33.0**

[18] CEL's first PPA was extended in 2015 up to 2018 for operation on coal only (33)

4.3.4. Onshore Wind

Onshore wind is not expected to expand as quickly as solar PV between 2015 and 2025. This is partly due to the longer process to obtain planning permission with potential for objectors due to amenity concerns particularly if located near a tourist area.

The LTES indicated that power system impact studies had found that the grid on Mauritius could only accommodate up to 30% of the overnight load (i.e. minimum grid load). At the time of the LTES publication, 30% of the overnight load equated to approximately 60 MW. Considering the recent growth in the night time load between 2009 and 2015, this now equates to approximately 70 MW.

The CEB initiated an Expression-of-interest (EOI) which identified 17 projects with the potential capacity of 197 MW in total. This study assumes that approximately 30%, or 60 MW, of the proposed capacity can be implemented by 2025 in keeping with the findings from power system studies that have been carried out, see Table 28.

Table 28: List of onshore wind projects installed in 2015 and proposed out to 2025 (Central Electricity Board 2016)

	Name of Onshore Wind Farm	Proposed Capacity (MW)[19]	2015 Installed Capacity (MW)	Potential 2025 Installed Capacity (MW)
1	Curepipe Point (Plaine Sophie)	9.35	0	9.35
2	Plaine de Roches	29.4	0	29.4
3	CEB EOI – 17 project submissions totalling 197 MW		0	60
	Total	**38.75**	**0**	**98.75**

4.3.5. Solar PV

To achieve the 2025 target of 35% renewable energy the CEB is planning a significant expansion of Solar PV projects. The current installed capacity of solar PV projects as of 2015 was 17.9 MW with the potential to expand solar PV to an installed capacity of 140 MW by 2025, see Table 29.

Table 29: List of Solar PV projects installed in 2015 and proposed out to 2025 (Central Electricity Board 2016)

	Name of Solar PV Scheme or Power Station	Location	Proposed Capacity (MW)	2015 Installed Capacity (MW)	Potential 2025 Installed Capacity (MW)
1	IPP - Sarako	Bambous		15	15
2	SSDG	Mauritius	3.8	2.06	3
3	SSDG - PECR	Mauritius	2.14	0.84	2
4	SSDG - Phase 3 - Cat 1	Mauritius	3.892		4
5	SSDG - Phase 3 - Cat 2	Mauritius	1.502		1
6	Synnove Solar	L'esperance	2		2
7	Synnove Solar	Petite Retraite	2		2
8	Alteo Astonfield Solar	FUEL	2		2
9	Astonfield Solar Ltd	Gaulette	2		2
10	Solar Field Ltd	Mon Choisy	2		2
11	RFP for 3 x 15 MW	TBD	45		45
12	RFP for 1 to 9 MW	TBD	20		20
13	MSDG - 10 MW	TBD	10		10
14	MSDG - Prosumers 30 MW	TBD	30		30
	Total			**17.9**	**140**

[19] Both the Curepipe Point and Plaine de Roches are expected to be operational by the end of 2016.

Under the small-scale distributed generation (SSDG) project the CEB plans to integrate a total of 10 MW projects using renewable energy (RE) technologies, of which the majority is expected to be solar PV, in the Mauritian grid (Central Electricity Board 2016):

- SSDG Phase 1 was opened for 2MW
- SSDG Phase 2 was opened for an additional of 1MW
- SSDG Phase 2 was opened for PECR (Public Educational Charitable and Religious Institution) for a total capacity of 2MW.
- SSDG Phase 3 was the launch of 5 MW net-metering scheme

CEB currently has the following medium to large scale schemes and projects underway or planned:

- Plan to launch a 10 MW net-metering medium-scale distributed generation (MSDG) scheme
- Plan to launch a 30 MW net-metering Prosumers MSDG scheme
- Energy Supply and Purchase Agreements (ESPA) signed for five 2 MW solar farms:
    - Synnove Solar 1 Ltd at L'esperance
    - Synnove Solar 1 Ltd at Petite Retraite
    - Alteo Astonfield Solar Ltd at FUEL
    - Astonfield Solar Ltd at La Gaulette
    - Solar Field Ltd at Mon Choisy
- RFP for three 15 MW solar PV projects launched in Oct 2015
- Proposal to launch RFP for 1 to 9 MW solar farms for total capacity of 20 MW

4.4.5. CEB Thermal

There is a planned replacement of the oldest six diesel engines at the St Louis power station between 2017 and 2018. The plan is to replace these engines with four new Wartsila heavy fuel oil engines of higher capacity, an increase from 5 to 15 MW per engine while decreasing the total number of engines by 2, see Table 30 and Table 31.

Table 30: St Louis thermal generation units 2015

Power Station	Unit	Fuel	Technology	Manufact.	Date Commis.	Capacity		
						Rated	Effective	Injectable[20]
Saint-Louis	G1	HFO 180 cST	Thermal, plant, diesel engine	Wartsila	2018	>15	15	60
	G2				2018	>15	15	
	G3				2018	>15	15	
	G4				2018	>15	15	
	G5	HFO 180 Cst	Thermal, plant, Diesel engine, Medium speed	Wartsila	2006	13.	13	39
	G6				2006	13.	13	
	G7				2006	13.	13	
Total						>99	99	99

[20] Injectable capacity refers to capacity that can be injected into the electricity grid and contribute to peak power supply.

Table 31: St Louis thermal generation units 2025

Power station	Unit	Fuel	Technology	Manufact.	Date commis.	Capacity [MW]		
						Rated	Effective	Injectable
Saint-Louis	G1	HFO 180 cSt	Thermal, plant, diesel engine	Wartsila	2018	>15	15	60
	G2				2018	>15	15	
	G3				2018	>15	15	
	G4				2018	>15	15	
	G5	HFO 180 cSt	Thermal, plant, diesel engine, medium speed	Wartsila	2006	13.8	13	39
	G6				2006	13.8	13	
	G7				2006	13.8	13	
Total						**>99**	**99**	**99**

The CEB is contemplating the installation of a new Combined Cycle Gas Turbine thermal power plant of 135-150 MW capacity at its Les Grandes Salines site in the Port Louis harbor vicinity (Republic of Mauritius 2015). Initially the plans are to run the facility on gasoline and then change over to LNG once it becomes available assuming a third-party project to bring LNG to Mauritius goes ahead. It is assumed that the Les Grandes Salines project will be dependent on the LNG project progressing.

A subsequent report commissioned by the CEB and written by WorleyParsons (WorleyParsons RSA (Pty) Ltd. 2014) found that the most appropriate power plant size was a GE LM6000 PF gas turbine. The proposed GE LM6000PF configured in a 2x1 gas turbine combined cycle configuration provides a capacity of 98 MW, see Table 32.

Table 32: Proposed Les Grandes Salines power station

Power station	Unit	Fuel	Technology	Manufact.	Date commis.	Capacity [MW]		
						Rated	Effective	Injectable
Les Grandes Salines	G1	Dual LFO/ LNG	Thermal, plant, combined cycle gas turbine (CCGT)	TBD	2022	110	98	98
Total						110	98	98

Although the economic case for the implementation of LNG on Mauritius does not look favourable (WorleyParsons RSA (Pty) Ltd. 2014), the additional plant at Les Grandes Salines may still be required to meet peak load conditions around 2025. Therefore, this study will assume that this plant will be built but may consist of a different generator arrangement but be of similar capacity as that proposed in Table 32. The current installed capacity of CEB thermal power stations as of 2015 was 415 MW with the replacement of engines planned at St Louis and the proposed new power station at Les Grandes Salines the total installed capacity in 2025 is expected to be >575 MW, see Table 33.

Table 33: CEB Thermal power stations in 2025

Name of Power Station	Location	Year of Operation	Installed capacity (MW)	Effective capacity (MW)	Energy Source Used
St. Louis	Pailles	1954	>99	99	Heavy Fuel Oil (HFO)
Les Grandes	Port Louis	2022	110	98	Dual fuel LFO/LNG
Fort Victoria	Cassis	1964	109.6	107	Heavy Fuel Oil (HFO)
Fort George	Mer Rouge	1993	138	134	Heavy Fuel Oil (HFO)
Nicolay	Port Louis	1988	78.4	72	Jet A-1 / Kerosene
Total			**>535**	**510**	

4.4. Modelling of 2025 Energy Mix

Modelling was carried out using HOMER[23] to determine the total electricity generation by each generation source based on the likely installed generation capacity for Mauritius in 2025, see section 4.4. The results of the modelling are listed in Table 34 which provides the total electricity generation for export to the grid broken down by fuel type for 2025.

The total electricity generated, including the self-consumption total, is used to determine the total renewable energy generation for Mauritius, for 2025 the modelling results indicate that renewable energy will account for approximately 35.0% of total electricity generation on the Island, see Table 35.

Table 34: Total electricity generated and exported to the grid by type as modelled for 2025

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse	356	11.0%
	Hydro	92	2.8%
	WtE	157	4.8%
	Onshore Wind	262	8.1%
	Solar PV	234	7.2%
Sub Total (Renewable)		**1,101**	**33.9%**
Non-renewables	Fuel Oil	1,415	43.6%
	Coal	729	22.5%
Total Electricity Exported to CEB Grid		**3,245**	**100.0%**

[23]The HOMER energy modelling software is a powerful tool for designing and analysing solar PV systems, http://homerenergy.com/

Table 35: Electricity exported to the grid and self-consumed by IPP generators as modelled for 2025

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse (crop season)	356	10.2%
	Hydro	92	2.8%
	WtE	157	4.5%
	Onshore Wind	262	7.5%
	Solar PV	234	7.2%
Sub Total (Renewable)		**1,101**	**33.9%**
Non-Renewables	Fuel Oil	1,415	43.6%
	Coal(non-crop season)	729	22.5%
Total Electricity Exported to CEB Grid		**3,245**	**92.6%**
IPP Self-consumption	Renewable—Bagasse (crop season)	124	3.5%
	Non-renewables—Coal (non-crop season)	136	3.9%
Total Electricity Generation		**3,505**	**100.0%**
Total Excess Electricity Generation		**0**	**0.0%**
Total Grid Load/Demand Serves		**3,505**	**100.0%**
Total Renewable Generation		**1,225**	**35.0%**
Total Non-renewable Generation		**2280**	**65.0%**

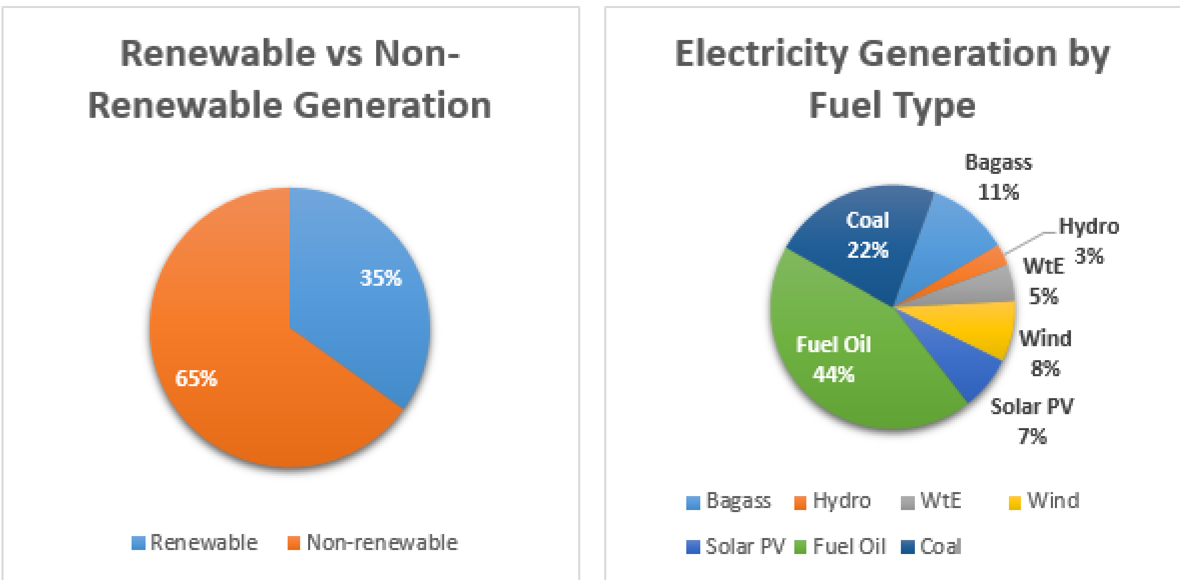


Figure 23: Electricity sources for Mauritius as modelled for 2025

4.5.1. Modelling Assumptions

The following key assumptions were made:

- Business as usual (BAU) growth in electricity continues to 2025 to reach 3,505 GWh annually.
- Network upgrades have been carried out to support the integration of intermittent renewable energy sources:
  - Some form of storage has been integrated into the grid.
- No growth in Bagasse or Hydro generation from 2015 baseline.
- Onshore wind capacity reaches 99 MW by 2025.
- Solar PV capacity from all sizes (i.e. SSDG, MSDG and solar farms) reaches 140 MW.
- Waste-to-energy (WtE) adds another 30 MW to the 2015 baseline.
- CEB Thermal capacity increases to +535 MW in line with supporting the increase in demand and summer peak load:
  - Replaces G1 through G6 at the Saint Louis power station with four 15 MW units
  - Adds new Les Grandes Salines power station at Port Louis with 100 MW capacity

5. Commercialised RE Technology Options

This chapter describes the currently available commercialised renewable energy conversion technologies and the nation's associated renewable energy resources that could be harnessed by these technologies. A summary list is provided of the commercialised technologies that could be used to harness the associated renewable energy resources, see Table 36.

Table 36: Summary of Commercialised RE Technology Options

Technology	Resource	Sub-category	Recommended to meet future RE Targets	Technology Risk	Challenge
Solar energy	Very good	Small scale distributed generation (SSDG) – solar PV	✓	Low (fixed, non-tracking)	Land and roof availability
		Medium scale distributed generation (MSDG) – solar PV	✓	Low (fixed, non-tracking)	Land and roof availability
		Utility scale solar PV	✓	Low (fixed, non-tracking)	Land availability, grid node capacity limit
Onshore Wind energy	Good	Small wind turbine (SWT)	× (cyclone risk)	Medium but need to consider cyclone risk	Amenity, finding potential sites, grid node capacity limit, land availability and cyclone risk
		Large wind turbine (LWT)	✓	Low but need to consider cyclone risk	Amenity, finding potential sites, network connection and integration, water depth and cyclone risk
Hydropower	Limited/ Fully exploited	Impounded	×(limited water resource)	Low	Available/reliable water source
		Diversion	× (limited water resource)	Low	Available/reliable water source
Waste to energy (WtE)	Limited/ Poor	Combustion	× (limited beyond current development)	Low	Business case difficult/ sufficient waste stream
Biomass	Limited/ conflicts with other land use	Thermal Technologies	✓ (incremental improvements)	Low	Land availability, reducing coal use in duel -fuelled biopower plants, climate change.
		Anaerobic digestion	× (limited resource)	Medium	Available/reliable biomass sources

5.1. Solar Energy

The economic viability of solar energy is determined by the solar resource at the site, the cost of energy from the grid, and the installed capital cost of the solar generator at selected site. There are three categories of solar generators: photovoltaic (PV), concentrating solar thermal (CST), and concentrating photovoltaics (CPV) technologies. Each of these technologies is summarised in Table 37. This section will look at Solar PV only as both CST and CPV are not yet considered fully commercialised technologies and will be covered in the next section of the report. For a more detailed overview of these technologies refer to APPENDIX B |Technology descriptions.

Table 37: Summary of the solar generators by category

Solar generator category	Description
Solar Photovoltaic (PV)	Solar photovoltaic (PV) cells convert solar radiation to electricity via semiconductor materials, which exhibit the photovoltaic effect. These cells are arranged into panels, and when several panels are mounted together on a roof or other appropriate structure it is known as a Solar PV array.
Concentrating solar thermal (CST)	Concentrating solar thermal (CST) technologies use mirrors to reflect and concentrate sunlight onto receivers that collect solar energy and convert it to heat. The thermal energy can then be used to produce electricity via a heat engine or steam driven turbine or be stored as molten salts for later use.
Concentrating photovoltaics (CPV)	Concentrating photovoltaics (CPV) technologies work by concentrating solar radiation onto a high-efficiency semiconductor PV cell which converts the energy into electricity. These technologies make use of mirrors or lenses constructed using inexpensive materials such as glass, steel and plastics which concentrate the sunlight 2 to 1,200 times.

5.2. Solar PV Categories

Solar PV is typically separated into size categories, for this report the following 3 size categories will be considered: small, medium, and utility scale. The definition or size range often varies significantly, however, for this study the definitions shown in Table 38 are used.

Table 38: Solar PV categories

Category	Size	Description
Small Scale Distributed Generation (SSDG)	< 10 kW	Small scale distributed generation is typically installed by households and small business onto roof tops and occasionally ground mounted. The connection is behind the meter.
Medium Scale Distributed Generation (MSDG)	10 to 100 kW	Medium scale distributed generation is typically installed by medium and large businesses onto roof tops and occasionally ground mounted. The connection is behind the meter.
Utility Scale	>= 1 MW_{ac}	Utility scale systems are typically connected directly to the electricity network and are ground mounted.

5.3. Tracking Systems

Ground mount systems can be mounted onto either a rigid frame or a tracking system that moves the solar PV panel to track the sun and achieve a higher capacity factor (i.e. greater generation versus a fixed panel system). Due to the potential for Mauritius to be subject to cyclonic wind conditions, tracking systems are generally not considered appropriate, unless they can be deployed to inland areas less prone to high winds. However, tracking systems can be designed to withstand high wind conditions, this will likely add addition capital cost to a system that is already more expensive than a rigid system and may cancel out any economic benefit from the tracking system. It should be noted that the use of single-axis tracking systems is not ruled out, but these systems may not make economic sense in the short term for areas subject to cyclonic winds it there is a significant cost adder.

5.4. Available Solar Resource

Given that solar energy generation is entirely dependent on the sun, the solar resources of the region first need to be considered. Regional specific solar data is required as solar resources are influenced by factors such as prevailing weather (amount of cloud cover) and latitude.

Solar irradiation, also known as insolation, is the rate of delivery of solar radiation per unit of surface area. It is measured as the amount of solar radiation energy received on a given surface area and recorded during a given time. It is expressed as "hourly irradiation" if recorded during an hour or "daily irradiation" if recorded during a day. The unit recommended by the World Meteorological Organization is megajoules per square metre (MJ/m^2). Practitioners in the solar PV industry typically use the unit Watt-hours per square metre (Wh/m^2) or kilowatt-hours per square metre per day ($kWh/m^2/day$) for daily values.

A key source of solar data available for the Mauritius region is the solar radiation data obtained from the NASA Langley Research Center - Atmospheric Science Data Center Surface meteorological and Solar Energy (SSE) web portal supported by the NASA LaRC POWER Project. Solar irradiance data for Saint Louis on Mauritius was obtained from NASA's Surface Solar Energy Data Set accessed via HOMER. The baseline data is a one-year time series representing the average global solar irradiation, expressed in kWh/m^2, for each time step of the year. HOMER displays the monthly average radiation and clearness index of the baseline data in the graph shown in Figure 21.

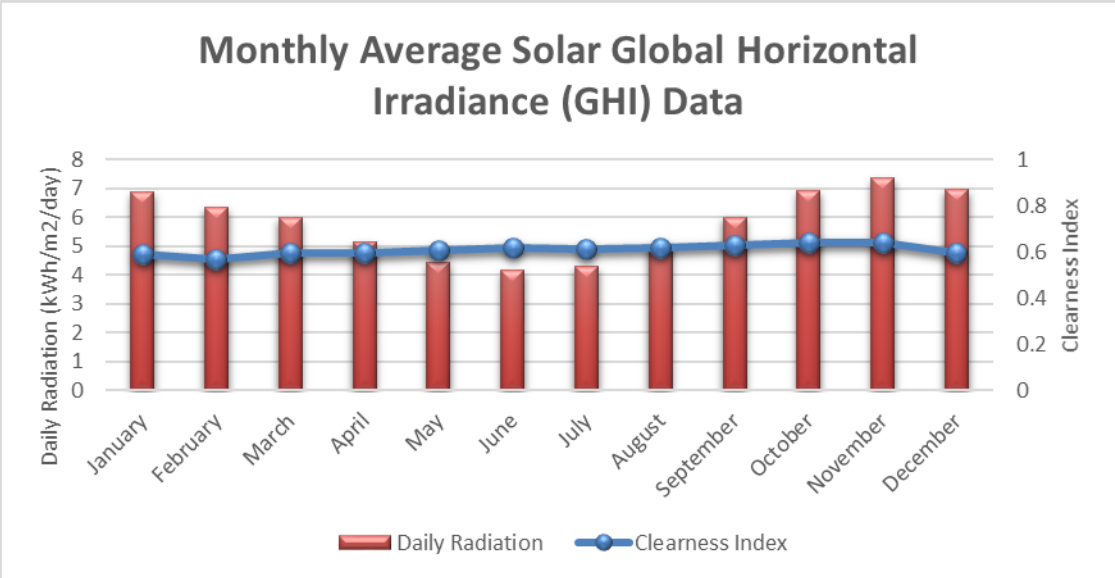


Figure 24: Average daily horizontal radiation and clearness index per month for Saint Louis

The clearness index is a measure of the clearness of the atmosphere. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. It is a dimensionless number between 0 and 1, defined as the surface radiation divided by the extra-terrestrial radiation. The clearness index has a high value under clear, sunny conditions, and a low value under cloudy conditions. The symbol for the monthly average clearness index is K_t. Typical values of K_t range from 0.25 (a very cloudy month, such as an average December in London) to 0.75 (a very sunny month, such as an average June in Phoenix).

Overall, Mauritius is considered to have a very good solar resource. Table 39 compares the Global Horizontal Irradiance (GHI) resource with that of Germany, which is considered to have only low to medium solar resource, and with Fresno in California, USA with a very good solar resource. Due to the abundance of the solar energy resource in Mauritius, a scheme was established to provide grants to households to install solar hot water (SHW) heaters. Across the 3 phases of the scheme, held between 2008 and 2012, approximately 58,000 grants were approved which represents greater than 15% penetration of the household market (Maurice Ile Durable 2013).

Table 39: Solar resource comparison of Island of Mauritius with key World locations (Daily Radiation: kWh/m2/day)

Month	Saint Louis		Stuttgart, Germany		Fresno, CA, USA	
	Clear-ness Index	Daily Ra-diation (GHI)	Clearness In-dex	Daily Radiation (GHI)	Clearness In-dex	Daily Radia-tion (GHI)
January	0.591	6.86	0.415	1.14	0.511	2.45
February	0.57	6.33	0.453	1.92	0.581	3.59
March	0.594	5.98	0.452	2.94	0.63	5.09
April	0.596	5.14	0.45	4.03	0.662	6.55
May	0.608	4.45	0.46	4.96	0.691	7.68
June	0.62	4.15	0.462	5.34	0.723	8.36
July	0.615	4.3	0.483	5.36	0.714	8.05
August	0.617	5.01	0.49	4.65	0.714	7.3
September	0.628	6	0.463	3.32	0.698	5.98
October	0.643	6.91	0.41	1.96	0.676	4.48
November	0.642	7.35	0.387	1.17	0.597	3.01
December	0.594	6.95	0.379	0.88	0.526	2.3
Annual Av-erage		5.79		3.14		5.4

A DMap—short for data map—is a graph that shows one year of time series data. It has time of day on one axis and day of the year on the other. Each time step of the year is represented by a rectangle which is coloured according to the data value (in this case, power in kW) for that hour. The DMap format often allows you to see daily and seasonal patterns more easily than you could with a simple time series plot. The DMap of solar irradiance for Saint Louis is shown in Figure 25.

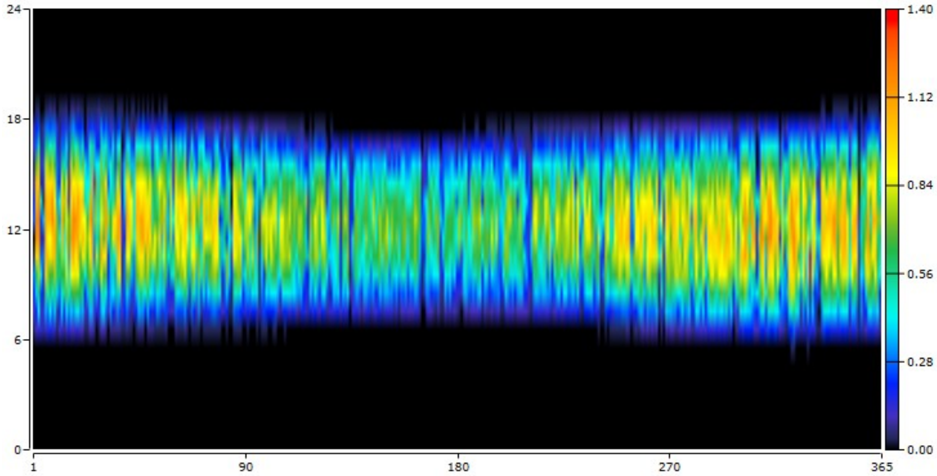


Figure 25: DMap for the average hourly horizontal radiation for Saint Louis (kW/m2 for each hour of the year)

5.5. Geographic Distribution of Solar Resource

The solar resource will vary by area across Mauritius, in particular, there will be more cloud associated with the prevailing weather side of the higher island interior. The Mauritius Meteorological Services (MMS) maintains weather stations across the Island with key stations located at Medine, Pamplemousses, Fuel, Plaisance and Vacoas considered to be representative of the five main regions of the Island. Mauritius receives an annual average of between 6 and 8 hours of sunshine per day, see Figure 23 (Mauritius Meteorological Services 2016, United Nations (UNFCCC) 1999).

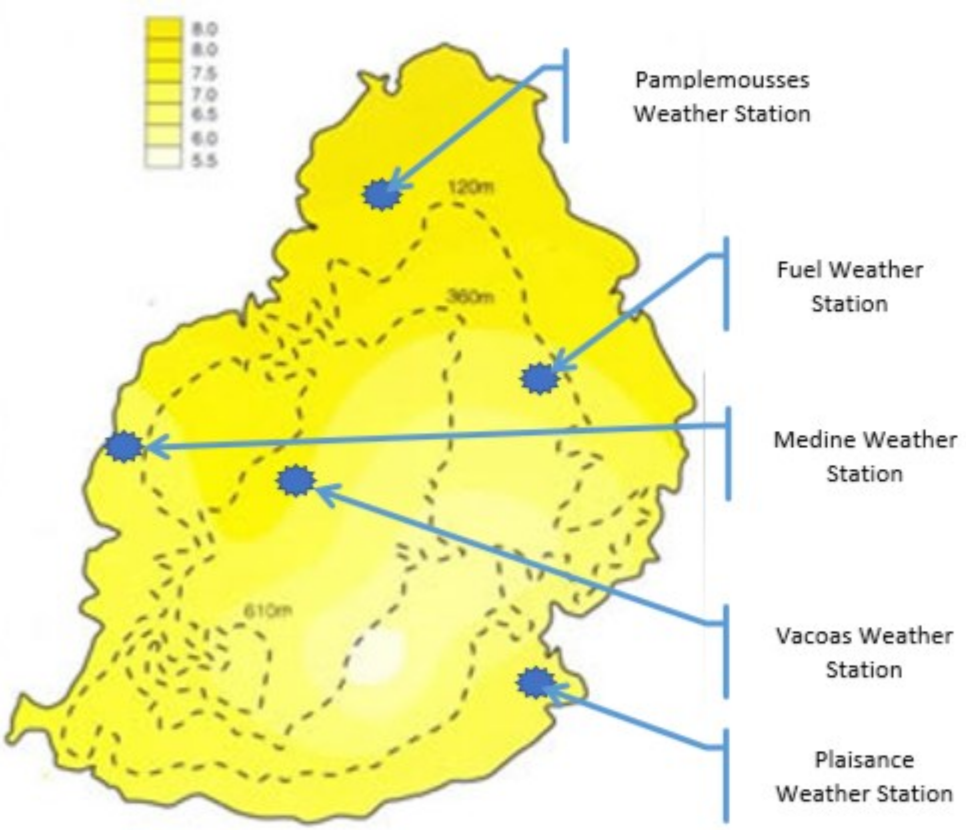


Figure 26: Duration of bright sunshine (Annual average hours per day) with added location of Mauritius Meteorological Services weather stations (United Nations (UNFCCC) 1999)

The average daily duration of sunshine by month for each of the five main regions, as represented by one of the MMS weather stations, is presented in Table 40. Overall, the distribution of the solar resource across Mauritius is very good. The only area that may underperform due to high levels of cloud cover is in the south east near Grand Bois. Both the west and north of the island have a very good solar resource with daily average hours of sunshine exceeding 7.5 hours.

Table 40: Average duration of sunshine per month for several weather station sites around Mauritius (Mauritius Meteorological Services 2016)

Month	Medine (West)		Vacoas (Central)		Plaisance (South)		Fuel (East)		Pamplemouses (North)	
	Daily Hrs	Mean Monthly	Daily Hrs	Mean Monthly	Daily Hrs	Mean Monthly	Daily Hrs	Mean Monthly	Daily Hrs	Mean Monthly
January	7.5	233.5	7.3	225.9	7	216.3	7.7	239.7	8.1	250.2
February	7.4	207.5	6.9	193.6	6.6	186.1	7.1	198.7	7.7	216.9
March	7.3	224.8	7.3	225.3	6.7	209.4	6.9	212.9	7.6	235.5
April	7.2	215.5	6.9	205.9	6	179.1	6.5	194.1	7.4	223.3
May	7.8	241.6	7.4	228.5	6.3	193.9	6.6	203.2	7.6	235.9
June	7.6	226.6	7.2	215.6	6.1	182.8	6.1	182.1	7.4	223
July	7.6	236.5	7.3	225.5	6.1	187.6	5.5	170.9	7.6	236.8
August	7.6	234.2	7.2	224.4	6.1	187.7	5.9	181.4	7.7	237.7
September	7.3	220.3	7.3	218.8	6.3	189.5	6.7	200.8	7.5	225
October	7.8	241.3	7.6	236.6	6.8	210.1	7.6	236.3	8.2	255.2
November	8	240	7.9	236.3	7.3	219.8	8.8	265.4	8.7	260.9
December	8	246.6	7.2	223.4	7	216.8	8.4	259.7	8	248.8
Annual Average	7.6	230.7	7.3	221.5	6.5	198.3	7	212.1	7.8	237.4

5.5.1. Solar PV and Load Profile

As described, Mauritius has a very good solar resource but how well this matches the islands electricity load profile needs to be assessed, Figure 27 shows the islands summer and winter weekday load profile- with the solar energy profile overlaid. The load profile increases towards the middle of the day and then drops a little in the late afternoon before peaking in the evening.

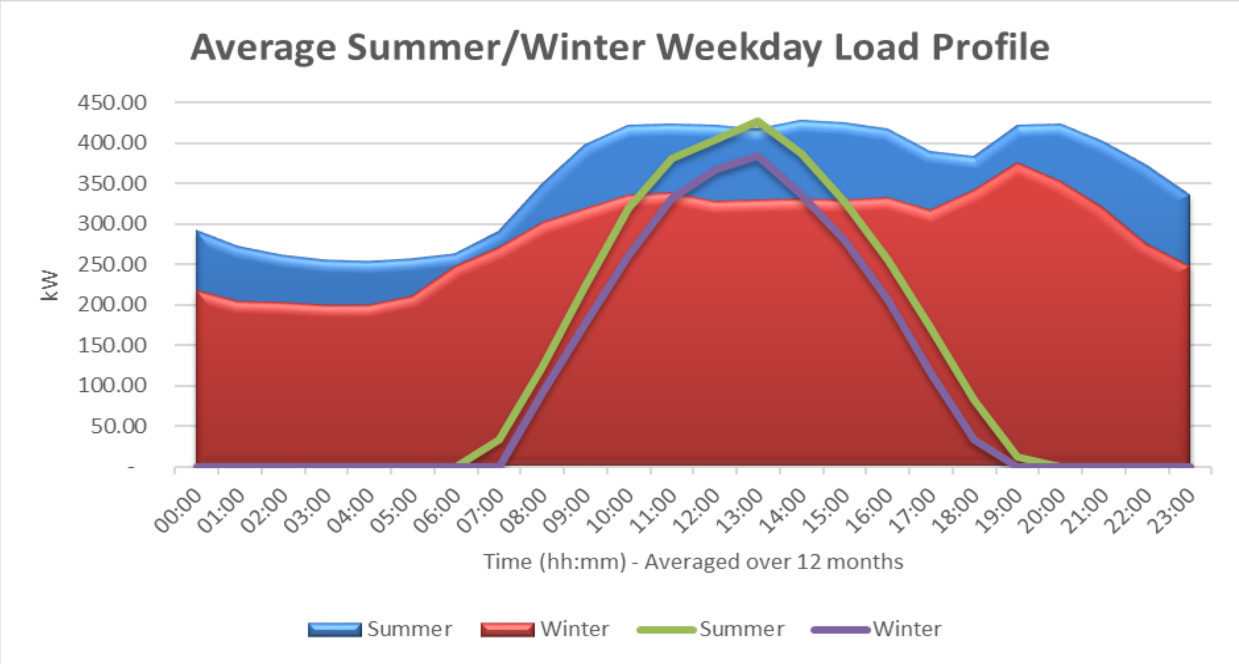


Figure 27: Average summer and winter weekday load profile with solar energy profile overlaid

Although solar PV does provide a significant amount of energy during the middle of the day, it does not match the entire daytime load well. To help match the solar PV to the Islands load there is potential for behind the meter battery storage so that excess generation from the middle of the day is shifted into the evening when the daily usage peak occurs.

5.5.2. Mauritius Solar PV Survey

Carnegie Wave Energy and the MRC collaborated on a solar PV survey see *APPENDIX C | Mauritius Solar PV Survey Results* for the full survey results. Of the residences, which had installed solar PV, 11 out of the 14 owned their place of residence (Table 41). Roof top solar hot water was installed on 96 out of 156 residences (or 62%) who responded to the survey indicating that the solar hot water incentive scheme had been very successful. Almost all residences surveyed had concrete roofs, meaning any solar PV scheme should target installation systems for concrete roofs (Table 41 & Table 42).

Table 41: Mauritius Solar PV Survey Results - Ownership and solar installation

Ownership of Residence?	Is rooftop Solar PV installed on your residence?		Is roof top Solar hot water installed on your residence?		What Material is your roof constructed of?		
	Yes	No	Yes	No	Concrete	Tile	Other
Yes	11	106	73	44	110	2	5
No	3	36	23	16	38	0	1
TOTAL	14	142	96	60	148	2	6

Table 42: Mauritius Solar PV Survey Results - Solar PV Installation versus Roof Construction Material

Is roof top Solar PV installed on your res-	What material is your roof constructed of?			Total
	Concrete	Tile	Other	
Yes	14	0	0	14
No	134	2	6	142
TOTAL	**148**	**2**	**6**	**156**

The survey results also indicated that greater than 60% respondents had roof space available of a size equal to or greater than 4 metres by 4 metres (Table 43). Of the respondents that had applied for solar PV, 71.4% had indicated that system size they were applying for was 3 kW or greater (Table 44).

Table 43: Mauritius Solar PV Survey Results - Ownership versus Roof Space

Ownership of residence	How much space would you estimate you have on your roof for a roof-top solar PV system					Total
	1x1	2x2	3x3	4x4	>4x4	
Yes	7	16	21	11	62	117
	6.0%	13.7%	17.9%	9.4%	53.0%	
No	2	6	7	5	19	39
	5.1%	15.4%	17.9%	12.8%	48.7%	
Total	9	22	28	16	81	156
	5.8%	14.1%	17.9%	10.3%	51.9%	

Table 44: Mauritius Solar PV Survey Results - Ownership versus Solar PV Size

Ownership of residence	What size have you placed in your application				Totl
	1.5kW	6kW	5kW	>5kw	
Yes	4	5	2	1	12
	33.3%	41.7%	16.7%	8.3%	
	0	0	0	2	2
	0.0%	0.0%	0.0$	100.0%	
Total	4	5	2	3	14
	28.6%	35.7%	14.3%	21.4%	

5.5.3. SSDG and Available Roof Space

Under the small-scale distributed generation (SSDG) project the CEB plans to integrate a total of 10 MW of projects using renewable energy (RE) technologies, of which the majority is expected to be solar PV, in the Mauritian grid (Central Electricity Board 2016):

- SSDG Phase 1 was opened for 2MW
- SSDG Phase 2 was opened for an additional of 1MW
- SSDG Phase 2 was opened for PECR (Public Educational Charitable and Religious Institution) for a total capacity of 2MW.
- SSDG Phase 3 was the launch of 5 MW net-metering scheme

Section 3.1 discussed the number of buildings on Mauritius, a total of 1,217,175, where broken down into the following categories:

- Buildings: Total of 297,500
  - 84.8% of buildings in the Republic of Mauritius in 2011, were wholly residential buildings.
- Housing Units: Total of 344,700
- Private Households: Total of 329,950

If 200,000 household dwellings have the potential to install roof mount solar PV (i.e. a conservative combination of wholly residential buildings, housing units and private households with available roof space), possible scenarios for future installation potential are given in Table 45 provided the right incentives are in place. This would indicate that the current SSDG scheme could be scaled up in terms of total installations considerably. This correlates well with the Mauritius solar PV survey results as listed in the previous section.

Table 45: SSDG solar PV scenarios for housing units and private households

Scenario	Percentage of Dwellings install solar PV	Number of Dwellings suitable for solar PV	Average size of solar PV system installed	Potential SSDG Solar PV Capacity
1	15%	200,000	3 kW	90 MW
2	20%	200,000	3 kW	120 MW
3	25%	200,000	3 kW	150 MW
4	30%	200,000	3 kW	180 MW
5	40%	200,000	3 kW	240 MW

5.5.4. MSDG & Prosumers

CEB currently has the following medium scale schemes and projects underway or planned:

- Plan to launch a 10 MW net-metering medium-scale distributed generation (MSDG) scheme
- Plan to launch a 30 MW net-metering Prosumers MSDG scheme

There are an estimated 45,000 non-residential buildings on Mauritius. A portion of these will be warehousing and buildings with large roof spaces for which solar PV can be installed. Without a survey of these buildings it is difficult to concluded the likely capacity for medium scale solar PV on Mauritius. The CEB's current MSDG schemes total 40 MW, however, a conservative estimate would size the total capacity at around 100 MW.

5.5.5. *Utility Scale Solar PV Farms*

CEB currently has the following utility scale schemes and projects underway or planned:

- Energy Supply and Purchase Agreements (ESPA) signed for five 2 MW solar farms:
  - Synnove Solar 1 Ltd at L'esperance;
  - Synnove Solar 1 Ltd at Petite Retraite;
  - Alteo Astonfield Solar Ltd at FUEL;
  - Astonfield Solar Ltd at La Gaulette; and
  - Solar Field Ltd at Mon Choisy.
- RFP for three 15 MW solar PV projects launched in Oct 2015.
- Proposal to launch RFP for 1 to 9 MW solar farms for total capacity of 20 MW.

Available land for utility scale solar PV farms is going to be limited by several factors:

- Proximity to the electricity network substations/grid connection points (i.e. large distances increase capital cost significantly)
- Ability of the local electricity network to absorb the electricity generated without causing problems such as reverse power flows and fault protection issues
- Availability of land near the electricity network connection points

With proper planning, co-ordination, and appropriate network upgrades the future capacity for utility scale solar PV farms is likely to be significant, in the order of 100 to 200 MW or greater.

5.5.6. *Challenges*

There can be many challenges to overcome when integrating new technologies into an existing energy system. Table 46 lists some of the typical challenges associated with solar PV projects that are likely to be encountered in Mauritius.

Table 46: Summary of likely challenges to be encountered by solar PV projects in Mauritius

Challenges	Discussion
Ability to withstand cyclonic winds	Solar PV has the highest wind rating of the solar technologies and would be better suited to coastal areas. Fixed (non-tracking) solar PV systems can be, and have been, designed for installation in cyclone risk areas. Some tracking systems can be re-engineered to render them suitable for installation in high wind areas but this increases both the installed and maintenance costs and complexity of the system.
Ability to find suitable site	A suitable site is critical to ensuring that a solar farm meets the planned capacity factor to ensure financial viability. Most suitable sites will be located close to substations/grid connection points. This means that any potential solar farms will be competing with the local community for land. In addition, local building roofs could be used to "house" local solar PV panels.
Integration with local grid	This is highly dependent on the local electricity supplier, in this case the CEB and its policies and ability to provide technical information for the integration of renewable energy. If new diesel or gas plants with excess capacity have been built, then they may not want to integrate renewable energy until the capacity of the plant meets demand or there is a substantial increase in fuel costs. In addition, any solar PV farm would need to be located within a short distance of the grid otherwise there may be significant costs to connect. Due to the inherent variability of solar energy, managing the solar-generated electricity delivered to the grid is of concern to the grid operator. Depending on the location of the grid connection additional ancillary services may be needed to compensate for voltage variations for example. The future potential for solar PV and batteries behind the meter may be favourable due to the ability of these systems to absorb excess energy during the day and make it available to local households during the evening peak.
Tourism, recreation and visual amenity	Perceived visual impacts are a major planning issue for installing larger scale solar PV farms, and this is likely to be the major issue if located close to towns or in tourist areas. It is better for solar PV farms to be away from the coast to avoid salt spray on panels which would reduce efficiency.

Table 46: Summary of likely challenges to be encountered by solar PV projects in Mauritius

Challenges	Discussion
Parks and protected areas	Mauritius is fringed by sensitive coastline, has two marine parks and several national parks. Any solar farm will need to be set back from such areas.
Solar variability and prediction	Solar can be intermittent and seasonal. This inherent variability has been a key challenge for solar power, although some grids are now seeing greater 30 to 50 % solar penetration levels without significant generation or grid stability issues. Several factors account for the high penetration of solar power, the matching of solar energy generation with high air-conditioning loads and times of peak demand. Modern solar farms have the ability to reduce output when required which also helps with variability. Distributed solar PV across a geographic area has been shown to reduce variability from cloud cover and reduce the size of ancillary equipment to smooth the output.
Financing new solar farms	Although costs are reducing for a range of solar technologies the upfront capital cost of medium size solar farms is still considerable which will make financing a considerable exercise and difficult to obtain commitment from both private and the public sector investors. Innovative financing models and perhaps collaboration with international agencies such as the World Bank may overcome some of these barriers. The Mauritius government has committed to considering appropriate financial incentives for private investors such as co-financing with CEB and proposed feed-in-tariffs (United Nations Development Program 2015).
Jobs	Jobs will be created for the installation and maintenance of the solar farms.
Regulatory	Mauritius government has committed to establishing an independent regulator and for developing the necessary regulatory framework for MV and HV solar PV systems (United Nations Development Program 2015).

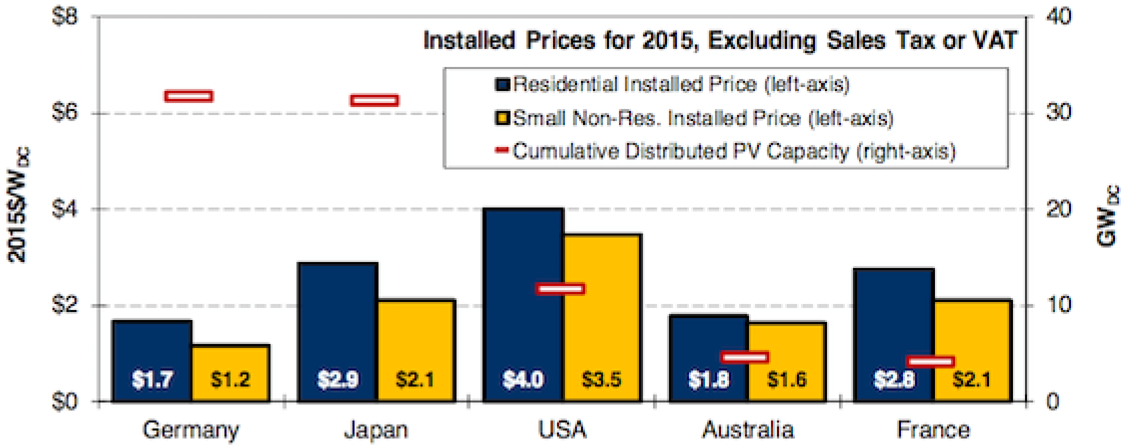
5.5.7. Competitiveness

The cost of electricity generated from solar PV arrays is estimated to be around US$0.07/kWh for utility scale and US$0.20/kWh for residential solar PV in 2020, making them competitive with the cost of electricity supplied from the grid or from stand-alone power supply systems, see Table 47. The output of solar PV systems is well matched to loads that peak during the day, which are typically loads dominated by daytime space heating or cooling loads. For loads that are flatter during the middle of the day, the modules can be oriented east and west so that the output of the solar PV systems better matches loads.

Table 47: LCOE for solar PV in the US

Source	2010	2014-15	2020
IEA - utility scale (EIA 2016)			US$0.0742
Lazard – Rooftop Residential (Lazard		US$0.18 to $0.30	
Lazard – Utility Scale (Lazard 2015)		US$0.05 to $0.07	US$0.043 to $0.046
IRENA – Utility scale (IRENA 2015)	US$0.23 to $0.50	US$0.11 to $0.28	US$0.06 to $0.12
IRENA – Residential (IRENA 2015)	US$0.33 to $0.92	US$0.15 to $0.49	US$0.14 to $0.47

The installed price, in 2015 US$, for residential and small non-residential solar PV systems across 5 countries is shown in Figure 28. Prices for these projects vary from $1.2 to $4.0 per W_{dc} installed. This study carried out by the Lawrence Berkely National Laboratory in the US indicated that other the impacts of import duties, the costs of PV modules and other hardware were similarly priced across countries (Barbose and Darghouth 2016). Soft costs accounted for the differences between the total system costs in each country.



Notes: Installed price data for Japan, France, and Australia are based on the IEA Photovoltaic Power Systems Programme's National Survey Reports (IEA-PVPS 2016) and for Germany are based on data compiled by the Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW 2016). Data for cumulative distributed PV capacity additions are based on IEA-PVPS (2016) and SPE (2016).

Figure 28: Installed price comparison in 2015 across national markets (Barbose and Darghouth 2016)

Utility scale solar PV has been dropping in price significantly over the past 10 years. The change in installed price for systems in the US are shown in Figure 29. Fixed utility scale solar PV is now being installed for a median price of US$2.5/$W_{ac}$ (US$~2.0/$W_{dc}$).

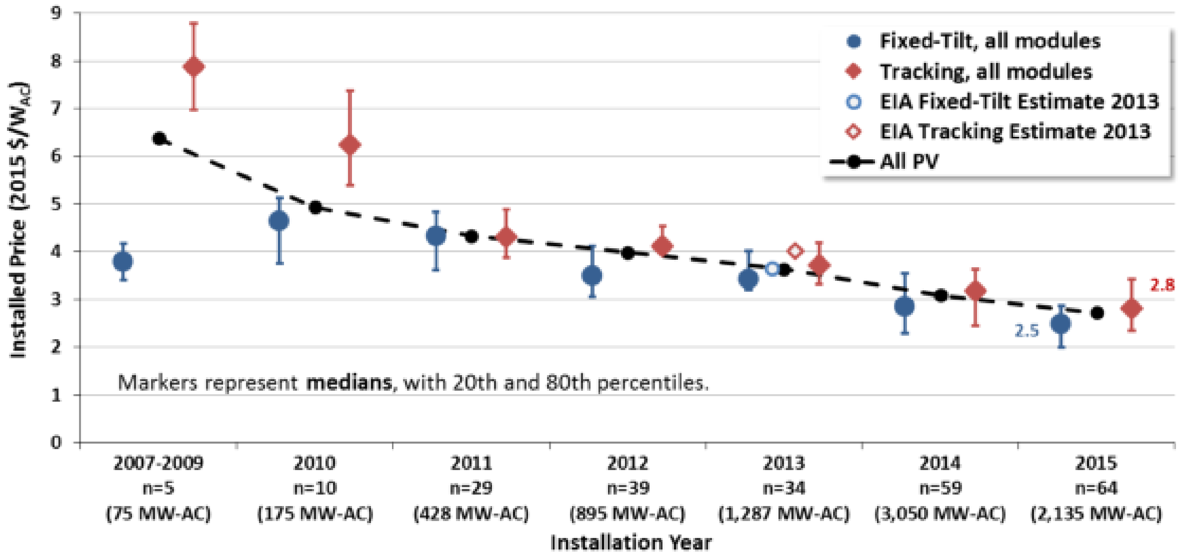


Figure 29: Installed price of utility scale solar PV by mounting type and installation year for the US (Blinger and Seel 2016)

In Australia, prices for recent utility scale projects have been dropping with new projects being built for around AUD$1.8/Watt in 2017. Expression of Interest (EOI) results released by ARENA in 2016 had a surprising effect on the state of affairs of the Australian market. Figure 30 below shows the outcome of the EOI process and the RFT process is expected to produce even more competitive prices during the bidding stage.

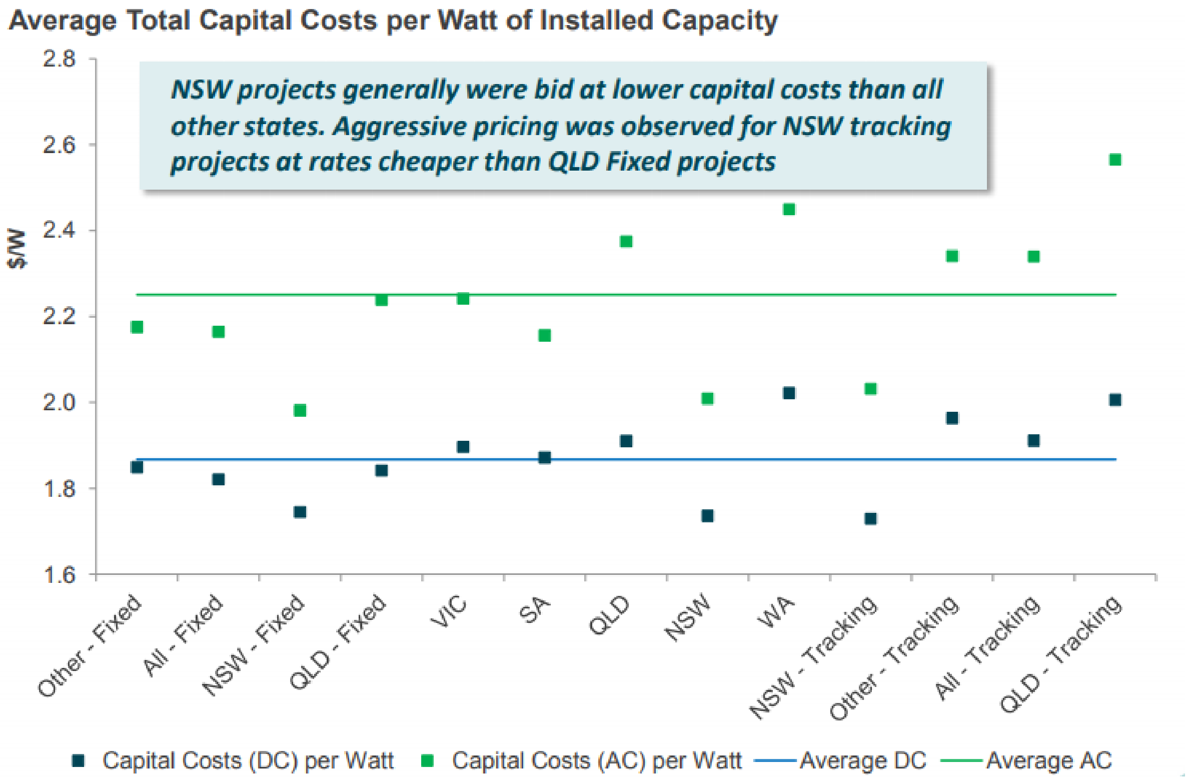


Figure 30: Average Total Capital Costs per Watt of Installed Capacity

5.5.8. Summary

Mauritius is considered to have a very good solar resource with the potential to contribute 5-6% (without storage) of the total generation depending on generation mix. Solar PV technology is ideally suited to the island nation as the systems can be designed for installation in cyclonic risk areas, while being one of the lowest cost renewable energy technologies available. By installing solar PV in a distributed nature across Mauritius may also help to reduce the impacts of cloud variability. A summary of each solar technology is provided in Table 48.

Table 48: Summary for solar energy technologies

Solar PV	SSDG & MSDG	Utility Scale
Technology risk	Low	
Difficulty of implementation	Low – provided the CEB has the capacity to provide technical assistance and expertise to integrate a large amount of solar PV onto the grid.	
Potential installed capacity implementation (MW)	> 300 MW. Suitable for installation across the entire Island of Mauritius. Ability of grid in high population areas to support large amount of DG needs further analysis.	> 100 MW. Only suitable for sites where the grid can support a large connection.
Potential annual output (MWh/year)	Moderate, +500 MWh/year (potential for at least 5% of total generation without storage based on modelling in section 7)	
LCOE (US$/kWh)	$0.10 to $0.35	$0.05 to $0.20
Installed cost (US$/$W_{AC}$)	$1.2 to $4.0	$1.5 to $1.75 – Fixed-tilt $1.75 to $2.0 – Tracking (single-axis)

5.5.8.1. *Solar PV with Storage.*

Mauritius is considered to have a very good solar resource with the potential to contribute at least 5-6% (without storage) of the total generation based on modelling in section 7. This total can be greatly increased with the addition of storage. There are numerous storage technologies available, however, battery storage based on lithium-ion and similar chemistries are currently the most common for home energy storage and are becoming popular for grid applications. A summary of each solar technology with storage is provided in Table 48.

Table 49: Summary for solar energy technologies

Solar PV	SSDG & MSDG with Storage	Utility Scale with Storage
Technology risk	Low	
Difficulty of implementation	Low – provided the CEB has the capacity to provide technical assistance and expertise to integrate a large amount of solar PV onto the grid.	
LCOE (US$/kWh)	$0.39	$0.15 to $0.30
Installed cost (US$)	$1,800 per usable kWh	$3.9/$W_{AC}$

5.6. Onshore Wind Energy

The economic viability of wind turbines is determined by the wind resource at the site. Site specific wind data is required as wind resources are highly localised as they are influenced by factors such as vegetation, direction of prevailing winds and ground slope, obstacles, such as trees and nearby buildings. These factors also affect the wind speed with height above ground level (due to wind shear) and therefore the optimal height of a wind turbine at the site. A wind monitoring mast would need to be installed on the preferred site and data recorded for at least 12 months to be able to make an accurate assessment of the viability of wind turbines.

Wind turbines are typically separated into 3 size categories: small scale, small and large (Table 50).

Table 50: Wind turbine categories

Category	Size	Description
Small Scale Wind Turbines (SSWT)	< 10 kW	Domestic size wind turbines either grid connect or for stand-alone systems
Small Wind Turbines (SWT)	10 to 100 kW	These range from small stand-alone systems to more sophisticated grid connected and hybrid off-grid systems.
Large Wind Turbines (LWT)	100 kW to 3 MW	Usually have yaw and blade pitch control allowing for automatic shutdown in strong winds
	> 3 MW	Have advanced yaw and blade pitch control to handle higher wind loadings

Both small scale wind turbines (SSWTs) and small wind turbines (SWTs) are not designed to withstand high wind loads or cyclonic conditions. Even large wind turbines (LWTs) may not be able to withstand cyclonic conditions. Therefore, SSWT and SWT wind turbines are not recommended for Mauritius.

5.6.1. Available Wind Energy Resource

Trade winds dominate the weather of Mauritius. The trade winds are continuous throughout the year and blow from the subtropical high pressure zone from the south east towards Mauritius. This means that the wind has a much greater impact on the south eastern coastal areas versus the western coastal areas that are somewhat protected by the central plateau and some mountains. This also means that clouds accumulate on the south-east side of the mountains meaning more rain and less sunshine hours per day.

As there is no wind atlas available for Mauritius, the analysis of the wind energy resource will rely on wind data from weather stations maintained by the MMS. The MMS maintain key weathers stations located at Medine, Pamplemousses, Fuel, Plaisance and Vacoas are considered to be representative of the five main regions of the Island. Of the 5 weather stations, the stations located at Vacoas and at Plaisance have had the wind data analysed in the greatest detail, see Table 51 and Figure 31 for location.

Table 51: Annual mean wind speeds and Weibull parameters for Plaisance and Vacoas weather stations (Mauritius Meteorological Services 2016, Dhunny, Lollchund and Rughooputh, Statistical Modelling of Wind Speed Data for Mauritius 2014)

Weather Station (Location)	Plaisance (South)			Vacoas (Central)		
	Mean Wind Speed	Weibull k parameter	Weibull c parameter	Mean Wind Speed	Weibull k parameter	Weibull c parameter
Annual Mean Wind Speed (m/s)	**4.05**	**2.544**	**4.4695**	**3.57**	**2.5771**	**4.0811**

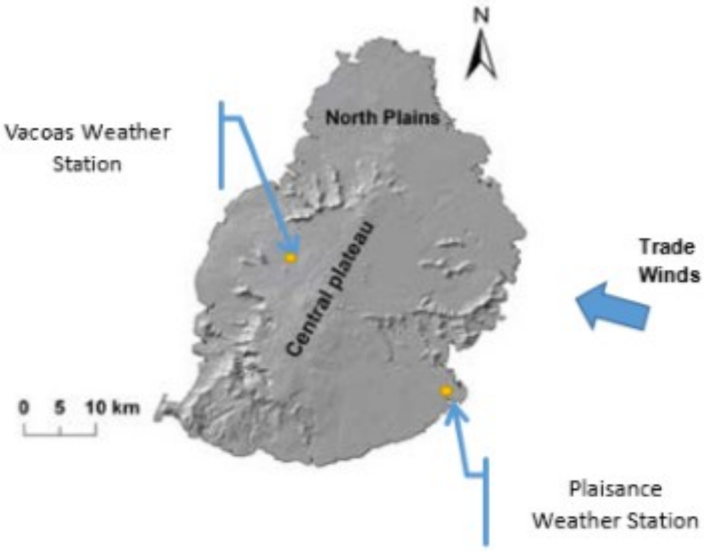
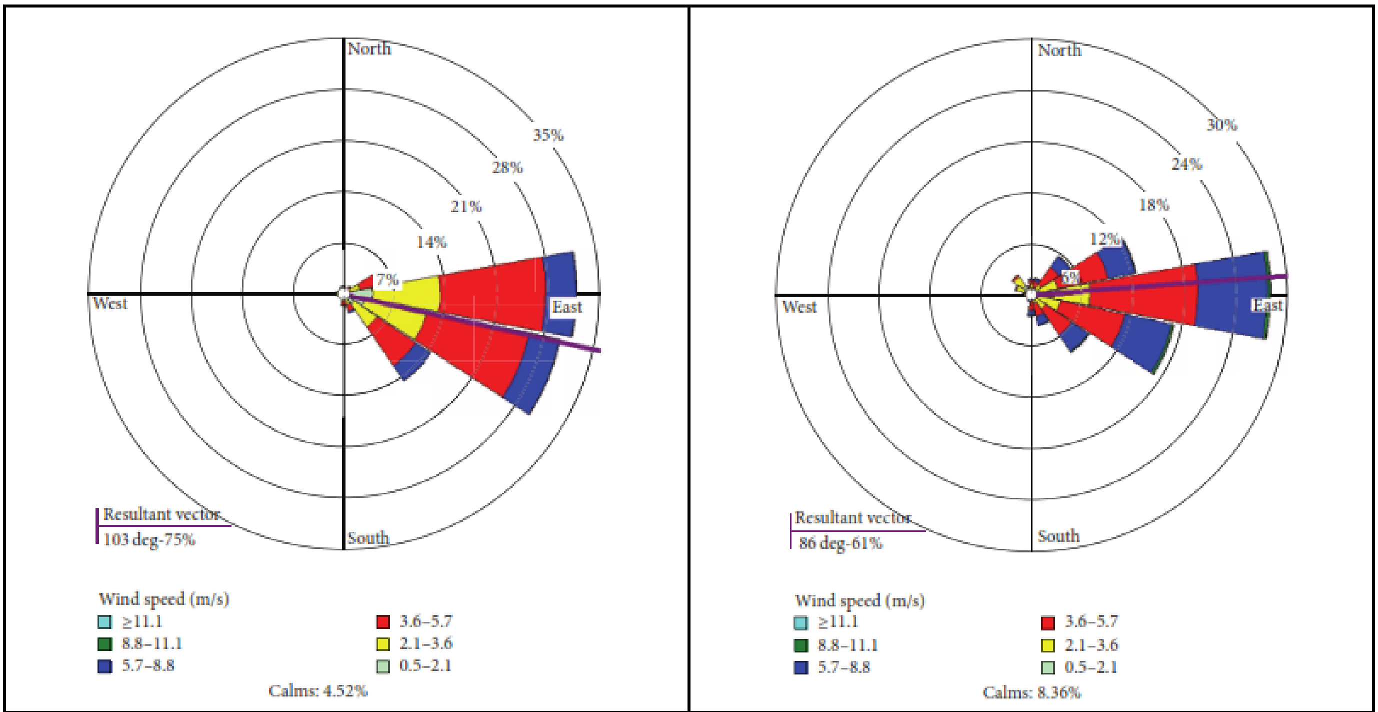


Figure 31: 3D image of Mauritius (Nigel 2009)

A study was carried out looking at the available energy from SWT for residential applications which looked at two locations, Vacoas and Plaisance, for which they obtained historical wind speed information for the weather stations and developed the wind roses presented in Figure 32 (Dhunny, Lollchund and Rughooputh, Long-term Wind Characteristics at Selected Locations in Mauritius for Power Generation 2015). The wind roses collaborate the direction and nature of the trade winds in the vicinity of Mauritius. Note that the wind direction is very predictable at both locations.



Daily mean wind data at Vacoas at 10 m above ground level from 1 June 1977 to 31 July 2013	Daily mean wind data at Plaisance at 10 m above ground level from 1 June 1973 to 31 July 2013

Figure 32: Wind rose for both the Vacoas and Plaisance weather stations on Mauritius (Dhunny, Lollchund and Rughooputh, Long-term Wind Characteristics at Selected Locations in Mauritius for Power Generation 2015)

The monthly mean wind speed for the Plaisance weather station is provided in Figure 33. The average monthly wind speed varies between 4.0 m/s and 6.2 m/s. This data would indicate that the prevailing trade winds, although generally predictable and consistent throughout the year, are considered to be a wind resource of moderate potential.

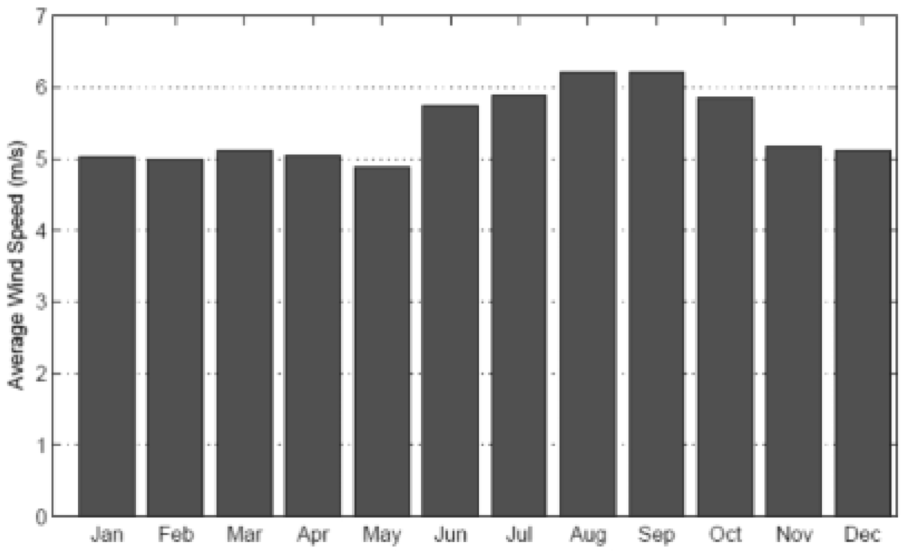


Figure 33: Monthly average wind speed (m/s) at Plaisance (for 60 metre height) (Dhunny, Lollchund and Rughooputh, Evaluation of a wind farm project for a smart city in the South-East Coastal Zone of Mauritius 2016)

There are currently two wind farms on Mauritius, both either commissioned or being commissioned at the time of publication, see Table 52. The installed wind turbine generation capacity on Mauritius is 39 MW. The CEB has carried out an Expression-of-Interest process to assess the potential for additional onshore wind farms, the process resulted in a total of 17 project submissions with a total capacity of 197 MW.

Table 52: List of onshore wind projects currently installed and/or being commissioned (Central Electricity Board 2016)

	Name of Onshore Wind Farm	Proposed Capacity (MW)
1	Curepipe Point (Plaine Sophie)	9.35
2	Plaine de Roches	29.4
	Total	**38.75**

5.6.2. Challenges

There can be many challenges to overcome when integrating new technologies into an existing energy system. Table 53 lists some of the typical challenges associated with onshore wind projects that are likely to be encountered in Mauritius.

Table 53: Summary of likely challenges to be encountered for onshore wind in Mauritius

Challenges	Discussion
Ability to withstand cyclonic winds	Many LWTs can shut down during high winds. However, the turbine needs to continue to rotate and adjust the blades during the period of high winds. Loss of grid power means that some sort of backup power supply is required or alternatively the turbines need to be de-mountable and quickly stowed prior to the high winds reaching the area. These options will add cost to the final solution. The use of lay-down towers to avoid damage from high winds speeds may be an advantage for conducting maintenance, as it could then be conducted at ground level thereby eliminating some of the safety issues of working at height on a wind turbine.
Ability to find suitable site	A suitable site is critical to ensuring that a wind farm meets the planned capacity factor to ensure financial viability. Most suitable sites will be located close to coastal areas and will need to be close to the townships where the electricity is consumed and/or close to grid connection points. This means that any potential wind farms will be competing with the local community for land. In addition, the height of the wind turbine will also have an effect meaning smaller turbines may produce less energy per kW versus large turbines which are typically much higher from the ground and surrounding objects.
Integration with local grid	This is highly dependent on the local electricity supplier, in this case CEB and their policies for the integration of renewable energy. If new diesel or gas plants with excess capacity have been built, then they may not want to integrate renewable energy until the capacity of the plant meets demand or there is a substantial increase in fuel costs. In addition, the wind farm would need to be located within a short distance of the grid otherwise there may be significant costs to connect. Due to the inherent variability of wind, managing the wind-generated electricity delivered to the grid is of concern to the grid operator. Depending on the location of the grid connection additional ancillary services may be needed to compensate for voltage variations for example. However, some wind turbines now have the capacity to reduce this impact on the grid and can add resilience to a network by providing a source of reactive power. Modern LWTs are electronically controlled and can be integrated with power electronics to control the amount of reactive power delivered to the grid.
Suitable wind resource	As mentioned the wind resources are highly localised as they are influenced by factors such as vegetation, direction of prevailing winds, ground slope, obstacles such as trees and nearby buildings. Accurate wind mapping can be carried out to determine the wind resource at a potential wind farm site.
Anti-wind protest groups	Although there are no known established anti-wind groups on Mauritius, these groups have proven to be very disruptive in other countries. It is therefore very important to discuss any proposals with the local community and address concerns early in the planning stages to avoid later conflicts and project delays.

Challenges	Discussion
Tourism, recreation and visual amenity	Perceived visual impacts are a major planning issue for installing wind turbines, and this is likely to be the major issue if located close to towns or in tourist areas. Erecting LWTs on the foreshore may meet with community/business opposition as the wind turbines will intrude on the ocean views.
Parks and protected areas	Mauritius is fringed by sensitive coastline, has two marine parks and several national parks. Any offshore wind farm will need to be located with consideration for such areas.
Wind variability and prediction	Wind can be intermittent and seasonal. This inherent variability has been a key challenge for wind power, although some grids are now seeing greater 30 to 50 % wind penetration levels without significant generation or grid stability issues. Several factors account for the high penetration of wind power, the ability to accurately forecast wind conditions a day in advance as is done in in Australian by the National Electricity Market operator in combination with load forecasts. Modern wind turbines can reduce output when required which also helps with wind variability.
Financing new wind farms	Although increasing size is making wind energy more competitive, LWT have significant up front capital costs. SWTs have greater costs per kW increasing payback periods.
Jobs	Being the first region to install a significant number of turbines in an area that is affected by cyclones could become the source for skilled workers when/if other areas decide to install similar turbines. Jobs for installation and maintenance of the turbines and potentially constructing the turbine towers for de-mountable turbines.
Wildlife impacts	The impact of wind turbines on birds is a major issue, particularly in locations within bird migration paths. The potential impacts of LWTs on birds would need to be assessed.
Noise impacts and shadow flicker	To avoid adverse noise impacts and shadow flicker on the amenity of the surrounding community, wind farm developments should include sufficient buffers or setbacks to noise and shadow sensitive premises. As a guide, the distance between the nearest turbine and a sensitive building not associated with the wind farm, is likely to be 1 km.

5.6.3. Competitiveness

Onshore LWTs in areas with suitable wind speeds remain the most competitive form of renewable energy and the cost of electricity generated by LWTs is rapidly becoming competitive with the cost of electricity generated by large coal and gas fired generators due to the merit order effect[32]. For mini-grid applications, as exist in the system on Mauritius, the capital cost of the turbines will be significant in relation to capital cost of equivalent diesel or gas generators. However, the marginal costs and the levelised cost of electricity (LCOE) over the life of the wind turbine could be lower due to the wind turbine's zero fuel cost.

5.6.3.1. Onshore large wind turbines (LWTs)

As an example of a smaller LWT, we have used the WES 250, which is manufactured in The Netherlands. The WES 250 is a mid-sized wind turbine with a rotor diameter of 30 m. The cut-in wind speed is 3.5 m/s and the cut-out wind speed is 25 m/s rated at 250 kW. Tower height options are 30 m, 39 m and 48 m and the output at an average wind speed of 6.5 m/s is 560,000 kWh/year would yield a capacity factor of 25.6 %. The capital cost is approximately US$450K, or US$1,800 per kW. With shipping, installation and web portal monitoring, the cost would be approximately US$520K, or US$2,200 per kW. Annual O&M costs would be between US$3,400 and US$17,000 per year. With a 20-year life, the LCOE over the life of the wind turbine would be between US$0.11 and US$0.13 per kWh. The turbine can survive wind speeds up to 60 m/sec or 216 km/h.

Additional costs may be incurred to ensure the wind turbine can meet cyclonic wind conditions or be demountable like the units installed on Rodrigues and New Caledonia with special lay-down towers, see Figure 34. Alternatively, a few companies are offering turbines that can withstand very high wind speeds such as the NPS100 from Northern Power Systems, see Figure 35, two of the turbines pictured withstood Hurricane Irene in August 2011, a category 3 hurricane. A third turbine was installed after the Hurricane had hit the Caribbean island.

[32] Increasing the supply of renewable energy tends to lower the average price per unit of electricity because wind energy and solar energy have very low marginal costs: they do not have to pay for fuel, and the sole contributor to their marginal cost is operational cost. As a result, their electricity can be less costly than that from diesel, coal or natural gas.

Figure 34: Vergnet 275 kW lay-down model turbines as used on Rodrigues (Clarke 2014) and New Caledonia

Figure 35: Three NPS100 100kW "hurricane resistant" wind turbines installed on the island resort of Over Yonder Cay, Bahamas (Over Yonder Cay 2015, Jakovlev 2014)

Large scale wind farms (100 to 200 MW) in Australia are thought to be producing electricity for approximately US$0.07 per kWh. The cost of producing electricity from a smaller wind farm constructed on Mauritius would be higher. The organisation Megavind has a LCOE calculator that can be used to calculate the approximate costs of generating electricity for a site from different renewable energy resources. Using that calculator, the LCOE produced from a 2.75 MW wind farm constructed at a site on Mauritius, including network upgrade and connection costs would be approximately US$0.115 per kWh (Megavind 2016).

To accurately evaluate a site on Mauritius, wind monitoring would need to be carried out. The large wind turbine towers would need to be delivered to the closest deep water port and transported to site.

Capacity factor

The capacity factor is the ratio of actual yield to the maximum output of the wind turbine or farm. Different types of turbines will yield a different capacity factor for any given site. To accurately estimate the actual yield, electricity generation is calculated by modelling the interaction between the wind distribution and proposed wind turbine(s) for that site.

For example, if a 1MW turbine yields 2628 MWh annually and its theoretical maximum annual output is 8760 MWh (1 MW * 24 hours * 365 days). Then the capacity factor or ratio of actual yield to maximum output will be 30% (2628 MWh/ 8760 MWh).

5.6.4. Summary

Mauritius is considered to have a moderate wind resource with the potential to contribute between 15-25% of the total generation. Large scale onshore wind technology is suited to Mauritius as the systems can be designed for installation in cyclone risk areas while being one of the lowest cost renewable energy technologies available. There are several manufactures offering wind turbines that can withstand high wind speeds such as Vergnet and Northern Power Systems. A summary of each onshore wind technology is provided in Table 54.

Table 54: Summary for onshore wind turbines

Technology risk	Small Scale	Large Scale Wind Turbines
Technology risk	Low	Low
Difficulty of implementation	High due to potential for cyclonic winds	Low to Medium
Potential installed capacity implementation (MW)	Low due to constraints on using coastal sites and low wind speeds at inland sites	Low to moderate due to constraints on available coastal sites and potential amenity issues
Potential annual output (MWh/year)	Unknown, but likely to be low	Moderate to High
LCOE (US$/kWh)	$0.175 to $0.45	$0.07 to $0.15
Installed cost (US$/W)	$3.0 to $6.0	$1.25 to $1.70

5.7. Hydropower

Hydropower is a renewable energy source derived from falling or running water to generate power or 'hydroelectricity'. The water is channelled through a turbine where the resulting pressure spins the turbine blades to drive an electrical generator to produce electricity. Hydropower is the worlds most advanced and mature renewable energy source.

Conventional hydropower plants can be divided into two main types, impounded and diversion. The most common non-conventional hydropower plant in use today is called pumped storage hydropower which combines the ability to both store and produce electrical energy using a system of interconnected reservoirs. Pumped storage systems will be discussed in the following section on emerging technologies.

5.7.1. Conventional Hydropower

The impoundment facility is the most common type of hydropower facility. Figure 36 shows a typical impoundment facility that uses a large dam or reservoir to store rainwater runoff from rivers and streams. Water is release from the dam via a penstock through a turbine, spinning it and a generator to produce electricity. Water may be released to serve agriculture, electricity production or the need to maintain a constant reservoir level.

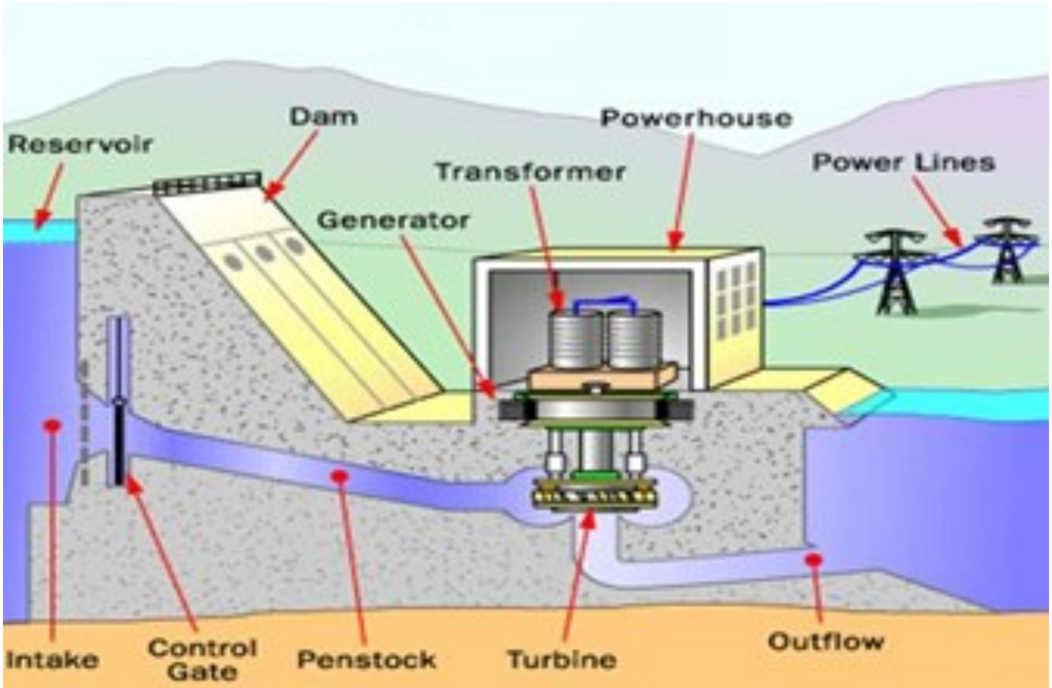


Figure 36: Impoundment type hydropower plant facility (Bonsor 2001)

Figure 37 shows a diversion (sometimes called run-of-river) type hydropower plant. This type of plant may or may not require the use of a dam or reservoir to store water. Water is either released from a dam or a portion of a river is captured at an intake/diversion point. From this point the water is channelled to the powerhouse containing the electricity generators by one or more canals and/or penstocks.

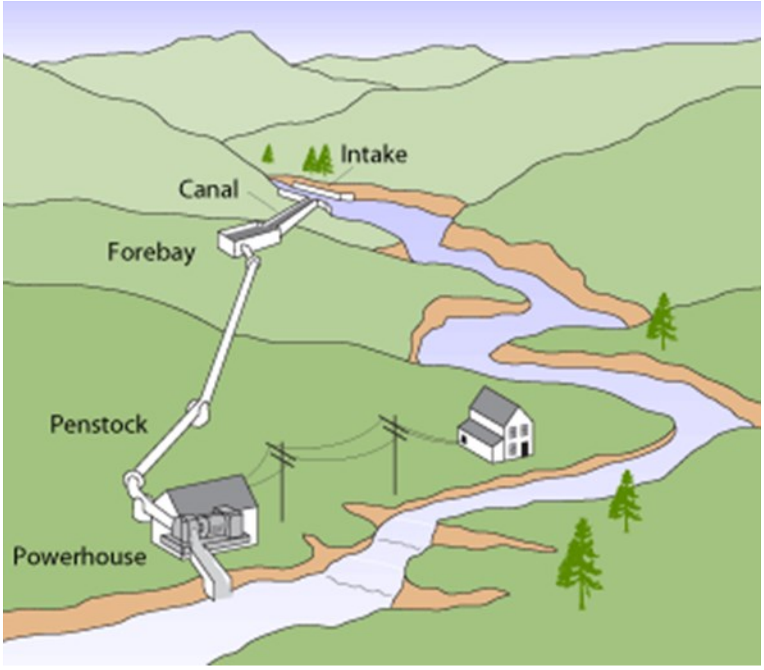


Figure 37: Diversion type of hydropower plant (Energy, Microhydropower Basics 2015)

Conventional hydropower plants vary in size ranging from small systems used to power individual homes to large utility scale projects. The type of hydropower plant can be categorised based on the generation capacity of the project as listed in Table 55.

Table 55: Types of hydropower plants

Type	Sub Category	Size	Description
Large		> 30 MW	Although definitions vary as to the size of plant, typically from 10 MW to 50 MW, the application is typically for large scale utility power generation.
Small		≤ 30MW	The application of small hydropower varies greatly from utility power generation to generation for single home applications.
	Mini	100 to 1,000 kW	The application of mini hydro is usually for larger communities/ villages or as grid connected enterprise to sell power to a utility.
	Micro	< 100 kW	The application of micro hydro is usually for smaller communities/ villages, single families or small enterprise.
	Pico	< 5 kW	Typically used to power individual homes

Hydropower plants are very flexible when it comes to the plants ability to rapidly increase or decrease output in response to fluctuations in electricity network demand. They are particularly good at providing electricity to meet peak demand situations as they are more responsive than other sources of generation, see Table 56.

Table 56: Flexibility of different power generation technologies (Eurelectric 2011)

	Nuclear Power Plants	Hard coal fuelled power plants	Lignite fuelled power plants	Combined-cycle gas power plants	Hydro power plants
Start-up time cold	~ 40 hours	~ 6 hours	~ 10 hours	< 2 hours	~ 0,1 hours
Start-up time warm	~ 40 hours	~ 3 hours	~ 6 hours	< 1,5 hours	~ 0,1 hours
Load gradient increase nominal output	~ 5% per minute	~ 2% per minute	~ 2% per minute	~ 4% per minute	> 40% per minute
Load gradient decrease nominal output	~ 5% per minute	~ 2% per minute	~ 2% per minute	~ 4% per minute	> 40% per minute

.7.2. *Available Hydropower Resource*

Mauritius has a long history of Hydropower dating as far back to 1899 when electricity was first produced on the island. When Mauritius achieved independence in 1968, hydropower was contributing as much as 50-60% of the energy generation mix. Today that share of electricity generation has dropped significantly to be less than 3% of the total generation on Mauritius.

Many sources make the claim that hydropower on Mauritius is or is close to being fully exploited. In addition, there are competing uses for the water stored in the reservoirs on Mauritius including potable water supply and irrigation for agriculture as well as electricity generation. Therefore, the storages cannot be guaranteed for electricity generation alone. Any future reservoir or hydropower development must find a balance, not only between these uses, but also with the environmental impact on the limited Island ecosystem.

Mauritius has a central plateau around 600 m above sea level from which approximately 50 rivers flow to the surrounding ocean. In 2012, the total rainfall received across Mauritius was 3,001 Million m^3 of which it was estimated that the total water utilisation was 800 Million m^3 with 218 Million m^3 or 27% being utilised by Hydropower (Elahee 2014). The island's total water utilisation is split between ground and surface water with each contributing 15% and 85% respectively. A mean rainfall of 1,609 mm was recorded across Mauritius during 2012.

In any given year, the amount of hydropower generation is dependent on several factors such as rainfall, storage levels, and demand (from agriculture and potable water services). Climate change impacts will also affect hydropower generation due to the predicted increase in the frequency of extreme weather events, heavy rains and storms. Long term analysis of rainfall over the past century indicates a decreasing trend in annual rainfall of around 57 mm on average per decade across Mauritius (Mauritius Meteorological Services 2016). The energy generated from hydropower between 2002 and 2015 is shown in Figure 38 with an annual average over the period of approximately 92 GWh.

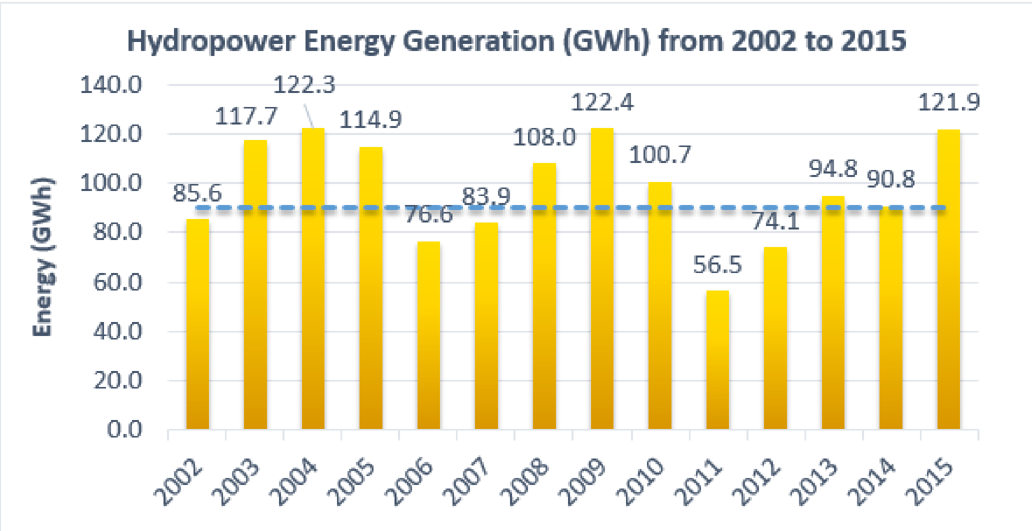


Figure 38: Hydropower energy generation from 2002 to 2015 with average for the period – dotted blue line

In an article by Assoc. Professor Khalil Elahee discussing Hydropower in Mauritius (Elahee 2014), the author states that the cost of hydropower on the island to be in the range of Rs0.50 (US$0.015) to Rs1.00 (US$0.030) per kWh or approximately 10 times less that the cost of the kerosene-powered gas turbine at Port Louis. The key ongoing costs associated with hydropower, once established, is typically maintenance and renewal of plant.

5.7.3. Rainfall

Inter-annual variation in rainfall amount depends on the passage of cyclones which can multiply the “normal” monthly rainfall depth by 2 to 3 (Willaime, 1984; Padya, 1989). Concerning intra-annual variability, on average 80% of mean annual rainfall is received during the summer period. February is the wettest month and has the highest probability of cyclone formation and October is the driest month of the year. The rainfall amount across Mauritius for the month of February is given in Figure 39 and indicates that the lowest rainfall areas are along the north and west coasts of Mauritius. There is also a strong spatial intra-annual variation in rainfall especially in the western and northern regions where very little rainfall is received in winter. The rainy regions in the central uplands shows, however, a less pronounced intra-annual variability and where, even in winter, there is relatively high rainfall recorded (compared to the northern and western regions).

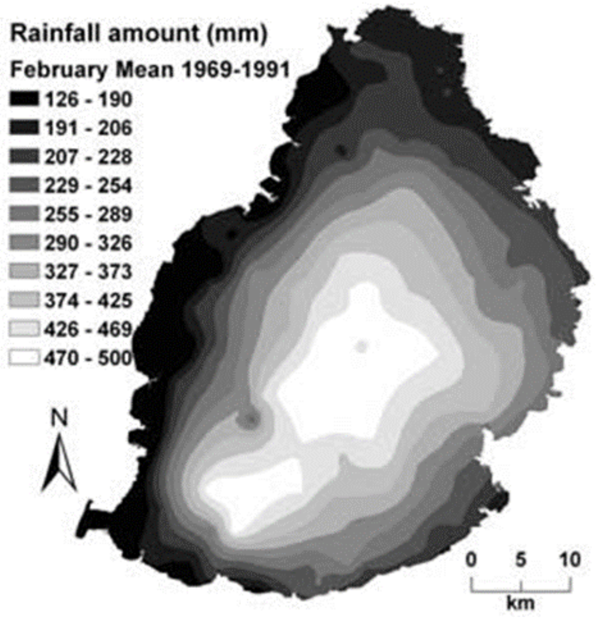


Figure 39: Rainfall map for February (Nigel 2009)

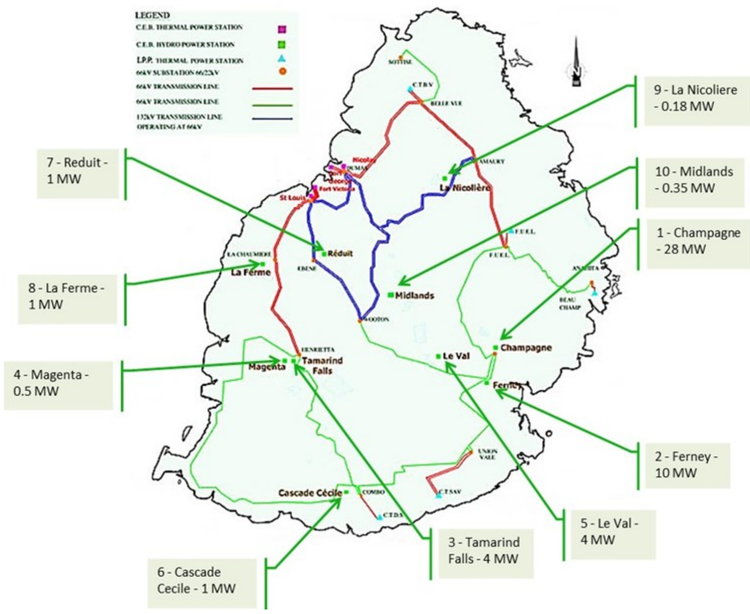


Figure 40: Location of the Hydropower stations on Mauritius

5.7.4. Hydropower Installations on Mauritius

The hydropower facilities installed on Mauritius consist entirely of small hydropower plants with no pumped storage facilities, see Figure 40 (above) and Table 57. The total effective capacity of all hydropower plants is 56.5 MW which, when competing use allows provides a substantial facility for grid support services and help with managing peak loads. These power plants contribute to the reduced need for the kerosene-powered gas turbine at Port Louis which only produced 2 GWh in 2014 versus 90.8 GWh from the combined generation from all hydropower plants.

5.7.5. Summary – Hydropower

The biggest impediment to hydropower is that it relies on natural features that exist only in some locations. In terms of hydropower generation, most economically viable locations appear to have been exploited on Mauritius. Even if some new conventional hydropower plants can be added or existing plants upgraded the additional contribution to the amount of electricity generated from hydropower on Mauritius will not be significant, however, were possible the projects should be pursued.

Table 57: Hydropower Installations on Mauritius

Name of Power Station	Operator	Location	Year of Operation	Installed capacity (MW)	Effective capacity (MW)
Champagne	CEB	Mahebourg	1984	30	28
Ferney	CEB	Mahebourg	1971	10	10
Tamarind Falls	CEB	Henrietta	1945	11.7	9.5
Magenta	CEB	Henrietta	1960	0.94	0.9
Le Val	CEB	Riche en Eau	1961	4	4
Cascade Cecile	CEB	Surinam	1963	1	1
A.I.A (Reduit)	CEB	Reduit	1984	1.2	1
La Ferme	CEB	La Ferme	1988	1.2	1.2
La Nicoliere F.C	CEB	Nicoliere	2010	0.35	0.35
Midlands	CEB	Midlands	2013	0.35	0.35
Connected to grid	Private	Riche en Eau		0.1	0.1
Connected to grid	Private	Bois Cherie		0.1	0.1
100 kW not connected to grid	Private	Britanna		n/a	n/a
Totals				**60.94**	**56.5**

5.8. Waste-to-Energy (WtE)

Waste-to-energy (WtE) plants are used to recover energy from waste streams and in particular from municipal solid waste (MSW). The newest WtE technologies can utilise various forms of wastes such as plastics, rubber, glass, tyres, oil, paper, and wood or a combination as the primary feedstock. Some plants are design to process a specific type of waste steam whereas others process a pre-sorted MSW stream which can be composed of both organic and in-organic materials.

Many countries, Mauritius included, have limited space available for landfill, therefore, employing WtE technology to process the waste to reduce both the volume and weight makes sense. Combustion technologies are capably of reducing the volume of material by around 90% and the materials weight by about 75% while producing heat which can be used for other processes such as district heating, manufacturing, or in the generation of electricity (Stringfellow 2014).

WtE technologies have been deployed more commonly in Europe than other jurisdictions, with more than 430 such facilities in 2014 (Stringfellow 2014), primarily because European countries have less land available and the cost to send waste to the limited number of landfill sites is high.

Conversion of waste into energy is usually achieved by thermal methods such as pyrolysis, gasification, and combustion. A typical thermal waste to energy (WtE) plant is shown in Figure 37.

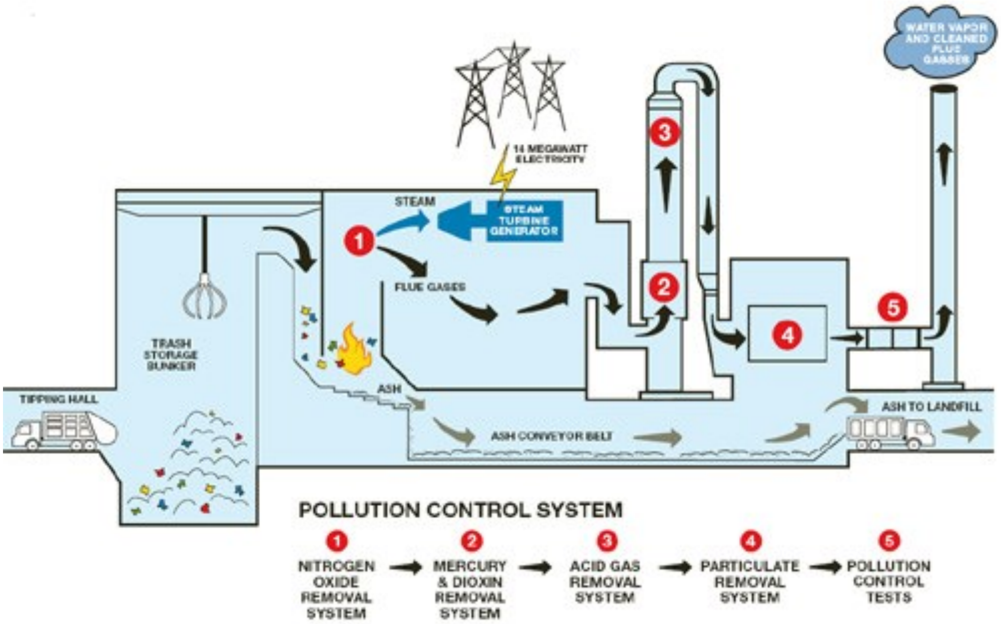


Figure 41: Typical Waste-to-Energy (WtE) plant (The Pennsylvania State University 2016)

5.8.1. WtE technologies

As the focus of this report is the generation of electricity and offsetting fossil fuel generation, the WtE technologies considered are those that produce sufficient energy for electricity generation. WtE technologies for treating waste and pure incineration are not considered.

The thermal technologies that can generate electricity are list in Table 58. Each technology type is distinguished by the ratio of oxygen (or air) required for complete combustion, defined as ‘lambda’ (l), and whether external heat is applied.

Table 58: WtE conversion technologies

Technology Type	Specific technology	Lambda (l[33])	Thermal treatment	Produces
Pyrolysis	Pyrolysis ‘cracking’ technology used for plastics/rubber, plants appear to be highly dependent on the type of feedstock used	l=0, no air	By external heat source without combustion	Water Vapour & cleaned flue gases, Syngas, bio-oil, carbon char, and ash
Gasification	Conventional Gasification, Ultra -High Temperature (UHT) Gasification or Plasma Arc Gasification	l=0.5	Use or partial use of external heat (via induction or plasma arc) without combustion	Water Vapour & cleaned flue gases, Syngas, slag
Combustion	Mass Burn and Refuse Derived Fuel	l=1.5+	No external heat with combustion	Water Vapour & cleaned flue gases, ash that is sent to Landfill

Pyrolysis is the thermochemical decomposition of organic material brought about by elevated temperatures and an absence of oxygen. Pyrolysis occurs at temperatures above 390°C and produces syngas and carbon char, the syngas is typically passed through a thermal oxidizer for further decomposition and clean-up of the gas. Depending on the feedstock the syngas can either be condensed into bio-oil to produce liquid fuels or cleaned further for the direct combustion in engines or boilers to produce electricity.

[33]Represents the ratio of oxygen input/ oxygen required stoichiometrically for complete oxidation of all organic compounds.

Conventional gasification operates at temperatures of 540°C to 1,540°C to convert organic material through a thermal process with a limited air/oxygen supply. The process produces syngas and requires significant gas clean-up and flue treatment. To overcome these issues UHT gasification was developed that produces a cleaner syngas and ultimately cleaner flue gases. The basic process has the waste materials with a moisture content of less than 30% feed into a reactor chamber using an auger. The chamber is a reaction controlled environment where both the oxygen and temperature are controlled. The process uses electrically induced or plasma arc thermal energy to create ultra-high temperatures in the range of 1,700°C to 11,000°C.

Mass Burn technology has been in existence for many decades and literally burns/combusts all the waste stream feedstock leaving only non-combustible materials. With the introduction of emissions regulations, Mass Burn technology has had to implement flue gas cleaning techniques and has resulted in other WtE technologies which produce less emissions being favoured. Refused Derived Fuel combustion technology relies on the removal from the MSW waste stream of recyclable and non-combustible materials. The remaining waste can produce a combustible material by dewatering, shredding or pelletizing.

5.8.2. Available resource/feedstock

As Mauritius is a relatively small island nation, the quantity and availability of feedstock for WtE conversion is always going to be limited to that produced by the local population. There is a plan to build and operate two WtE plants with a total electricity supply capacity of 30 MW. The plan is for the plants to use UHT gasification technology (Government of Mauritius 2014). The REMMPAP also indicated a limited volume of waste and that the potential beyond 30 MW supply capacity was limited. Therefore, it is assumed that there is limited opportunity for an additional WtE projects on Mauritius.

Feedstock quality can be an important factor in the economic and operational outcome of a WtE plant. Feedstock quality is usually measured by the moisture content, heating value and organics content.

5.8.3. Summary

The biggest drawback of any WtE technology is that it requires a consistent quality and quantity of feedstock. As the most commonly available feedstock is drawn from the MWS and that the proposed plants will already make use of this, there is limited opportunity for any additional WtE production on Mauritius. A summary of each WtE technology is provided in Table 59.

Table 59: Summary for WtE energy

Technology risk	Thermal WtE Conversion Technology
Technology risk	Low/Medium – depends on the feedstock and the specific technology in use, note that some newer gasification and pyrolysis technologies are not fully commercialise and have a high technology risk
Difficulty of implementation	Low/Medium – depends on type of WtE technology implemented
Potential installed capacity implementation (MW)	Low, current plans are for two plant with combined capacity of around 30 MW
Potential annual output (MWh/year)	Low, around 260,000 MWh/year based on the 24-hour operation of the proposed WtE plants
Key Benefits	Ability to reduce the waste to landfill and thus space for landfill Ability of the technology to produce electricity
LCOE (US$/MWh)	Estimated to be $50-$200 per MWh – depends on the type of WtE technology, the quality of the feedstock and whether any pre-processing of the feedstock is necessary such as pre-sorting to remove non-combustible materials or dewatering to reduce moisture to acceptable levels.
Capital Cost based on Capacity (US$/kW)	Estimated to be $7,000-$11,500 per kW installed – depends on the type of WtE technology used

5.9. *Biomass – Biopower*

Biomass is the oldest form of renewable energy and has been in use by humans for thousands of years, primary the burning of wood for heat and cooking. Biomass is any organic matter that occurs as a result of plants converting sunlight into chemical energy, see Figure 38. Biomass feedstocks refer to the type of biomass sources used as an energy source. These include plants, agricultural and forestry residues (include bagasse from sugar cane processing), organic component of garbage (MSW) and industrial wastes, and marine plants (algae, seaweed etc.). When biomass is used primarily to generate electricity and/or heat it is typically referred to as biopower. Plants that convert primarily organic wastes from the municipal solid waste (MSW) to energy are referred to as Waste-to-Energy (WtE) plants and are discussed in the previous section. Biomass can also be used to produce biofuels for transport, however, this section will focus on biopower and the production of electricity.

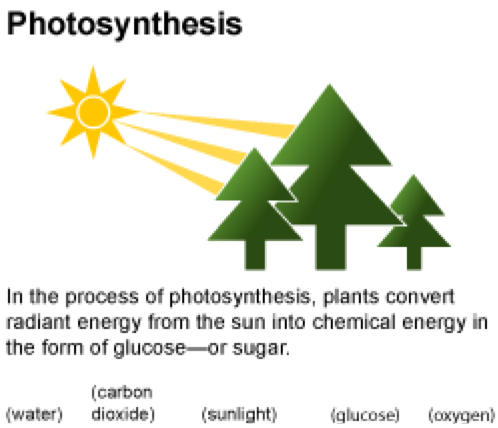


Figure 42: Photosynthesis, the conversion of radiant energy from the sun into biomass (US Energy Information Administration 2016)

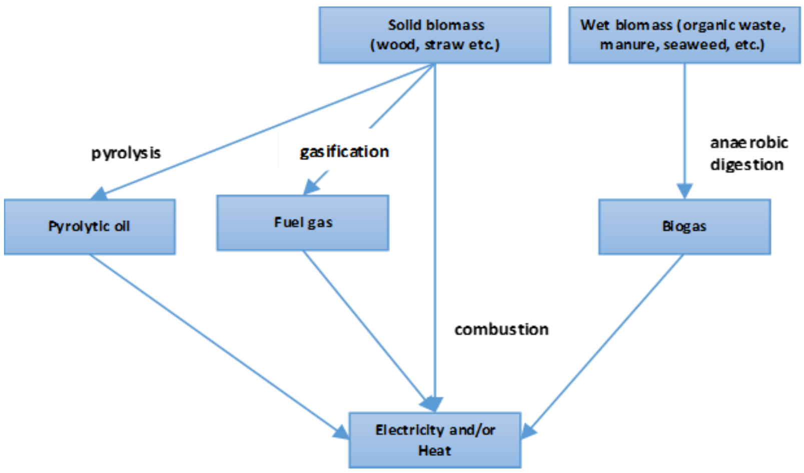


Figure 43: Biopower energy conversion – modified from Biomass Energy Conversion Overview (United Nations Foundation 2008)

The type of biomass used in the generation of biopower can be classified either as solid or wet biomass. Conversion of biomass into biopower can be achieved by different methods which are broadly classified into: thermal (pyrolysis, gasification, and combustion) and biochemical (anaerobic digestion) (Figure 39). For more information on the different types of biomass conversion processes see APPENDIX B |Technology descriptions.

5.9.1. Biopower conversion technologies

For thermal processes, there are three primary ways in which to recover energy from solid biomass feedstock. These processes include pyrolysis, gasification and combustion. Each technology is distinguished by the ratio of oxygen (or air) required for complete combustion, defined as ‘lambda’ (l), and whether external heat is applied, see Table 60: Biopower conversion technologies. The thermal conversion technologies are all like the WtE conversion technologies – see previous section for more details.

Combustion and gasification technology is considered the most mature for biomass unless the goal is to produce bio-oil and biochar in which case pyrolysis would be used, however, pyrolysis is not considered fully commercialised yet and is highly customised to the available feedstock and is typically the least efficient in the production of electricity.

Dual combustion plants, also known as duel-fuelled plants, are designed to operate from either biomass or coal and typically use high-efficiency coal boilers. In Mauritius, the plants operate from biomass during cropping season and from coal during the non-cropping period.

Combustion plants can also be configured for co-firing. This allows both coal and the biomass to be used at the same time and has been proven in most standard boiler technologies. The idea is to be able to replace a portion of the coal with a renewable biomass feedstock which can significantly reduce the sulphur dioxide emissions of the coal-fired plant (Office of Energy Efficiency & Renewable Energy 2013).

Anaerobic digestion is a biochemical process whereby complex organic materials are broken down into simpler compounds by microbes (Khanal 2010). The process utilises the natural decomposition process of organic material in the absence of oxygen. It is the principle process that occurs in landfills and results in the creation of landfill gas (Demirbas 2009).

Table 60: Biopower conversion technologies

Technology	Lambda (l)	Thermal treatment	Other	Produces
Pyrolysis	l=0, no air	By external heat source without combustion	Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen. Has not been fully commercialised.	Water Vapour & cleaned flue gases, Syngas, bio-oil, carbon char, and ash
Gasification	l=0.5	Partial use of external heat without combustion	Gasifiers operate by heating biomass in an environment where the solid biomass breaks down to form a flammable gas. The biogas can be cleaned and filtered to remove problem chemical compounds.	Water Vapour & cleaned flue gases, Syngas, slag
Combustion	l=1.5+	No external heat with combustion	External heat may be applied to maintain temperatures to ensure complete combustion and conversion of organic compounds as exhaust treatment.	Water Vapour & cleaned flue gases, ash that is sent to Landfill
Anaerobic digestion	Not applicable	Partial use of external heat to maintain temperatures to both maintain the correct environment for the biochemical process and to preheat feedstock that is being added.	The microbes that make this process possible are mostly anaerobic bacteria. The process consists of several stages of decomposition which is driven by microbes present and cultivated during the process.	Biogas, compost

5.9.2. Available resource/feedstock

There are a variety of feedstock that can be used in biopower applications, see Table 61: List of the types of feedstock used in biopower applications. However, for biopower to be economically viable the feedstock needs to be in large enough quantities to continually feed a large plant either year-round or as is done in the sugar industry where bagasse is used for process heat and electricity generation during the sugar cane processing season. Other potential sources of biomass on Mauritius include biomass from garbage, human sewage, landfill and marine plants such as seaweed.

Table 61: List of the types of feedstock used in biopower applications

Feedstock	Use	Typical Conversion Process	Classification
Wood and wood processing wastes	Includes fast-growing trees and grasses combusted to heat buildings, to produce process heat in industry, and to generate electricity	Combustion	Solid biomass
Agricultural crops and waste materials (includes bagasse)	Combusted to heat buildings, to produce process heat in industry, and to generate electricity	Combustion	Solid or wet biomass
Food, yard, and wood waste in garbage	Solid and wet biomass separated from garbage can be either combusted or used as a feedstock for anaerobic digestion to generate process heat and electricity	Combustion, Gasification or Biogas	Solid (if dried) or wet biomass
Animal manure and human sewage	Can be used as a feedstock for anaerobic digestion to generate process heat and electricity	Biogas	Solid (if dried) or wet biomass
Marine plants	Can be used as a feedstock for anaerobic digestion to generate process heat and electricity	Biogas	Wet biomass
Landfill	Gas collected from landfills and converted to electricity and heat using reciprocating engines	Biogas	Wet biomass

Biopower technologies are only economically successful if either the feedstock is free or the current cost of handling that feedstock is excessive, such as the case in Europe and Western Countries where it is expensive to landfill waste. In the case of a sewage anaerobic digestion system the business case will be based on the ability to offset electricity purchased from the grid to achieve a reasonable payback period.

It may be possible to grow a viable biomass feedstock on Mauritius, however, any agricultural land diverted from sugar cane production may be just replacing one crop with another, for no net benefit. Therefore, extensive research is required before new biomass crops are introduced to determine what the likely economic, social, and environmental impacts will be.

It is understood that methane capture is already occurring at the main sewage treatment plant and energy produced used to power the sewage and water treatment systems. There is a landfill WtE project at the Mare Chicose landfill site with a total capacity of 3.3 MW and a composting facility at La Chaumiere.

5.9.3. Sugar Industry & Bagasse By-product

Sugar production has played an important role in the Mauritian economy since its introduction to the Island in the seventeenth century. Each year the industry produces about 600,000 tons of sugar from around 5.8 million tons of sugarcane which results in the production of about 1.8 million tons of Bagasse as a by-product of the sugar extraction process (Zafar 2014). A total agricultural area of up to 72,000 hectares has been cultivated in the past for sugarcane production with up to 11 sugar factories operating on the island. A total agricultural area of 52,387 hectares was cultivated for sugarcane production in 2015 (Statistics Mauritius 2016).

Mauritius is the only island in the Indian Ocean vicinity where the sugar production industry sells electricity on a large scale (Mohee, Surroop and Jeetah 2012). Using bagasse to generate heat and electricity at sugar production facilities offers many unique benefits:

- Sugar production is self-sufficient in terms of energy consumed
- It removes the need to transport and dispose of the bagasse by-product
- Surplus electricity generation can be exported to the grid for additional income
- Electricity generation from bagasse has the potential to generate less greenhouse gas emissions than conventional fossil-fuel generation
- If bagasse were left to rot, it would break down and release greenhouse gases, particularly methane, which has 28 times the global warming potential of carbon dioxide
- It plays an important role in helping Mauritius achieve its Renewable Energy target supplying 17.3% of total electricity generation in 2015 (including sugar production self-consumption)
- Mauritian sugar mills help to drive the development of many rural communities and help underpin the economic stability of the nation

Bagasse is used in 4 dual-fuelled co-generation plants used by the sugar production industry, see Table 62: IPP Bagasse and dual-fuelled Bagasse/Coal power stations is operation in 2015. Mauritius obtains 17.2% of its electricity from Bagasse biopower generation and 40% from the use of coal, see Table 56 and Figure 40. In 2015, 9% of this electricity generation (from both bagasse and coal) is self-consumed while both bagasse and coal together supplied 57.3% of total electricity generation on the island, see Table 63 and Figure 44.

The LTES indicates that through more efficient use of Bagasse resources and more energy efficient generation equipment, annual average generation from Bagasse could increase from approximately 300 GWh in 2009 up to 600 GWh by 2025. In 2015, the generation from Bagasse had reached an annual total 510 GWh, with 380 GWh exported to the CEB grid.

Other efficiency gains that have been discussed include the collection and processing of the dry and green leaves and tops from the sugarcane which represent about a third of the total mass. Dry leaf trash alone has about double the net heat energy of bagasse. It has been estimated that the cane tops and leaves represent around 1.5-2.0 million tonnes per year in Mauritius with forecasts that electricity production from sugarcane by-products could be doubled (Mohee, Surroop and Jeetah 2012).

Table 62: IPP Bagasse and dual-fuelled Bagasse/Coal power stations is operation in 2015

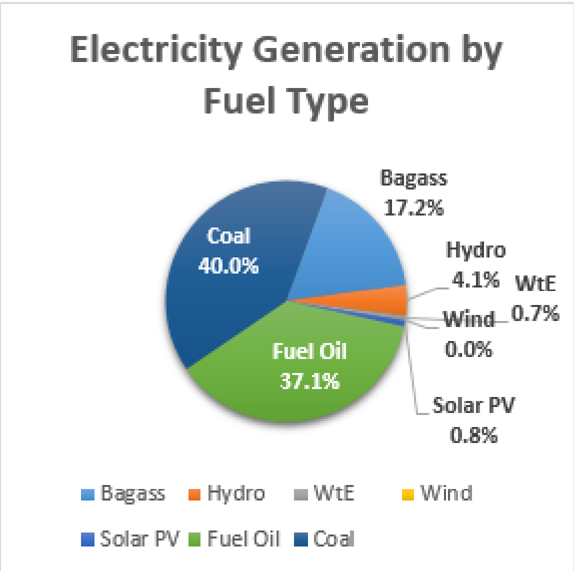
Name of Power Station	Location	Year of Operation	Installed capacity (MW)	Effective capacity – bagasse (MW)	Effective capacity – coal (MW)	Energy Source Used
Alteo Energy Limited (ex FSPG)	FUEL	1998	36.7	20	27	Coal/ Bagasse
Terragen Ltd (ex CTBV)	Mapou	2000	71.2	46	62	Coal/ Bagasse
OTEOLB (ex CTSav)	L'escalier	2007	90	65.5	74	Coal/ Bagasse
MSML (ex Medine)	Bambous	2015	21.7	11		Bagasse

Table 63: Total electricity generated by type for Mauritius in 2015

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse	509.8	17.2%
	Hydro	121.9	4.1%
	WtE	20.4	0.7%
	Onshore Wind	0.0	0.0%
	Solar PV	23.8	0.8%
Sub Total (Renewable)		**675.9**	**22.9%**
Non-renewables	Fuel Oil	1096.5	37.1%
	Coal	1183.8	40.0%
Total Electricity Exported to CEB Grid		**2956.2**	**100%**

Table 64: Electricity exported to the grid and self-consumed by IPP generators in 2015

Fuel Type		Units Generated (GWh)	%
IPP Exported Electricity	Bagasse (crop season)	381.0	12.9%
	Coal (non crop season)	1047.0	35.4%
Total Electricity Exported to CEB Grid		**1,428**	**48.3%**
IPP Self-consumption	Renewable—Bagasse (crop season)	128.8	4.4%
	Non-renewables—Coal (non-crop season)	136.8	4.6%
Total Electricity Generation—Self-Consumption		**265.6**	**9.0%**
Total Electricity Generation from Bagasse		**509.8**	**17.3%**
Total Electricty Generation from Coal		**1,183.8**	**40.0%**
Total Electricity Generation		**1,693.6**	**57.3%**



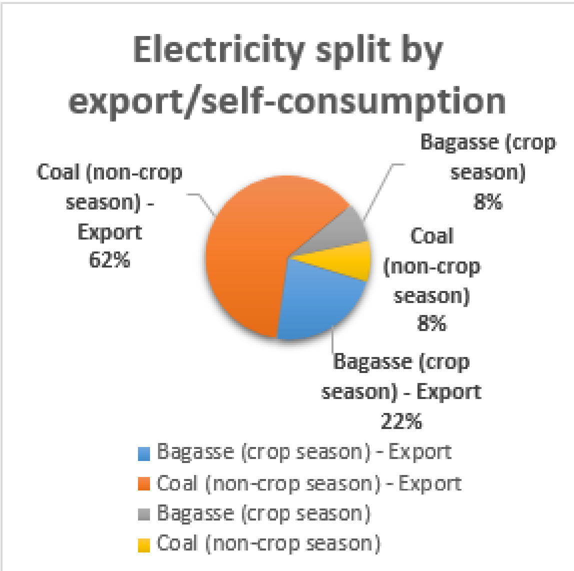


Figure 44: Electricity sources for Mauritius in 2015

5.9.4. Land Availability

Statistics Mauritius reported that a total agricultural area of 61,098 hectares was cultivated for sugarcane, tea, and food crop production in 2015 (2016), this total excludes areas used for the production of livestock, poultry and related grazing areas. A total agricultural area of 52,387 hectares was cultivated for sugarcane production in 2015, see Table 65.

Table 65: Agricultural crops: Area harvested and production, 2014 – 2015 (Statistics Mauritius 2016)

Crops	2015		2014	
	Area (Ha)	Production (tonnes)	Area (Ha)	Production (tonnes)
Sugarcane	52,387	4,009,232	50,694	4,044,422
Tea (green leaves)	574	6,732	672	7,607
Food crops	8,137	100,528	8,459	113,957
TOTAL	61,098	4,116,492	59,825	4,165,986

A total of approximately 72,000 hectares has previously been cultivated for sugarcane production, however, for many small-scale farmers, recent low sugar prices and high maintenance costs have led them to abandon sugarcane land with most the abandonments occurring over the past 10 years. The total abandoned sugarcane land over the past 20 years is around 20,000 hectares, Table 66.

The Mauritius government has added incentives in recent budgets to set up an Agricultural Land Management System via the Mauritius Cane Industry Authority to identify and then restore abandoned sugarcane land for agricultural use. The budget also includes measures to support sugarcane growers that produce up to 60 tonnes of sugar with additional revenue of Rs 1,820 per tonne of sugar with up to 80% of advanced payment for crop production provided through the Mauritius Sugar Syndicate (Republic of Mauritius 2016).

Table 66: Sugarcane land abandoned over the last 10-20 years (Maxwell Stamp PLC 2016)

Region	Sugarcane land abandoned over the last 10 years		Total Sugarcane land abandoned over the last 20 years	
	Area (Ha)	Area (%)	Area (Ha)	Area (%)
North	3,453	20	5,107	26
South	6,331	38	7,424	37
East	5,875	35	5,999	30
West	1,196	7	1,360	7
TOTAL AREA	16,855		19,890	

It would be possible to convert some of the abandoned land to the production of biomass for energy. However, this would most likely require incentives to accomplish and should target crops that can be harvested such that the feedstock is available during the non-cropping season to offset as much coal use as possible.

5.9.5. Challenges

Like all energy sources there are environmental risks associated with biopower which need to be mitigated. If these risks are ignored or poorly managed, biopower can result in biomass being harvested at unsustainable rates, the production of harmful air pollution, damage to ecosystems, consumption of large quantities of water, and the production of net global greenhouse gas emissions (Union of Concerned Scientists 2015). Table 67 lists some of the typical challenges associated with biopower projects that are likely to be encountered in Mauritius.

Table 67: Summary of likely challenges to be encountered for biopower in Mauritius

Challenges	Discussion
Climate Change	Ability of crops to withstand rainfall variability (particularly if irrigated) and other climate change impacts such as more severe cyclones. The CEB will need to plan for the occurrence of cyclones that result in the sugarcane crop being dramatically reduced and the resulting recovery period until full sugarcane production can be restored. Allowance needs to be made for the loss of electricity generation capacity during this period and for production to be dominated by coal resulting in low renewable energy production.
Land Availability	Expanding the biopower industry has obvious restrictions in terms of available land on Mauritius that is suitable for feedstock crops. There is around 20,000 hectares that have been abandoned by sugarcane farmers and this may be able to be converted to crops that can be harvested such that the feedstock is available during the non-cropping season to offset as much coal use as possible. Converting land already utilised for sugarcane, tea, or food crops would not only be controversial in terms of food security but could impact potential export income and other net benefits to the Mauritian nation. Therefore, any potential change to an energy crop but would need to carefully consider the social, economic, and environmental impact of that change in land use.
Net Greenhouse Gas Emissions	The full carbon lifecycle should be considered for the sugarcane/bagasse industry because the lifecycle carbon emissions can vary greatly depending on type of feedstock, the way in which it is developed and harvested, the scale at which it is used and the technology being used to convert the feedstock into electricity. It may be cheaper to expand other renewable energy or low carbon industries and achieve a better greenhouse gas outcome.
Sustainability	This type of land use may not be consistent with the MID goals. High fertiliser and other land maintenance issues are typically not sustainable in the long term and must be considered when determining the most sustainable use of the limited agricultural land available for crop production. The combustion of coal in dual fuelled biopower plants to produce electricity (currently 40%) is not considered a sustainable or low carbon solution to electricity generation.
Harmful Air Pollution	When using coal in dual fuelled biopower plants the pollution emitted is usually high in sulphur dioxide and other particulates. These can have harmful effects on any communities or wild life near the power plants.
Tourism, Recreation and Visual Amenity	The use of coal does not meet the sustainable island image that Mauritius is targeting and could impact on eco-tourism initiatives.
Water Consumption	Biomass crops can consume large quantities of water and thus require significant irrigation. This would mean that the biomass crops would be competing for a scare resource which is also used as potable water for the population of Mauritius.
Renewable Energy Target	For Mauritius to significantly increase its renewable energy target it will need to look at ways to reduce the amount of coal combusted (currently 40% of electricity production) and replace that capacity with renewable energy or other low carbon technologies.
Coal Imports	As mentioned, coal combusted in biopower plants typically emits high levels of sulphur dioxide and significant greenhouse gas emissions per kWh of electricity produced. Although coal prices have been subdued recently, importing coal means that a significant portion of the cost of Mauritian electricity production is tied to global energy markets.

5.9.6. Summary

Biomass production for power generation and liquid fuels has been controversial as biomass production has often been found to have a low carbon emissions reduction benefit and often displaces high value food crops. It is often assumed that biopower is a low or near zero carbon solution because the energy source is derived from biomass and is said to be sustainable and renewable. However, when assessing the potential role of biopower as a renewable energy source or low carbon solution an assessment of its full carbon lifecycle is required. This is because the lifecycle carbon emissions can vary greatly depending on type of feedstock, the way in which it is developed and harvested, the scale at which it is used and the technology being used to convert the feedstock into electricity.

If biopower is used to displace fossil fuels, or other renewable energy or low carbon technologies, then the lifecycle emissions should be compared with the solutions it is competing with (Union of Concerned Scientists 2015). For Mauritius, the implementation of biopower has resulted in the establishment of co-fired plants which has had the perverse result of creating a coal import industry which results in high emission electricity generation during part of the year. Therefore, Mauritius must reduce its reliance on coal imports if it is to become a sustainable island and meet future high renewable energy targets.

Since the sugar industry is well established on Mauritius it would be reasonable in the short to medium term to promote efficiency gains in the industry to produce as much electricity as possible from the available sugarcane feedstock. These would include:

- plant upgrades to newer and more efficient high pressure boilers;
- investigate the feasibility of switching to co-firing;
- investigate fill-in crops, such as switch-grass which could be harvested in the non-cropping season from abandoned farmland to supplement current biopower production and offset coal use;
- investigate the feasibility/sustainability of harvesting the dry leaf trash and green leaves and tops of the sugarcane plant; and
- investigating the feasibility of extended the period when plants run from biomass through storage of biomass feedstock.

A review of studies by the Union of Concerned Scientists (2015) into the economic potential to increase biopower in the US concluded that there was little to no economic potential over the next two decades. This was due to the relatively high costs of increasing biopower compared to other renewable energy and low carbon technologies. For Mauritius, with an established biopower industry, energy efficiency improvements that increase the electricity generation from biomass and reduce coal use will be very beneficial. However, replacing a valuable crop such as sugarcane with an energy only crop only can have significant economic impacts for both the farmers and country. It would need a full carbon lifecycle analysis to determine the potential social, economic, and environmental impacts.

Although some agricultural land has been abandoned during low sugar price cycles, converting that land to biomass for energy production may be possible but will require incentives and should produce fill-in crops to offset coal use.

There is limited opportunity to expand the biomass industry in Mauritius because it will need to compete with newer renewable energy and lower carbon technologies which are more cost effective. A summary of each biomass technology is provided in Table 68.

Table 68: Summary for biopower [LCOE and Capital Cost source (IRENA 2012)

Technology risk	Thermal Technologies	Anaerobic digestion
Technology risk	Low – the technology is fully commercialised	Medium – although the technology has been commercialised it is often customised to the available feedstock quality and quantity
Difficulty of implementation	Low, already 4 duel-fuelled bagasse/coal plants in operation	Medium – although the technology has been commercialised it is often customised to the available feedstock quality and quantity
Potential installed capacity implementation (MW)	Medium, bagasse plants currently generate 17.3% of Mauritius's electricity demand. Future potential for increase is low/limited to efficiency gains.	Low – limited feedstock available to run an AD plant.
Potential annual output (MWh/year)	Currently produces around 510 MWh/year. Future potential for increase is low/limited to efficiency gains.	Low – limited feedstock available to run an AD plant.
Key Benefits	Sugar production is self-sufficient in terms of energy consumed It removes the need to transport and dispose of the bagasse by-product Surplus electricity generation can be exported to the grid for additional income Electricity generation from bagasse has the potential to generate less greenhouse gas emissions than conventional fossil-fuel generation	Compost output which could be used to replace fertiliser imports Electricity generation from bagasse has the potential to generate less greenhouse gas emissions than conventional fossil-fuel generation
LCOE (US$/MWh)	Estimated to be $40-$290 per MWh – depends on the type of biopower technology, the quality of the feedstock and whether any pre-processing of the feedstock is necessary such as dewatering to reduce moisture to acceptable levels.	Estimated to be $60-$150 per MWh – depends on the plant configuration, cost of biomass input if any, the quality of the feedstock and whether any pre-processing of the feedstock is necessary such as dewatering to reduce moisture to acceptable levels.
Capital Cost based on Capacity (US$/kW)	Estimated to be $1,880-$4,260 per kW installed for stoker boiler – however cost will depend on the type of biopower technology used	Estimated to be $2,574-$6,104 per kW installed – depends on the plant configuration

6. *Emerging Renewable Energy Technology Options*

A description of the renewable energy conversion technologies under development and the nation's associated renewable energy resources that could be harnessed by these technologies is provided in this chapter. A summary list is provided of the viable technologies that could be used to harness the associated renewable energy resources, see Table 69.

Table 69: Summary of Commercialised RE Technology Options

Technology	Resource	Sub-category	Recommended for region	Technology Risk	Challenge
Solar energy	Very good	Concentrated solar thermal (CST)	× (cyclone risk)	High – cyclone risk due to the tracking nature of the technology	Land availability near population centres, grid node capacity limit and integration and cyclone risk
		Concentrated photovoltaic (CPV)	× (cyclone risk)		
Offshore Wind Energy	Very good	Shallow Water	✓	Medium – cyclone risk to be resolved	Amenity, finding potential sites, network connection and integration, water depth and cyclone risk
		Transitional Depth	✓ (long term)		
Hydropower Pumped Storage	Limited	Conventional Pumped Storage	✓(potential resource)	Low	Cost, environmental impact, available/reliable water source, and network connection and integration
		Seawater Pumped Storage	✓ (potential resource)	Medium	Cost, environmental impact particularly with the use of salt water, land availability, and network connection and integration
Geothermal	Unknown/ Lack of close to surface high temperatures	Low temperature	× (limited application, resource not understood)	Low	Best suited to heating applications therefore limited application
		Hydrothermal	×(resource not understood)	Medium	Low efficiency electricity generation so relies on low cost resource
		High temperature	× (resource not understood, high cost)	High – should reduce with commercialisation	Finding low cost resource with reduced drilling and maintenance costs
Wave energy	Good	Point absorbers Linear attenuators Terminators	✓ (medium term)	High – until fully commercialised around 2025	Environmental impact
Ocean Current	Needs further investigation	Dynamic and potential energy devices	× (resource not understood)	High – should reduce with commercialisation although likely to remain higher than offshore wind or wave energy	Environmental impact, technical issues, available resource not well understood, and distance to network connection and integration
		Tidal	× (no tidal resource)	High – should reduce with commercialisation	Environmental impact
Ocean Thermal	Borderline	Open/closed cycle and hybrid plant	× (resource not understood)	High – should reduce with commercialisation	Finding potential location with access to ocean water at 1,000 metres, commercialisation, low efficiencies, economies of scale

6.1. Concentrated Solar Energy

As previously mentioned for commercial solar energy the economic viability is determined by the solar resource at the site, the cost of energy from the grid, and the installed capital cost of the solar generator at selected site. There are two solar technologies that can be classed as emerging technologies: concentrating solar thermal (CST), and concentrating photovoltaics (CPV) technologies. Each of these technologies is summarised in Table 70. For a more detailed description of these technologies see APPENDIX B |Technology descriptions.

Table 70: Summary of the solar generators by category

Solar generator category	Description
Concentrating solar thermal (CST)	Concentrating solar thermal (CST) technologies use mirrors to reflect and concentrate sunlight onto receivers that collect solar energy and convert it to heat. The thermal energy can then be used to produce electricity via a heat engine or steam driven turbine or be stored as molten salts for later use.
Concentrating photovoltaics (CPV)	Concentrating photovoltaics (CPV) technologies work by concentrating solar radiation onto a high-efficiency semiconductor PV cell which converts the energy into electricity. These technologies make use of mirrors or lenses constructed using inexpensive materials such as glass, steel and plastics which concentrate the sunlight 2 to 1,200 times.

6.1.1. Concentrating solar PV systems

Concentrating solar PV systems can be cost competitive with electricity supplied from the grid and from stand-alone power supply systems in sites with high levels of direct normal irradiation (DNI) photovoltaic. Concentrating solar system require sites with a high DNI level typically higher than 1,800 kWh/m^2/year in order to be competitive at today's prices (Bett, Burger *et al*. 2009). Mauritius has DNI levels greater than 2,120 kWh/m^2/year, and CSPV systems could be a viable generation option on Mauritius. The biggest limiting factor to using CSPV systems on Mauritius is that these systems typically use large parabolic dish solar collectors or heliostat mirrors to focus the solar energy on a central high efficiency solar PV device and they would require re-engineering to make them suitable for installation in high wind speed areas. It may be easier to use CSPV systems at inland sites than it would at sites close to the coast.

6.1.2. Concentrating solar thermal power with storage

Concentrating solar PV systems are not yet commercially mature. Most of the technologies are designed for capacities greater than 50 MW to achieve economies of scale, which makes them unsuitable for use in small grids. Their biggest advantage is that they operate on solar thermal energy and it is a lot simpler and lower cost to store thermal energy than it is to store energy in electrochemical batteries used with solar PV systems. Large scale CST power plants with the capacity to store sufficient thermal energy storage to be able to operate 24/7 during the summer period have been built in Spain.

Several companies are developing small scale CST power plant technologies, A US based company, Solar Reserve, offers solar tower CST power plants with heliostat solar collector fields down to 10 MW and its primary target market is the mining industry. Carbon reduction Ventures, a WA based company, has partnered with Solastor, a NSW based company that has developed a graphite solar thermal energy storage system and offers modular CST power systems of approximately 200 kWe.

6.1.3. Cyclone Risk

CPV technologies can be ruled out for Mauritius as they have not been developed for deployment in areas prone to cyclonic conditions. In addition, most CST technology uses either mirrors to reflect and concentrate sunlight onto receivers or a parabolic dish concentrator that tracks the sun, both of which are not robust in high wind conditions and are currently not suitable for cyclonic areas. New technologies may be developed in this space that are more robust in high wind conditions and may be worth considering.

6.1.4. Challenges

There can be many challenges to overcome when integrating new technologies into an existing energy system. Table 71 lists some of the typical challenges associated with CSP and CSV projects that are likely to be encountered in Mauritius.

Table 71: Summary of likely challenges to be encountered by CSP and CSV projects in Mauritius

Challenges	Discussion
Ability to withstand cyclonic winds	Due to the tracking nature of CSP and CSV solar collector tracking systems, such as parabolic troughs and parabolic dishes, are not suitable for installation in areas with high wind speeds.
Ability to find suitable site	A suitable site is critical to ensuring that a solar farm meets the planned capacity factor to ensure financial viability. Most suitable sites will be located close to the townships where the electricity is consumed. This means that any potential solar farms will be competing with the local community for land.
Integration with local grid	This is highly dependent on the local electricity supplier, in this case CEB and its policies for the integration of renewable energy. If new diesel or gas plants with excess capacity have been built, then they may not want to integrate renewable energy until the capacity of the plant meets demand or there is a substantial increase in fuel costs. In addition, the solar farm would need to be located within a short distance of the grid otherwise there may be significant costs to connect. Due to the inherent variability of solar energy, managing the solar-generated electricity delivered to the grid is of concern to the grid operator. Depending on the location of the grid connection additional ancillary services may be needed to compensate for voltage variations for example. However, CST with storage overcomes many of these issues along with being able to operate at up to 24 hours per day while providing dispatchable electricity aiding grid resilience.
Tourism, recreation and visual amenity	Perceived visual impacts are a major planning issue for installing larger scale concentrating solar generation, and this is likely to be the major issue if located close to towns or in tourist areas. It is better for solar technologies to be away from the coast to avoid salt spray on panels and mirrors which would reduce efficiency.
Parks and protected areas	Mauritius is fringed by sensitive coastline, has two marine parks and several national parks. Any solar farm will need to be set back from such areas.
Solar variability and prediction	Solar can be intermittent and seasonal. This inherent variability has been a key challenge for solar power, although some grids are now seeing greater 30 to 50 % solar penetration levels without significant generation or grid stability issues. Several factors account for the high penetration of solar power, the matching of solar energy generation with high air-conditioning loads and times of peak demand. Modern solar farms can reduce output when required which also helps with variability. New requirements from the utility will require solar PV generators to integrate a solar smoothing device, which will incorporate energy storage to eliminate variability in output caused by clouds passing over a site. (See the section of connection issues) Adding storage, such as with CST with storage technology, largely overcomes the intermittency issues and can allow some facilities to operate 24/7.
Financing new solar farms	Although costs are reducing for a range of solar technologies the upfront capital cost of medium size solar farms is still considerable which will make financing a considerable exercise. Innovative financing models and perhaps collaboration with international agencies such as the World Bank may overcome some of these barriers.
Jobs	Jobs for installation and maintenance of the solar farms.

6.1.5. Summary – Concentrated Solar Energy

Although Mauritius is considered to have a good solar resource, due to the tracking nature of CSP and CSV solar collector tracking systems, such as parabolic troughs and parabolic dishes, these technologies are not suitable for installation in areas with high wind speeds and thus are not recommended for Mauritius. A summary of each concentrated solar energy technology is provided in Table 72.

Table 72: Summary for concentrated solar energy technologies

Technology risk	CST	CPV
Technology risk	High – should reduce with commercialisation	High – should reduce with commercialisation
Difficulty of implementation	High – not suitable for installation in areas with high wind speeds	High – not suitable for installation in areas with high wind speeds
Potential installed capacity implementation (MW)	High – but the constraints relate to suitable sites (non-coastal)	Medium – but the constraints relate to suitable sites (non-coastal)
Potential annual output (MWh/year)	High in northern inland sites, but availability of land may be an issue	High in northern inland sites, but availability of land may be an issue
LCOE (US$/MWh)	$200-$300/MWh	$150-$350/MWh

6.2. Offshore Wind Energy

Offshore wind energy is the construction of wind farms offshore, usually in ocean depths to approximately 30 metres, to harvest wind energy to generate electricity. Key advantages of offshore wind include higher wind speeds, less turbulence and thus a better energy contribution per installed capacity compared to onshore wind (i.e. an improved capacity factor). In addition, opposition to offshore wind is usually weaker and because of the distance away from land, the turbines can be made much larger. Currently the biggest issue is the relatively high cost of constructing offshore wind farms, however, the industry expects these costs to fall significantly over the next 5 to 10 years as companies look for ways to decrease costs. One method being used to reduce the cost of farms is to increase the size of the wind turbines being installed with manufacturers now producing turbines with a rated capacity of 6 to 8 MW specifically for offshore applications.

There are two types of offshore wind structures currently used, either fixed-bottom (i.e. where the structure is fixed to the ocean floor) or floating, as summarised in Table 73. As shown in the table there are several types of offshore wind farms, either shallow water, transitional depth or deepwater floating, which is based on the ocean depth at the wind farm location.

Table 73: Summary of the offshore wind applications and types

Offshore Wind Structure	Offshore Wind Farm Type	Approximate Ocean Depth	Description
Fixed-bottom	Shallow Water	0-30 metres	Currently the only commercially proven offshore wind turbine structure with most currently operating offshore wind farms of this type. Some of these are now being constructed in ocean depths of up to 45 metres.
	Transitional Depth	30-60 metres	Offshore wind turbine structures for this ocean depth are currently being demonstrated and should be commercially available within 5 years
Floating	Deepwater Floating	> 60 metres	Concepts for floating wind turbine structures are currently undergoing concept development and testing

6.2.1. Maximum Depth

The maximum depth at which offshore wind turbines can be installed is currently limited by the mounting structures that have been commercially proven. This means that offshore wind turbines are currently limited to a depth of approximately 30 metres although development work is currently under way to prove mounting structures to a depth of 60 metres and floating structures for areas where water depths are greater than 60 metres, see Figure 45.

The majority, 97%, of offshore wind turbines built in Europe during 2015 used monopole substructures (Andrew Ho 2016), the remaining 3% used jacket foundations. The cost of the substructure increases with depth meaning the shallower areas will always be exploited first were available. Substructures are being developed for areas close to populated centres where there is limited or no available shallow water, however, these structures for the most part are still in the demonstration and development phase. Figure 46 demonstrates that the near shore and shallow locations are being exploited first before moving further offshore.

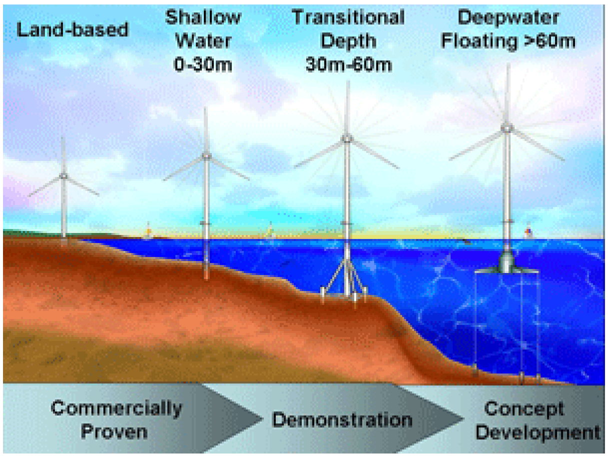


Figure 45: Wind turbine development from onshore to offshore (NREL 2014)

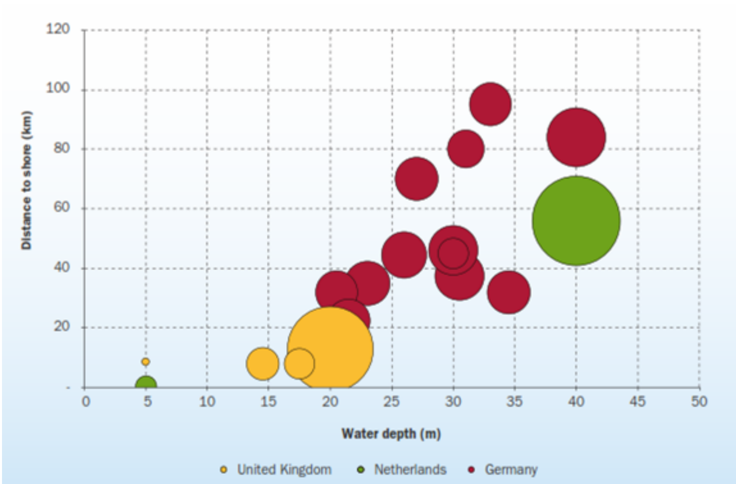


Figure 46: Water depth, distance to shore and size of offshore wind farms under construction in Europe during 2015 (Andrew Ho 2016)

6.2.2. Available Wind Resource

Trade winds dominate the weather of Mauritius. The trade winds are continuous throughout the year and blow from the subtropical high pressure zone from the south east towards Mauritius. This means that the wind has a much greater impact on the south eastern coastal areas versus the western coastal areas that are somewhat protected by the central plateau and some mountains. For more information on the available wind resource see subsection 5.2.1 Available Wind Energy Resource of section 5.2 Onshore Wind Energy.

6.2.3. Major Companies

Siemens currently dominates the offshore turbine market on measures such as total installed capacity and number of installed turbines, see Table 74, Figure 47 and Figure 48. However, other turbine manufacturers will provide stiff competition for Siemens over the next five years along with additional pressure to reduce costs across the offshore wind industry being applied from competition with large scale solar farms. Vestas currently produces the largest wind turbine for offshore use the Vestas V164, it has a rated capacity of 8.0 MW, has an overall height of 220 m, and a blade diameter of 164 m. The largest Siemens turbine in production is the SWT-7.0 154, a 7.0 MW turbine with a blade diameter of 154 m, which in combination with the smaller SWT-6.0 and SWT-4.0 are dominating orders out to 2017/18.

Table 74: List of estimated largest 9 offshore wind farms currently under construction (Wikipedia 2016)

Wind farm	Total (MW)	Country	Turbines & model	Completion
Gemini	600	Netherlands	150 x Siemens SWT- 4.0-130	2017
Gode Wind (phases 1+2)	582	Germany	97 x Siemens SWT-6.0-154	2016
Race Bank	580	United Kingdom	91 x Siemens SWT-6.0-154	2018
Dudgeon	402	United Kingdom	67 x Siemens SWT-6.0-154	2017
Veja Mate	402	Germany	67 × Siemens SWT-6.0-154	2017
Rampion	400	United Kingdom	116 x MHI Vestas V112-3.45MW	2018
Wikinger	350	Germany	70 × Adwen AD 5-135	2017
Nordsee One	332	Germany	54 × Senvion 6.2M126	2017
Sandbank (Phase 1)	288	Germany	72 × Siemens SWT-4.0-130	2017

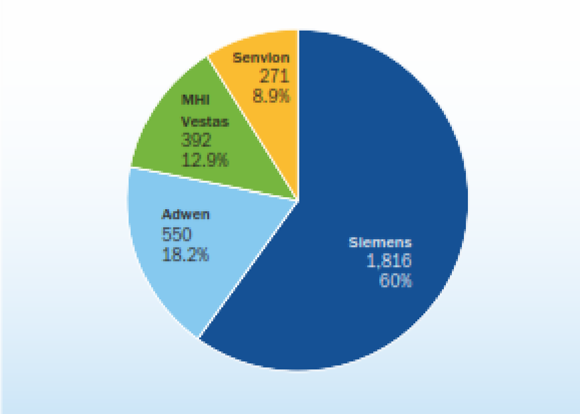


Figure 47: Offshore wind turbine Europe market share of annual installations in 2015 (Andrew Ho 2016)

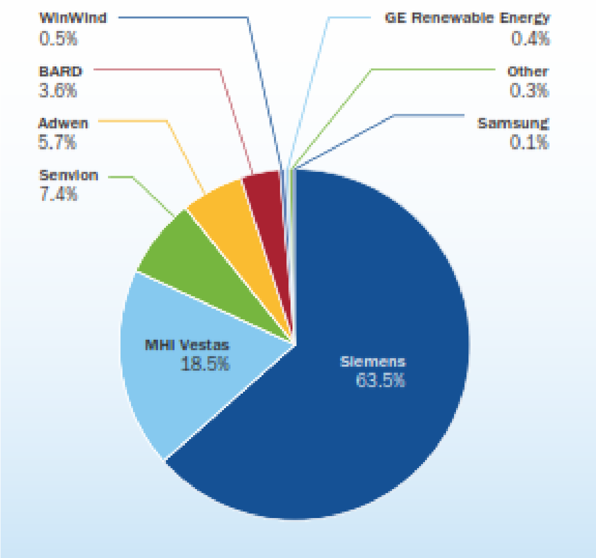


Figure 48: Offshore wind turbine European market share by cumulative capacity to 2015 (Andrew Ho 2016)

Offshore wind farm developers are led by E.ON, RWE and EnBW with 17.1%, 11.4% and 9.5% of market share respectively at the end of 2014, see Figure 49.

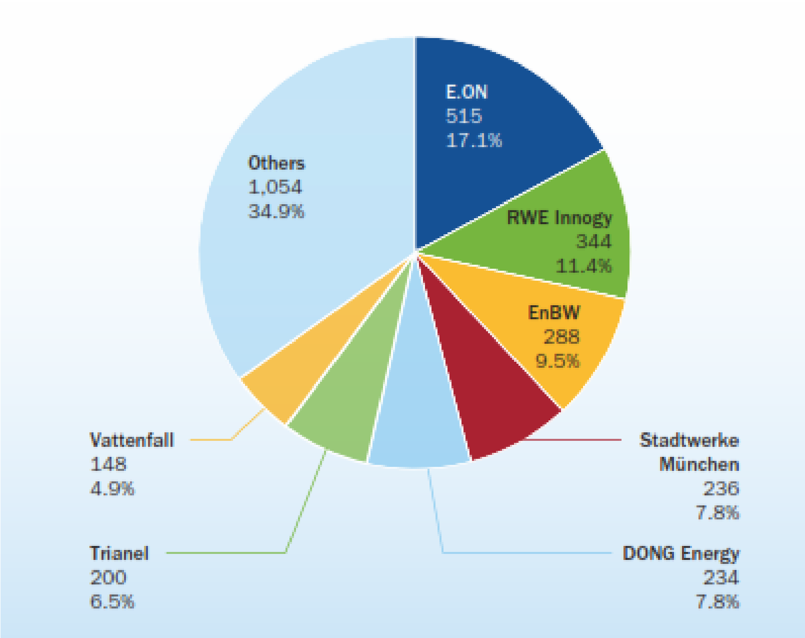


Figure 49: Offshore wind turbine developer market share at end of 2014

6.2.4. Offshore Wind Turbine Classes – Cyclone/Hurricane compliance

Mauritius is located within the tropical zone of the SW Indian Ocean and is subject to tropical storms including very intense tropical cyclones (VITC), see Figure 50 and Table 75. The last VITC to occur within proximity to Mauritius occurred in 2002 when Cyclone Dina, which passed 50 km north of the island. Cyclones of this intensity, VITC, are categorised as producing wind gusts that exceed 300 km/h. Predicted climate change impacts for Mauritius include an increase in frequency, number and intensity of storms with average wind speeds above 165 km/h or tropical cyclone strength (Mauritius Meteorological Services 2016).

Table 75: Mauritius Tropical Cyclone Rating System (See end of document for comparison of different rating systems)

Type	Characteristic
Tropical Disturbance	An area of low pressure with sparse cloud masses
Tropical Depression	A low-pressure system with gusts less than 89 km/h.
Moderate tropical storm	A tropical storm in which the estimated wind gusts range from 90 to 124 km/h.
Severe tropical storm	Estimated wind gusts range from 125 to 165 km/h.
Tropical cyclone	Estimated wind gusts range from 166 to 233 km/h.
Intense tropical cyclone	Estimated wind gusts range from 234 to 299 km/h.
Very intense tropical cyclone	Estimated wind gusts exceed 300 km/h.

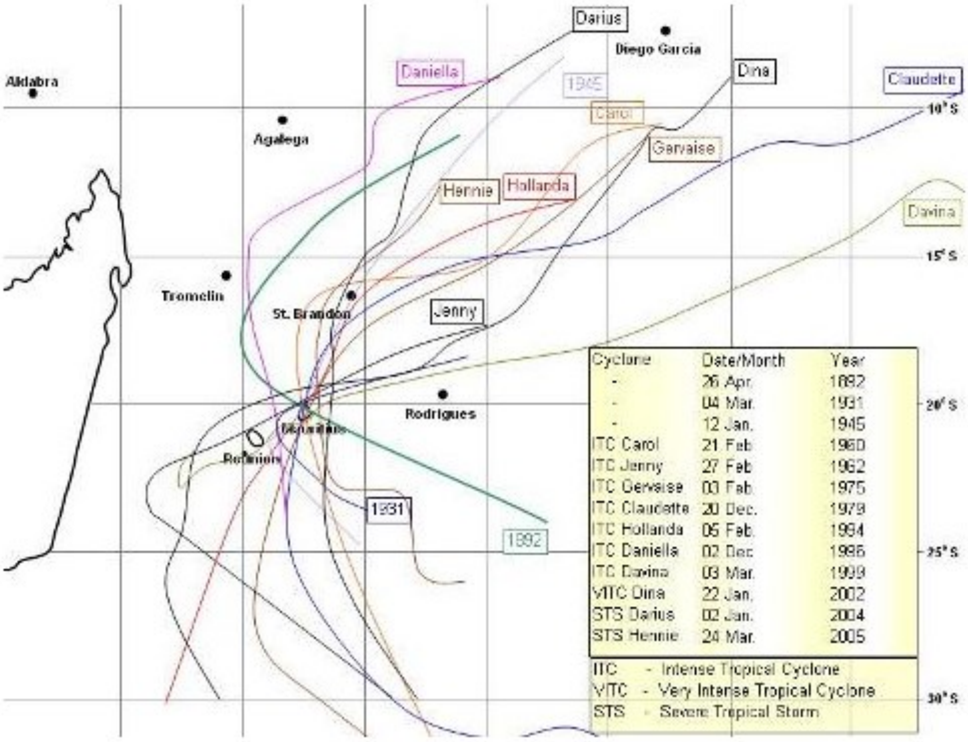


Figure 50: Track of worst cyclones to hit Mauritius (Mauritius Meteorological Services 2016, Mauritius-Holidays-Discovery.Com 2016)

Most offshore wind turbines installed worldwide do not have significant exposure to tropical storms such as cyclones. The existing IEC standards do not explicitly identify cyclones/hurricanes and other tropical events as part of their load cases. But the area surrounding Mauritius will experience tropical events annually, and therefore, facilities installed offshore must be designed for these conditions.

High winds are not new to wind turbine design, most offshore wind turbines adhere to IEC Class IA, and therefore, theoretically, most offshore wind turbines are already designed to survive tropical cyclone wind gust conditions, see Table 76. However, for offshore applications, the entire system, including the turbine, substructure and foundation, must be designed for extreme wind events as well as the influence of simultaneous wave loads and, particularly in tropical locations, the impact of much more intense storms must also be considered. The VITC that passed within 50 km of Mauritius in 2002 produced powerful storm conditions with peak gusts that exceed the basic 251 km/h criteria for an IEC Class IA design and are not adequately addressed by the current IEC standards. In addition, the current method in which the 50-year extreme wind IEC design load case is based solely on a 3-second gust may oversimplify the complex nature of a sustained 12-hour plus tropical storm event.

Table 76: Wind turbine class based rating system

Wind Class/Turbulence	Annual average wind speed at hub-height (m/s)	Extreme 50-year gust in meters/second (km/h)
Ia High wind - Higher Turbulence 18%	10.0	70 (251)
Ib High wind - Lower Turbulence 16%	10.0	70 (251)
IIa Medium wind - Higher Turbulence 18%	8.5	59.5 (214)
IIb Medium wind - Lower Turbulence 16%	8.5	59.5 (214)
IIIa Low wind - Higher Turbulence 18%	7.5	52.5 (188.3)
IIIb Low wind - Lower Turbulence 16%	7.5	52.5 (188.3)
IV	6.0	42.0 (151.3)

The American Wind Energy Association, recognising that the current specifications did not cover powerful storm conditions, including hurricanes, that may occur along the east coast of America, developed *Recommended Practices for Design, Deployment, and Operation of Offshore Wind Turbines in the United States*, which recognizes that hurricanes will present unique challenges for the United States and provides guidance on how to address their impacts on turbine design.

There appears to be no reason that the design challenges associated with designing a wind farm for an area subject to powerful tropical storms cannot be overcome, however, this presents additional risk both to the wind farm developer and insurance companies. Therefore, it is likely that this will add additional costs both to the design and possibly installation of the wind farm as well as increase operational costs due to potentially higher insurance costs.

6.2.5. Offshore wind costs

The capital and maintenance costs associated with offshore wind farms are, at present, roughly double that of onshore wind farms. However, as the offshore market expands and further cost reduction strategies are enacted, it's hoped these costs will decline to around US$100-$120/MWh by 2030, see Figure 47. Offshore wind energy costs (LCOE) ranged from US$164 to US$185 for 2015, see Table 77. There are several key areas where cost reductions are thought to have a significant impact over the next 10 years, these include (EY 2015):

- The introduction of higher capacity turbines with better energy capture and reliability with lower operating costs, leading to as much as a 9% reduction in costs. Responding to this, the industry has started rolling out larger 6-8 MW turbines
- A steady project pipeline allowing continuous production of support structures would cut up to 7%
- Greater competition between industrial actors in several key supply chain areas, would lower costs by as much as 7%
- Greater supply chain optimization and logistical integration could potentially achieve a 3% savings

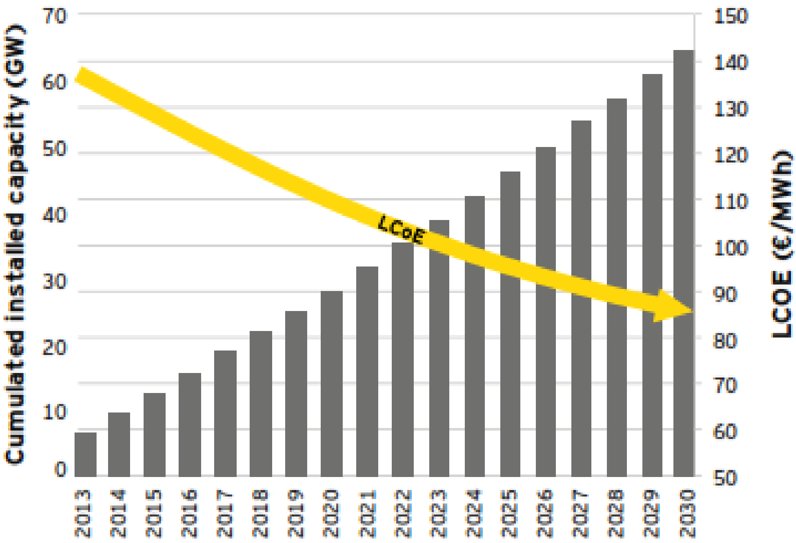


Figure 51: Predicted evolution of the LCOE for offshore wind energy according to the cumulated capacity installed (EY 2015)

Table 77: Table of Historical and projected LCOE figures (US$) for offshore wind energy

Source	2010	2011	2012	2013	2014	2015	2020	2025	2030
NREL (NREL 2015)	$232	$232	$225	$215	$193				
Offshore Wind UK (Deutsche Bank Group 2011)	£169 $225					£139 $185	£107 $143	£98 $131	£91 $121
IEA (EIA 2015)							$197		
Clean Energy Pipeline (PD Ports 2014)						£123 $164	£111 $148		
EY (EY 2015)							€110 $122	€95 $105	€90 $100
Expert Survey -Fixed-bottom (Wiser 2016)					$165		$145-160		$100-150

The National Renewable Energy Laboratory (NREL) in the United States carried out a sensitivity study on the key parameters affecting the LCOE for offshore wind, see Figure 52. The biggest impact on the LCOE will be the reduction in capital cost while other parameters such as capacity factor, which is very site specific, will mean careful site selection will help to keep the LCOE as low as possible.

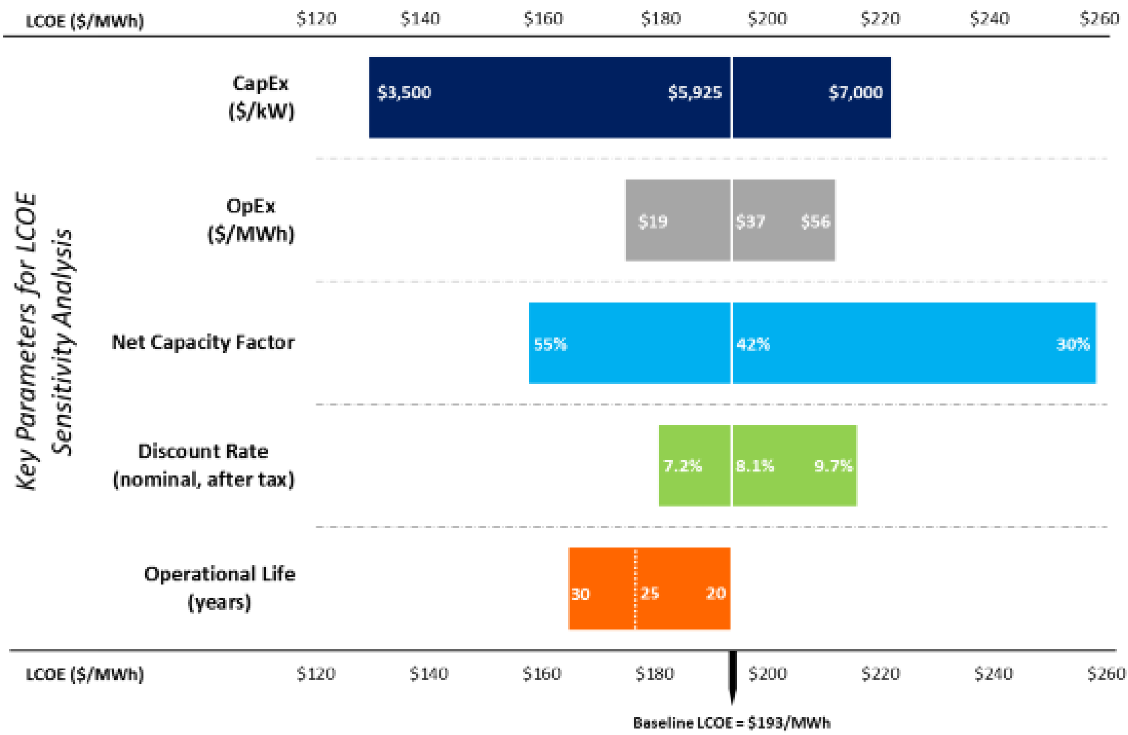


Figure 52: Sensitivity of offshore wind LCOE to key input parameters (NREL 2015)

A recent global elicitation survey of 163 leading wind experts was conducted by the Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory, in collaboration with IEA Wind and its member countries to better understand future wind energy costs and possible technological advancements (Wiser 2016). The survey results indicate that continuing technological advancements are expected to reduce the cost of both onshore and offshore wind energy into the foreseeable future.

The survey covered onshore, fixed-bottom offshore, and floating offshore wind applications. A summary of the key findings is presented in Figure 53 for each wind application. While fixed-bottom offshore is expected to remain less expensive than floating offshore, the survey revealed that experts anticipate medium cost reduction estimates of 25% for floating and 30% for fixed-bottom wind applications by 2030.

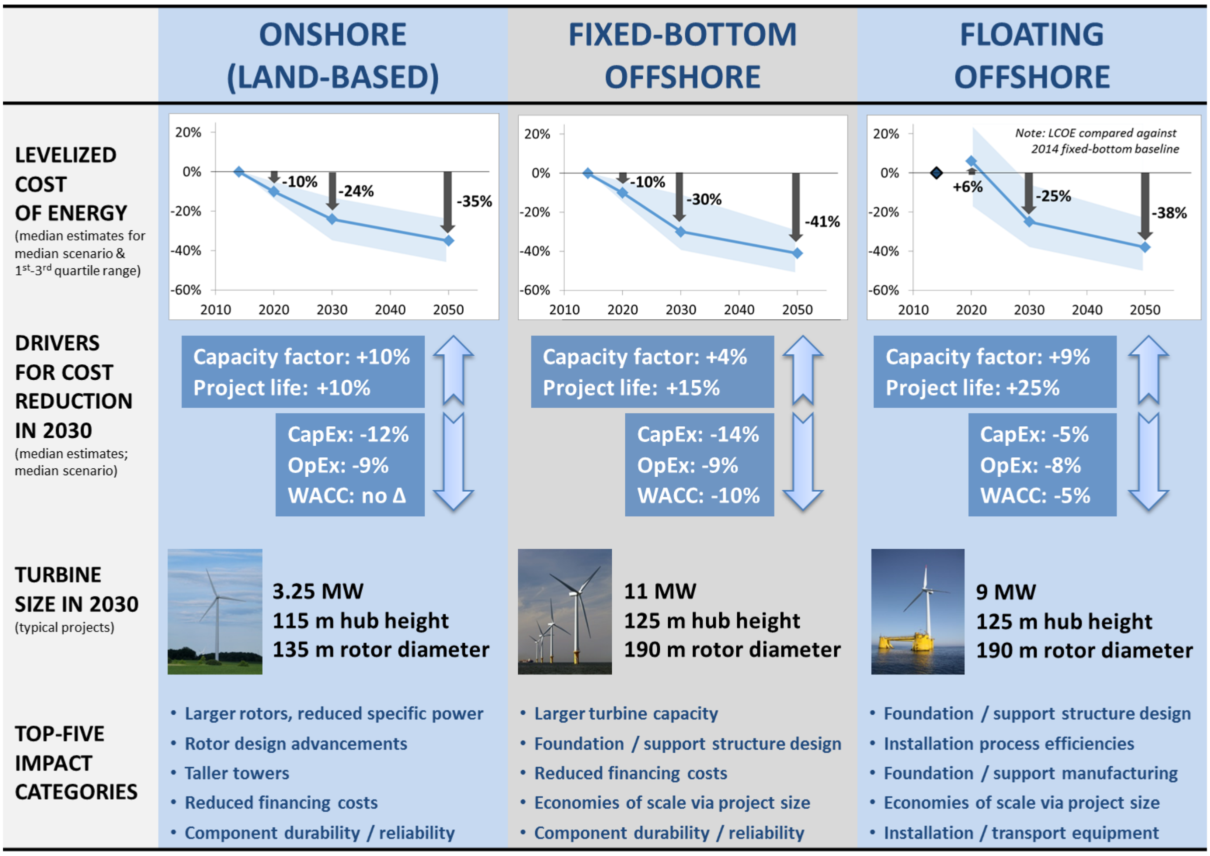


Figure 53: Summary of Expert Survey Findings (Wiser 2016)

The survey results show that there are larger absolute reductions and greater uncertainty in the LCOE for offshore wind applications as compared to onshore wind, see Figure 54.

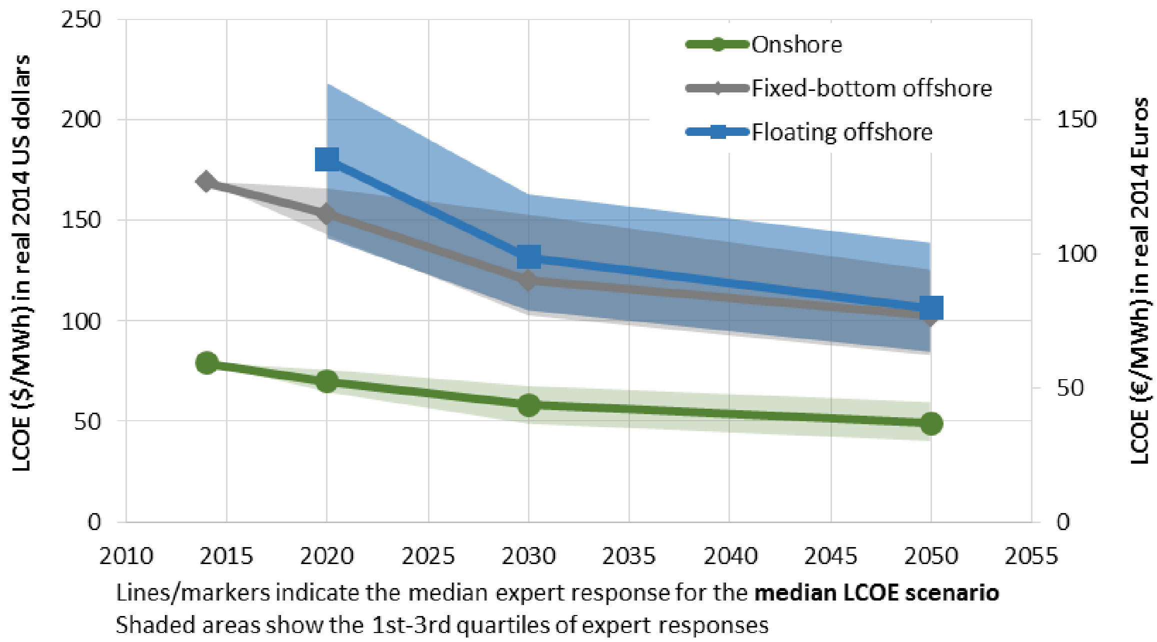


Figure 54: Expert estimates of medium-scenario LCOE for all three wind applications (Wiser 2016)

6.2.6. Offshore site availability in Mauritius

As the cost of substructure for fixed-bottom offshore wind turbines increases with depth, shallow areas will prove most cost effective. Mauritius being of volcanic origin means the ocean floor drops off relatively quickly from the shoreline. This means there are limited sites for the installation of fixed-bottom offshore wind were amenity will not be an issue due to the closeness to the shoreline. As the winds are dominated by trade winds from the south east of the island, locations along the south and east of the island will be the most favourable for offshore wind energy, see Figure 55.

Figure 55: Map of Mauritius – Lightest shade of blue indicates ocean depth to 100 metres (Ezilon.com 2015)

The Mauritius Research Council and The Embassy of the United States of America organised a half-day workshop on offshore wind energy on the 26th October 2016. The speaker at the event was Gautier de Martene from General Electric (GE) and who oversees the strategic marketing for the company's offshore wind activities.

During the presentation, de Martene named potential sites for offshore wind, including both Flic en Flac and Mahebourg at Mauritius and the island of Rodrigues. He noted that Mauritius has several challenges that need to be considered when developing offshore wind including natural phenomenon such as cyclones and tsunamis and the environment of the local coral reefs. De Martene noted that the island has a very good offshore wind resource with wind around the island being above average for offshore wind farms (54).

In an offshore wind resource assessment carried out by the National Renewable Energy Laboratory (NREL 2012), the wind resource potential for global locations was presented including Mauritius, see Table 78. The assessment indicated that there was the potential for 8.84 GW of shallow offshore wind energy all with an annual average capacity factor greater than 45%. Considering that the total installed electricity generation on Mauritius is currently around 1 GW, there would be no need to consider going to a greater ocean depth with the associated increase in cost unless amenity becomes an issue.

Table 78: Global wind potential supply curves for Mauritius by class (binned by annual average capacity factor) and depth (Quantities in GW) (NREL 2012)

	Shallow (0-30m)					Transitional (30-60m)					Deep (60-1000m)					Total
Country	34%-38%	38%-42%	42%-46%	>46%	Total	34%-38%	38%-42%	42%-46%	>46%	Total	34%-38%	38%-42%	42%-46%	>46%	Total	(GW)
Mauritius	0	0	0	8.84	8.84	0	0	0	48.46	48.46	0	0	0.14	236.26	236.4	293.7

6.2.7. Benefits of Offshore Wind

Offshore wind has several significant benefits including:

- Offshore wind farms can utilise higher and less-variable wind speeds than onshore farms;
    - For example, the capacity factor estimated for Mauritius offshore wind is greater than 45%.
- There is often more suitable (and available) space to build wind farms in offshore waters than there is on land. For example, Europe is densely populated and so the amount of land available for onshore wind farms is limited;
    - The assessed potential shallow offshore wind farm opportunity for Mauritius is in the order of 8 to 9 GW, enough to supply the entire island nation with electricity.
- Offshore wind turbines are far less visible than onshore turbines, which matters to a small minority of people;
- The wind resource offshore is generally much greater, thus generating more energy from fewer turbines;
- Most of the world’s largest cities are located near a coastline. Offshore wind is suitable for large scale development near the major demand centres, avoiding the need for long transmission lines; and
- Building wind farms offshore makes sense in very densely populated coastal regions with high property values, because high property values make onshore development expensive and sometimes leads to public opposition.

6.2.8. Challenges

There can be many challenges to overcome when integrating new technologies into an existing energy system. Table 79 lists some of the typical challenges associated with offshore wind projects that are likely to be encountered in Mauritius.

Table 79: Summary of likely challenges to be encountered by offshore wind projects in Mauritius

Challenges	Discussion
Additional design risks versus onshore wind energy	Offshore wind energy has a number of additional design risks that must be considered, including but not limited to: • Air and water temperature and gradients; • Tidal, storm surge, and extreme waves; • Ocean currents; • Atmospheric humidity, pressure, and density; • Icing characteristics; • Marine growth; • Hail and lightning frequency and severity; • Soil and seismic conditions; and • Wind speeds (very high wind speeds in areas subject to cyclones, typhoons, tornados or hurricanes); • In addition, there can be other concerns or bottlenecks for the timely development of off-shore wind energy, these include the availability of (Navigant Consulting 2011): • Forgings for systems greater than 3 MW; • Offshore electricity cables; and • Offshore wind installation vessels.
Ability to find suitable site	A suitable site is critical to ensuring the financial viability of an offshore wind farm. Most suitable sites will be located close to shore to reduce wind turbine structure costs and close to the town-ships where the electricity is consumed and/or close to grid connection points.
Integration with local grid	This is highly dependent on the local electricity supplier, in this case CEB and their policies for the integration of renewable energy. If new diesel or gas plants with excess capacity have been built, then they may not want to integrate renewable energy until the capacity of the plant meets demand or there is a substantial increase in fuel costs. In addition, the offshore wind farm would need to be located within a short distance of the grid otherwise there may be significant costs to connect. Due to the inherent variability of wind, managing the wind-generated electricity delivered to the grid is of concern to the grid operator. Depending on the location of the grid connection additional ancillary services may be needed to compensate for voltage variations for example. However, some wind turbines now have the capacity to reduce this impact on the grid and can add resili-ence to a network by providing a source of reactive power. Modern wind turbines are electroni-cally controlled and can be integrated with power electronics to control the amount of reactive power delivered to the grid.
Suitable wind resource	As mentioned the wind resources are very good around the south and east of the island due to the trade winds from the south east which are very predictable.
Tourism, recreation and visual amenity	Perceived visual impacts are a major planning issue for installing wind turbines, and this is likely to be the major issue if located close to towns or in tourist areas. Erecting an offshore wind farm in shallow water near the foreshore may meet with community/business opposition as the wind turbines will intrude on the ocean views.
Parks and protected areas	Mauritius is fringed by sensitive coastline, has two marine parks and several national parks. Any offshore wind farm will need to be located with consideration for such areas.
Wind variability and prediction	Wind can be intermittent and seasonal. This inherent variability has been a key challenge for wind power, although some grids are now seeing greater 30 to 50% wind penetration levels with-out significant generation or grid stability issues. Several factors account for the high penetration of wind power, the ability to accurately forecast wind conditions a day in advance as is done in in Australian by the National Electricity Market operator in combination with load forecasts. Modern wind turbines have the ability to reduce output when required which also helps with wind variabil-ity.
Financing new wind farms	Although increasing size is making wind energy more competitive, offshore wind farms have sig-nificant up front capital costs.
Jobs	Being the first region to install a significant number of turbines in an area that is affected by cy-clones could become a source for skilled workers when/if other areas decide to install similar turbines. Jobs for the installation and maintenance of the turbines and potentially constructing the turbine towers and fixed-bottom structures for shallow mounted turbines.
Wildlife impacts	The impact of wind turbines on birds is a major issue, particularly in locations within bird migra-tion paths. The potential impacts of offshore wind farms on birds would need to be assessed for each location.
Noise impacts and shadow flicker	Typically, not an issue for offshore wind farms.

6.2.9. Summary – Offshore Wind Energy

The biggest impediment to offshore wind energy for Mauritius appears to be cost, cyclone risk and amenity considerations for shallow offshore wind applications. In terms of potential offshore wind generation supply for Mauritius, and if looking at both shallow and transitional ocean depths for turbine installation, the total generation potential is an order of magnitude greater than the current electricity demand of the entire island nation.

Experts indicate that the cost of offshore wind energy is set to decrease by up to 30% for fixed-bottom applications with a LCOE that could be in the range US$120 to $150/MWh by 2020. During September 2016, Vattenfall, a Swedish state owned electricity provider, won a tender to build two offshore wind farms with a record low bid of just over €60 (US$67) per MWh, some 20% lower than the previous recoded set in July by Denmark's Dong Energy of €72.70 per MWh (Gosden 2016). The low bid was supported by the location of the wind farms which are situated near the shore, leading to lower foundation and transportation costs. In addition, these costs do not include grid connection which can add up to €30 per MWh. If given final approval the wind farms, with a total expected capacity of 350 MW, are scheduled to begin producing electricity for the grid in 2020.

Although offshore wind driven by trade winds is not as intermittent as say, solar PV, there will still likely be periods of fluctuating output which will need to be supported by a more sophisticated grid management systems incorporating wind prediction. Given that it is unlikely that offshore wind will be required before 2025-2030 there is significant time to plan for the required grid management system modification which may also require strengthening of the network to support large scale generation from the south or south eastern areas of the island. There is plenty of time to plan for and carry out the required network studies in advance. A summary of each offshore wind technology is provided in Table 80.

Table 80: Summary for Offshore Wind

6.3. Hydropower Pumped Storage

Technology risk	Shallow Water Wind Farm	Transitional Wind Farm
Technology risk	Medium – cyclone risk still an issue	High – should reduce with commercialisation
Difficulty of implementation	Moderate	Moderate
Potential installed capacity implementation (MW)	High – estimated capacity of greater than 8,000 MW	High – but the constraints relate to suitable sites (non-coastal), estimated at greater than 45,000 MW
Potential annual output (MWh/year)	High – with capacity factor greater than 45%	High – with capacity factor greater than 45%
Key Benefits	Capacity to supply the entire islands energy needs Utilise higher and less-variable wind speeds than onshore farms	
LCOE (US$/kWh)	$0.10 to $0.15 by 2025-30 $0.08 to $0.13 by 2035-50	Slightly higher cost versus Shallow once commercialised
Capital Cost based on Capacity (US$/kW)	$2,700-$4,500/kW – Lowest cost offshore wind technology	Slightly higher cost versus Shallow once commercialised

Pumped storage hydropower, also known as pumped hydroelectricity energy storage (PH-ES), works in a similar way to a battery in that it can store electricity generated by other power sources, including renewable energy sources, for later use. This type of facility typically consists of an arrangement of two reservoirs, although it can be more, with a lower one and an upper one at a higher elevation, see Figure 56. Energy is stored by pumping water from the lower reservoir to a higher reservoir using electricity generated during periods when electricity demand is lowest. When demand increases, the process can be reversed so that water is feed from the upper reservoir to the lower via electricity generating turbines. Pumped storage is both the largest-capacity and most mature grid energy storage option currently in use. At the end of 2012 the world had 127 GW of installed pumped storage capacity (The Economist 2012).

There are two types of pumped storage, the more conventional utilises fresh water reservoirs while the other uses seawater as the water storage medium where the ocean acts as the lower water reservoir. Figure 57 shows a conventional pumped storage facility, the Turlough Hill pumped storage facility in Ireland, which was commissioned in 1974 with a total generating capacity of 292 MW from four 73 MW turbines. The facility uses the standard system of an upper and lower reservoir and can go from standstill to full output in approximately 70 seconds (ESB 2016). The plant provides energy shifting from periods of low demand to high demand, additional supply and spinning reserve capacity for the local electricity network (DOE Global Energy Storage Database 2016).

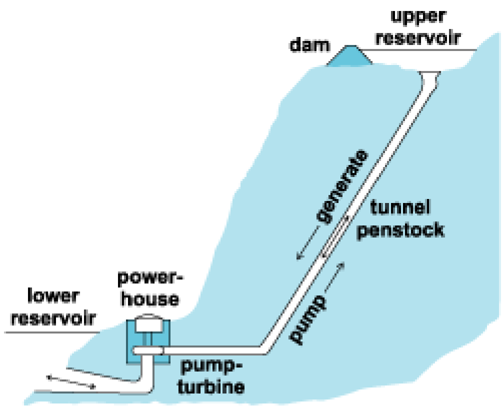


Figure 56: Pumped storage hydropower facility (Peak Hour Power LLC 2013)

Figure 57: Turlough Hill Pumped Storage Facility in Ireland (ESB 2016)

There are proposals for several unconventional pumped storage systems such as one proposed for Estonia where the ocean will act as the upper reservoir and disused underground excavation chambers as the lower reservoir (Pérez-Díaz 2014). Many of the unconventional pumped storage proposals take advantage of either natural or man-made formations such as underground chambers, potable and irrigation water networks, or open cut mine excavations and are thus very site specific.

A key advantage of the pumped storage facilities is that they can facilitate the integration of intermittent renewable energy sources such as solar PV and wind energy while also contributing to grid support services and managing peak loads. Excess energy from large scale wind and solar can be stored when demand is low and then reversed when there is a shortage of energy from these sources, this is particularly useful when baseload generators cannot respond quickly enough to the fluctuation in output from renewable energy sources. The full range of ancillary services, also known as grid-stabilising services, that hydropower storage can provide is summarised in Table 81.

Table 81: Summary of ancillary services that hydropower storage can provide (Eurelectric 2011)

Back-up and reserve	**Hydropower plants** have the ability to enter load into an electrical system from a source that is not on-line.
	Hydropower can provide this service while not consuming additional fuel, thereby ensuring minimal emissions.
Quick start capability	**Hydropower's** quick-start capability is unparalleled, taking just a few minutes – compared to 30 minutes for other turbines and hours for steam generation. This entails savings in start-up and shut-down costs of thermal plant and allows for a steadier operation, saving fuel and extending plant life.
Black start capability	**Hydropower plants** have the capability to run at a zero load. When loads increase, additional power can be loaded rapidly into the system to meet demand.
	Systems with available **hydroelectric** generation can restore service more rapidly than those solely dependent on thermal generation.
Regulation and frequency response	**Hydropower** contributes to maintaining the frequency within the given margins by continuous modulation of active power and to meet moment-to-moment fluctuations in system power requirements.
	Hydropower's fast response ability makes it especially valuable in covering steep load gradients (ramp rates) through its fast load-following.
Voltage support	**Hydropower plants** can control reactive power, thereby ensuring that power will flow from generation to load. They also contribute to maintaining voltage through injecting or absorbing reactive power by means of synchronous or static compensation.
Spinning reserve	**Hydropower** supports the dynamic behaviour of the grid operation.
	Hydropower plants can provide spinning reserve – additional power supply that can be made available to the transmission system within a few seconds in case of unexpected load changes in the grid.
	Hydropower units have a broad band of operations and normally operate at 60-80% of maximum power. This results in spinning reserve of up to 100%.

6.3.1. Seawater Pumped Storage

Using seawater allows for larger and more economical schemes without the need to use valuable and limited freshwater resources provided the coastal environment is suitable for such a facility (i.e. area located close to the ocean with a steep slope to provide adequate head for power generation). It will also dictate that all wet elements are suitable for the marine environment using marine grade steel, concrete, plastics etc. There are environment concerns that must be addressed around the containment of the seawater in the upper reservoir and impacts on the local marine environment where the seawater inlet/outlet is located.

The only sea water pumped storage system that has been built to date is the Yanbaru Okinawa facility, see Figure 58, Figure 59, Figure 60 and Table 82. With a maximum output of 30 MW, it is one of the world's smallest pumped storage facilities. Experience from the operation of the Yanbaru seawater pumped storage facility in Japan since 1999 has shown that seawater is perfectly adequate for use in such systems.

Figure 58: Yanbaru Okinawa pumped storage facility, Agency of Natural Resources and Energy Japan (Pérez -Díaz 2014)

Table 82: Technical Data (Pérez-Díaz 2014)

Okinawa Yanbaru Power Plant		Specification
Power plant	Max. Output	30 MW
	Max. Discharge	26 m³/s
	Effective head	136 m
Upper regulating pond	Type	Excavated type, Rubber sheet-lined
	Max. embarkment height	25 m
	Crest circumference	848 m
	Max. Width	251.5 m
	Total storage capacity	0.59x106 m³
	Max. depth	22.8 m
Waterway	Penstock	Inside dia. 24 m Length 314 m
	Tailrace	Inside dia. 27 m Length 205 m

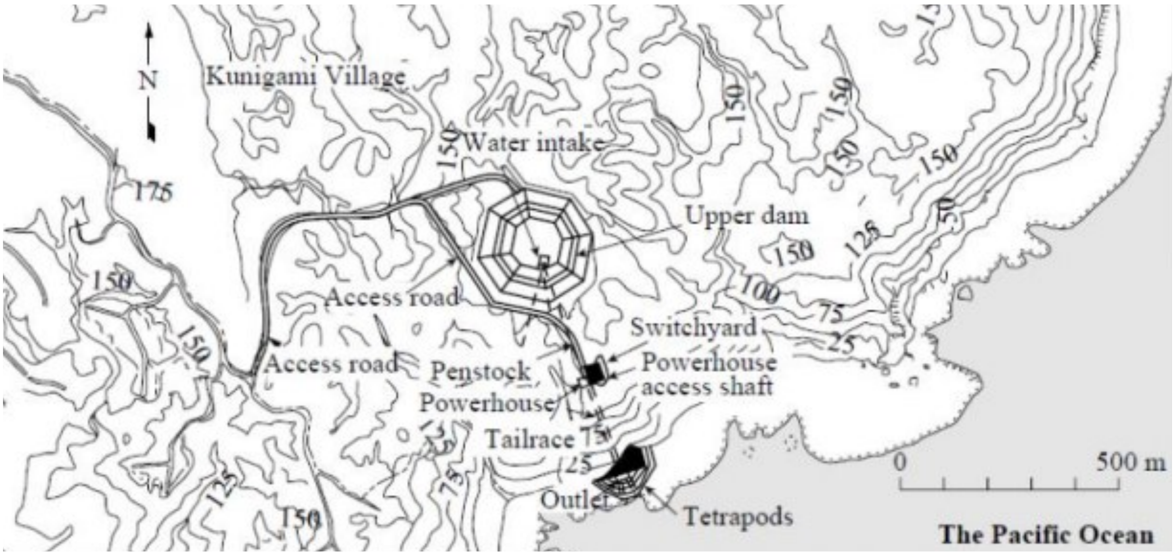


Figure 59: Plan view of the seawater pumped storage in Okinawa (Japan) (Fujihara 1998)

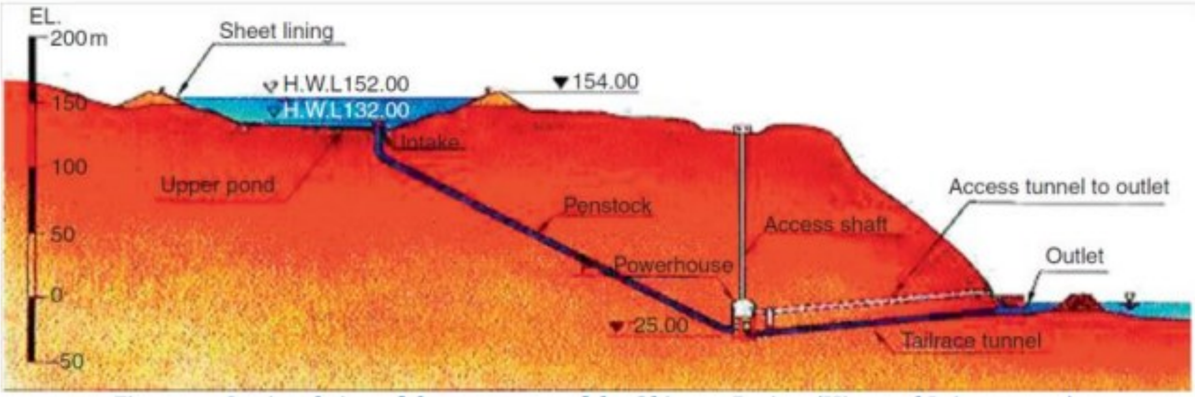


Figure *60*: Sectional view of the waterways of the Okinawa Project (Hino 2012)

This demonstration system has been in operation since 1999 and uses a “turkey-nest” type storage reservoir. The project has demonstrated the technical feasibility of a pumped storage facility using saltwater, but also that several unique technical issues had to be addressed. Those technical issues included saltwater corrosion of seals and using suitable materials, preventing permeation of saltwater into the ground at the upper reservoir, adhesion of marine organisms in the water conduits to the pump turbine, and the impacts on marine organisms near the inlet/outlet.

Mechanical equipment studies were carried out to define structural features of mechanical equipment for seawater applications and measures for preventing corrosion and adhesion of marine organisms (Fujihara 1998). The most significant impact factors were identified by a study committee as being:

- Outflow of muddy water from the construction area into the gullies and sea area near the river mouth
- Reduction of habitat area due to land changes
- Noise and vibration from heavy equipment
- Damages to small animals from construction vehicles and accidents to falling into roadside gutters.

Countermeasures were put into place to significantly reduce these factors, such as water chemical treatments, low-noise machinery, animal intrusion prevention nets, etc. (Hino 2012). Because of the positive results obtained by the Okinawa plant, other possible seawater projects, see Table 83, have been considered and feasibility studies have been proposed in the last years (Pina A. 2008, McLean 2014, Alterach 2014).

Table 83: Proposed seawater pumped storage facilities

Location	Rated Power	Description
Califor-nia	1,270 MW	HGE Energy Storage is proposing to construct a Hydrokinetic Pumped Storage project near Fort Ross, California. The Project would draw seawater and pump it up into a land-based reservoir. Seawater would then flow downhill back into the Pacific Ocean through a underground powerhouse to generate power. Seawater in the Land Reservoir would then flow downhill through the five Conduits, through five 254 MW Reversible Variable-speed Pump-turbines in the Powerhouse, and discharge through the Power-house back into the Breakwater Pool and Pacific Ocean (Cassell 2014).
Hawaii	30 MW	United Power Corp. has filed an application for a Federal Energy Regulatory Commission preliminary permit to study development of the South Maui Pumped-Storage project, which would use seawater from the Pacific Ocean to power the project on the south coast of Maui Island, Hawaii (Hydro World 2015).
Ireland	1,500 MW	A 6 GWh, 1,500 MW Glinsk Energy Storage Hub (incorporating a seawater pumped storage project) has been proposed by Organic Power, as a means of providing back up for intermittency. The sea-water pumped storage plant is providing energy storage for a 2,000 MW onshore wind farm, transform-ing this unpredictable energy source into reliable power available on demand. The project will be con-nected to the UK national grid only via a high voltage 1,500 MW DC link (Organic Power Limited 2015).
Scotland	132 to 264 GW	The largest seawater pumped hydro energy storage scheme that has been proposed to date is the proposed Strathdearn scheme in Scotland that would include a dam 300 m high and 2000 m long and would hold 4.4 G m3 of water and with an annual capacity of 6,800 GWh of energy (Scientist 2015).
Australia	1,500 MW	The idea of using a 1500 MW salt water storage in Western Australia has been developed by the Ener-gy Institute at Melbourne University. This group estimated the capital cost of pumped ocean storage in WA to be $2500/kW capacity, assuming a 10 per cent discount rate over 40 years, 7 per cent addition-al cost for operating and maintaining seawater systems and a life of 80 years. Energy cost would be about 8.6c/kWh. Given the excess wind energy stored would otherwise be wasted, it would cost only a few cents/kWh and it should be possible to supply low cost dispatchable / ‘peaking’ hydro energy at an LCOE of less than 14c/kWh (Patrick Hearps 2014).

6.3.2. Potential for Pumped Storage on Mauritius

To be cost effective, any pumped storage facility constructed on Mauritius would need to be close to the grid to avoid additional grid extension costs, within 2 km of the coast, have an elevation over 100 m, and an area over 100 ha. The areas on Mauritius that may meet these criteria are located on the south and east coast of the island, see Figure 61.

There have been proposals for converting existing hydropower systems to pumped storage on Mauritius. The CEB proposed to convert the Tamarind Falls power station to a 36 MW pumped storage system in 2003 but no project was established (Elahee 2014). A master’s degree student at the KTH Industrial Engi-neering and Management department at the University of Mauritius proposed the conversion of the Cham-pagne Power Station by adding a solar PV powered pumping system (Dhununjoy 2014).

Although there may be good technical opportunities for pumped storage on Mauritius, these schemes are usually constructed on a large scale, 30 MW or larger, to achieve economies of scale and render the pro-ject economically viable. This may be the biggest challenge to establish a pumped storage project as the capital costs are high.

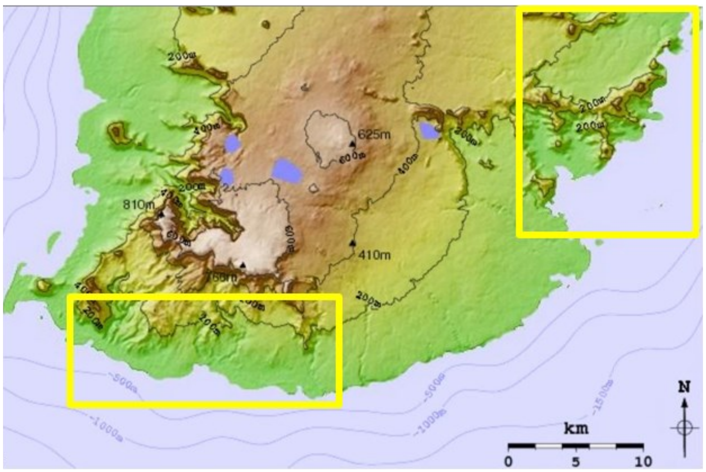


Figure 61: South Coast of IoM, areas for potential seawater pumped storage highlighted (Weather-forecast.com 2016)

6.3.3. Summary – Pumped Storage

There is significant value and possible potential for both the conversion of existing hydropower facilities to pumped storage and/or the installation of seawater pumped storage on Mauritius.

To ensure investment in pumped storage, either the CEB will need to justify the investment costs and carry out the installation or they will need to put in place incentives for the private sector to invest in grid support facilities, such as pumped storage. To facilitate the move to a higher percentage of renewable generation from intermittent sources, such as wind and large scale solar PV, it will be necessary for the CEB to establish the value to be attributed to ancillary services that storage such as pumped hydropower can supply to the local grid. Without such services available, the incentive to invest in large scale intermittent renewable energy may well be limited and vice versa. A summary of each pumped storage technology is provided in Table 84.

Table 84: Summary for Hydropower Pumped Storage

Technology risk	Conversion of Hydropower to pumped storage	Seawater pumped storage
Technology risk	Low	Low/Medium – due to the risk associated with seawater corrosion and marine life contamination of plant
Difficulty of implementation	Medium – will depend on how easy it is to convert current assets	Medium – will require a new facility
Potential installed capacity implementation (MW)	Low (~30MW) – due to the limited number of existing hydropower facilities, possibly higher for a closed loop system where the water is continually cycled between reservoirs.	Medium (~30-150 MW) – there appears to be sufficient locations available although further research is required
Potential annual output (MWh/year)	Dependant on the size of reservoirs used, but likely to be low	Dependant on the size of reservoirs used, but likely to be low
Key Benefits	Ancillary services (grid support services) such as: • Back-up and reserve; • Quick start capability; • Black start capability; • Regulation and frequency response; • Voltage support; • Spinning reserve; and • Facilitate the integration of higher percentage of large scale renewable energy sources such as wind and solar PV.	
LCOE (US$/MWh)	$25-150	
Capital Cost (US$/kW)	$1,000-4,000 (can vary greatly depending on size of storage reservoir)	

6.4. Geothermal

Geothermal energy systems utilise heat in Earth's crust to either generate electricity or to supply direct heat. Geothermal energy sources and energy conversion technologies are classified according to the nature of and the depth of the geothermal heat source. The three main types of geothermal energy resources that occur globally are (see Table 85, Figure 62, and Figure 63):

- Low temperature geothermal (ground source heat pumps)
- Hydrothermal or hot aquifer geothermal
- High temperature geothermal
  - A version of which is known as enhanced geothermal systems or hot dry rock (HDR)
  - The other type is derived from ground water in volcanic areas

Geothermal energy systems use existing heat engine technology and water pumping technology (Figure 63). For low temperature geothermal systems (aquifer or hydro geothermal), Organic Rankine Cycle (ORC) engine technology are used to convert heat in the low temperature water to electricity. ORC engine technologies are relatively mature and the technological risks are considerably lower than for EGS. The main risks are those associated with the unknowns related to the aquifer geology and hydrogeology, especially the permeability of the sedimentary aquifer layer and, therefore, water and heat flow rates. Further

Table 85: Types of geothermal resources and applications

Terminology	Source	Technology	Temperature	Applications
Low temperature geothermal	Close to surface aquifers (< 1000 m) & heat extraction from ambient rock formation	Heat pumps	> 35°C	Space heating
			> 45°C	Swimming pool heating
			> 50°C	Industrial process heating
			> 65°C	Desalination using multi-effect desalination
			> 85°C	Commercial and district heating
Hydrothermal or hot aquifer geothermal	Hot aquifers with good permeability up to 3000 m	Organic Rankine cycle (ORC) engines	80 to 250°C	Low efficiency, small-scale electricity generation
High temperature geothermal	Hot dry rock around 5000 m+ or ground water in volcanic areas	Steam turbines	> 250°C	Large scale electricity generation

information is required about temperatures at depths, as well as an understanding of the conduction, advection and convection process occurring within the sedimentary aquifer. These depend on the permeability, thickness, temperature gradients and salinity. Obtaining this data is essential to determine the viability of this technology.

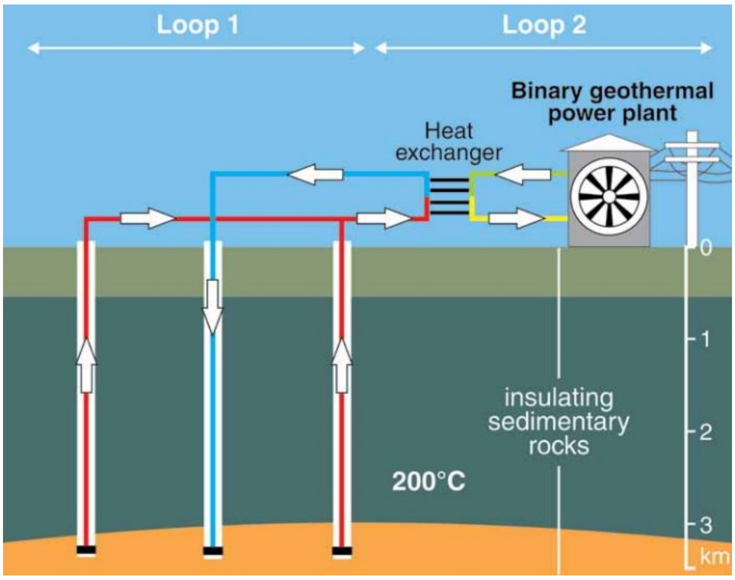


Figure 62: Example of a binary cycle power plant (AUSTRALIA 2012)

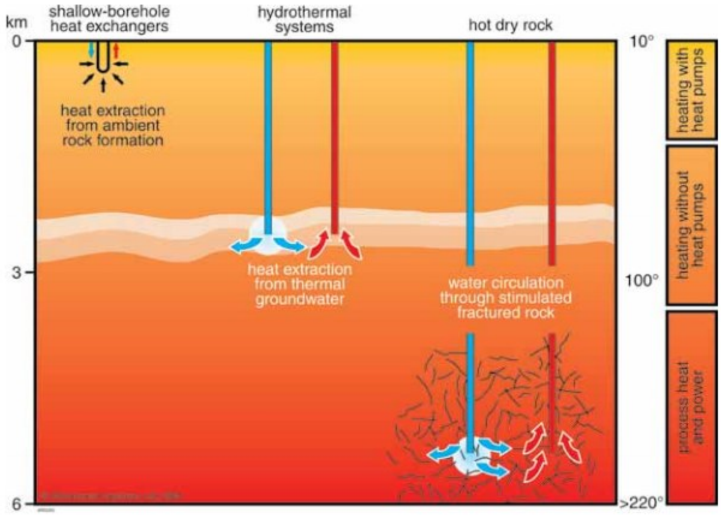


Figure 63: Types of geothermal resources from the Earth's heat (AUSTRALIA 2012).

6.4.1. Available geothermal resource

6.4.1.1 Low temperature geothermal – space/water heating/cooling applications

Ground source heat pumps are being used to heat and cool buildings throughout the world. In cooler climates with a suitable aquifer resource, heat pumps are used to provide heating and hot water for low temperature heating applications such as heating indoor swimming pools. The feasibility of using ground source heat pumps for cooling show that these systems are not cost competitive unless the cooling loads are sufficiently high and their application in Mauritius at this stage would appear to be relatively limited. In addition, where either heating or cooling is the primary load for the system, the ground source can become too cool or hot reducing the systems overall efficiency. The highest efficiencies are usually found in systems with a balanced heating and cooling load unless there is an available warm or cool source for the heat pump system such as deep ocean water cooling.

Table 86: Notional electrical power generated by a binary ORC turbine for various geothermal source temperatures and thermal power input (AUSTRALIA 2012)

GEOTHERMAL SOURCE TEMPERATURE (°C)	TYPICAL THERMAL POWER INPUT (KW)	TYPICAL ELECTRICAL POWER OUTPUT (KW)
90	120	10–12
150	2000	50–200
280	11,000	500–2000

6.4.1.2 Hydrothermal and high temperature geothermal – electricity generation

There is little information available regarding the available geothermal resource. The government of Mauritius through the Mauritius Research Council (MRC) have engaged with the private sector hoping to incentivise them to explore the geothermal potential in Mauritius. In 2012 the Mauritius government identified Bar Le Duc in the central part of Mauritius as a potential site for a geothermal power station (Bignoux 2012). Under the governments Long Term Energy Strategy, the government planned for exploration drilling of a 3,000 metre deep well to determine the local ground temperature profile and aquifer availability and produce a feasibility report on the geothermal energy potential for Mauritius. It is unclear now whether the government still intends to go forward with this program. It is likely that the costs of the exploration drilling exercise are high and without private sector support is not economically feasible.

No commercial enhanced geothermal or hot dry rock (HDR) power systems have yet been developed and the one pilot project in the Cooper Basin in central Australia owned and operated by Geodynamics has suffered several costly setbacks and since completing a $1MW_e$ trial plant began remediation of the site and shut down of the plant. The cost of electricity that could be produced from Enhanced Geothermal power plant (HDR) is not yet known accurately. Economic considerations come into play when one balances the amount of thermal energy that can be extracted from rocks of a particular temperature, the cost to gain access (i.e. drill and perhaps create fracture porosity and permeability at depths of up to 4-5 kilometres), and the mechanism to convert the thermal energy in the subsurface to usable energy at the surface (e.g. electricity, space heating, etc.). The cost to drill a relatively shallow 2,000 m well will be at least AUS$3 million, but could be higher depending on location. A 10-well development (five extraction and five injection wells to approximately 2,000 m each) will probably cost in excess of AUS$30 million, excluding the electricity generation plant and connection to an electricity-power grid. A report in 2008 has estimated the cost of electricity from HDR large scale geothermal plant in Australia to be around 12 c/kWh by 2030 (McLennan Magasanik Associates Pty Ltd (MMA) 2008). That cost, however, now looks overly optimistic when considering the project drilling costs and setbacks of the Cooper Basin project and may only be achievable in the long term beyond 2030. Furthermore, it would only be achievable for large scale projects, the costs of smaller scale projects would be significantly higher.

6.4.2 Geothermal Summary

Unless cheap geothermal reservoirs (low cost to drill and maintain a well, shallow resources) are identified in Mauritius, it is unlikely that hot aquifer or high temperature geothermal energy will play a significant role in the power energy generation mix of the country. A summary of each geothermal technology is provided in Table 87.

Table 87: Summary for geothermal energy

Technology risk	Hydrothermal or Hot aquifer	High temperature or HDR
Technology risk	Medium – the technology is not yet fully commercialised	High – should reduce with commercialisation
Difficulty of implementation	Medium – depends on shallow resource availability	High – depends on the cost to drill and maintain deep wells Medium – if shallow resource available in volcanic area
Potential installed capacity implementation (MW)	Low – Available resource is unknown	Low – Available resource is unknown
Potential annual output (MWh/year)	Dependant on the size of reservoirs used, but likely to be low	Dependant on the size of reservoirs used, but likely to be low
Key Benefits	Ability to provide electricity on a continuous (non-intermittent) basis Utilise higher and less-variable wind speeds than onshore farms	
LCOE (US$/kWh)	Unknown – likely to be very high until fully commercialised, can be site specific	
Capital Cost based on Capacity (US$/kW)	Unknown – likely to be very high until fully commercialised, can be site specific	

6.5. Wave Energy

Wave energy conversion (WEC) devices intercept wave energy before the energy is released on the shore and converts the kinetic and/or the potential energy in surface waves (swell), or the pressure fluctuations below the surface, into electricity. WECs consist of two basic elements: (i) a collector that is used to capture the wave energy, and (ii) a turbo generator that transforms the wave energy into electricity. Many WEC devices (over 1000) have been patented since the first WEC concept was patented in France in 1799 and many small-scale prototypes have been developed and tested since the 1970s. More than 200 different WEC devices are currently in various stages of development. Most of the development is centred in Australia, Europe and North America. Of these, about half a dozen have been scaled up and tested at sea and test data has been published. Five WEC devices are being developed in Australia three of which have been relatively advanced (Hayward and Osman 2011). However, the challenges confronting wave energy technology developers is highlighted by the fact that one of the companies in Australia developing a wave energy conversion device, Oceanlinx, went into receivership in April 2014 (Vorrath 2014) and Ocean Power Technologies abandoned its planned $232 million 19 MW wave power project off Portland, Victoria, in July 2014 (Parkinson 2014). This leaves Carnegie Wave Energy in Fremantle, Western Australia, as the only company in Australia who have deployed an array of grid connected Wave Energy Conversion devices and Biopower Systems Australia who currently have a device deployed off the coast of Victoria.

6.5.1. Available wave energy resource

The types of WEC devices that could potentially be deployed in the Mauritius region once commercialised, and the cost of the electricity produced, are dictated by the nature of the waters around the coast of Mauritius (wave energy resource, bathymetry and geological conditions) and the suitability of the various WEC devices for those water depths, distances from shore, etc. The wave energy resource in the region appears to be good, but these resources are only now being studied and understood with a wave energy focus.

Offshore, the wave energy resources are relatively high due to the geography of the region located toward the middle of the Indian Ocean. A preliminary assessment of the waves reaching the coast of Mauritius show the larger wave heights are located along the south-east coastline of Mauritius. The waves refract around the island from the south-east direction along the north-east and north-west coastlines where the wave height is typically smaller (Figure 64), wherein The black box in the left figure outlines the region highlighted in the right figure. The colour bar indicates the wave height in meters (Pomeroy 2016). A full assessment of the wave resource in Mauritius is currently underway and is being completed by the Oceans Institute team at the University of Western Australia (UWA). The wave resource assessment will be ready in the first quarter 2017.

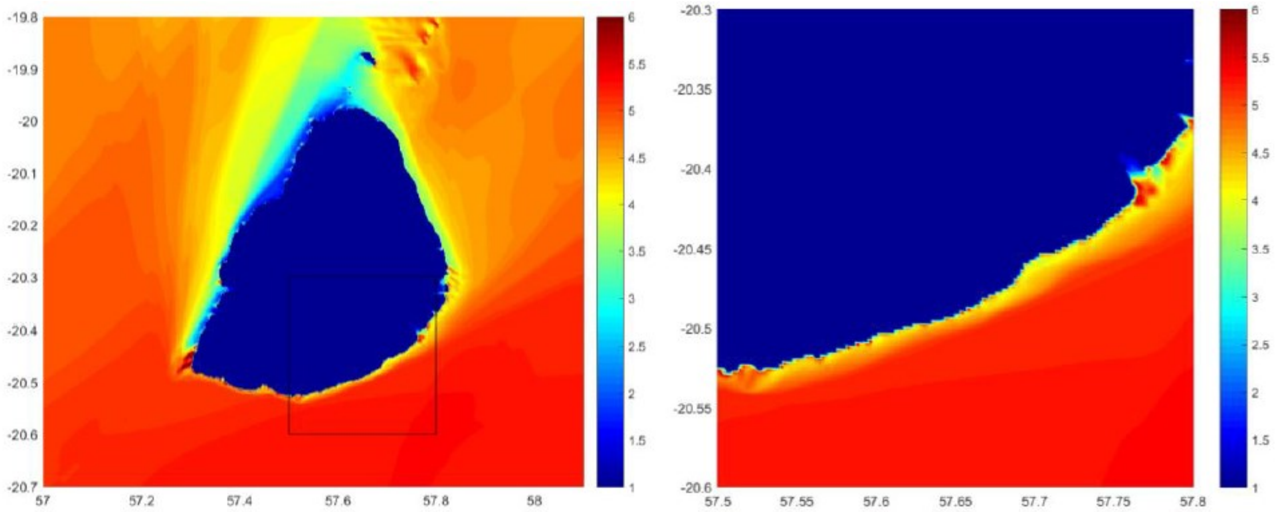


Figure 64: Mean daily significant wave height distribution for (left) the entire island of Mauritius and (right) the south-east coastline from Blue Bay to Souillac.

6.5.2. Research and development

The successful commercialisation of a wave power technology faces several challenges. The foremost is that the revenue derived from a WEC device is determined by the most commonly occurring waves, but the capital cost is driven by the engineering requirements for the device to survive the most severe wave conditions. The offshore annual mean wave power for Mauritius would be 30 to 40 kW/m (Figure 65). The WEC device would need to be designed to be able to withstand more energetic wave extremes in the area, or have a contingency plan for extreme weather. Developing and proving the survivability of a device that can be built at reasonable cost, but which has the structural strength, including the anchoring system, to withstand the constant ocean forces and can operate over long periods in the ocean environment has proved to be highly challenging for developers.

A second significant challenge is the conversion of the slow (approximately 0.1 Hz), random, and high-force oscillatory motion into useful motion to drive a generator with output quality acceptable to an electricity network operator. The problem is that the height and period of waves varies, which means that their power levels are variable. While gross average power levels can be predicted in advance, this variable input must be converted into smooth electrical output and this usually necessitates some type of energy storage system, or other means of compensation, such as an array of devices.

A third challenge stems from the fact that in offshore locations, wave direction is highly variable, and so wave devices must align themselves accordingly on compliant moorings, or be symmetrical, to capture the energy of the wave. This is not such an issue with near shore WECs as the directions of waves near the shore can be largely determined in advance owing to the natural phenomena of refraction and reflection.

A fourth challenge is that the ocean environment is a highly corrosive environment and developing WECs with reasonable maintenance costs is one of the major challenges faced by WEC developers.

The final challenge, which is an issue unique to wave power systems, is the need to obtain rights to the sea area for implementation of wave power infrastructure.

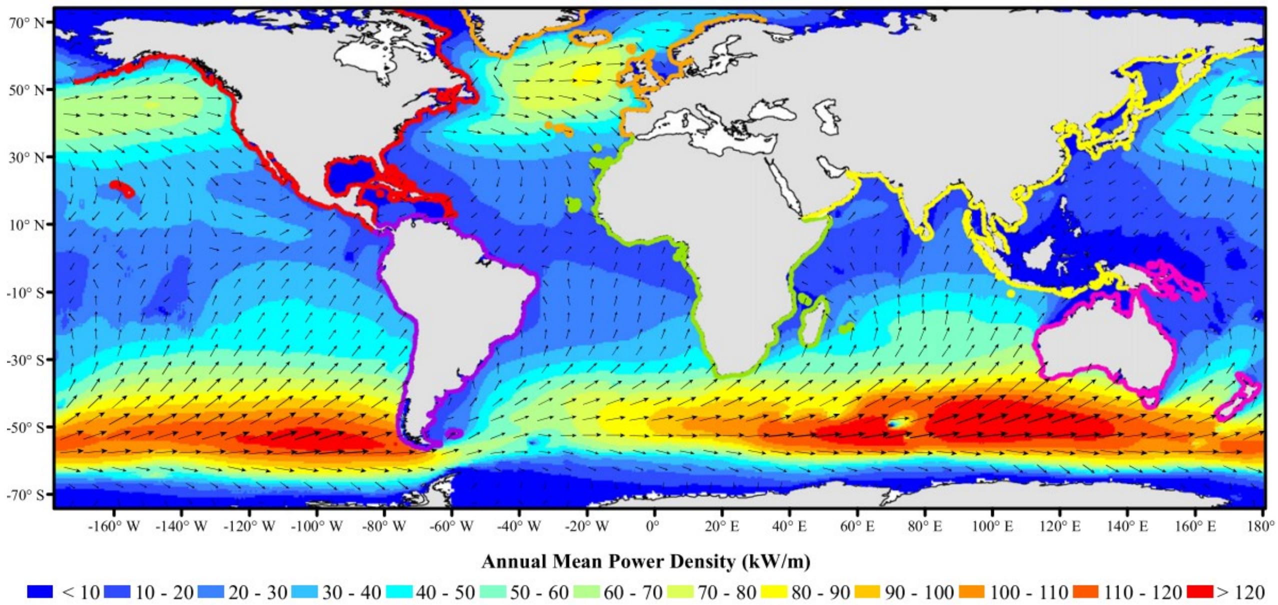


Figure 65: Annual mean wave power density (colour) and annual mean best direction. The land buffers used to quantify the resource are also shown and coloured by continent (Gunn and Stock-Williams 2012)

In terms of the 9 technology readiness levels (TRL), see Table 88, most of the WEC technologies are still in Phases 1-7.

Table 88: Technology Readiness Levels (Australian Renewable Energy Agency (ARENA) 2016)

Level	Summary
1	**Basic principles observed and reported:** Transition from scientific research to applied research. Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.
2	**Technology concept and/or application formulated:** Applied research. Theory and scientific principles are focused on a specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.
3	**Analytical and experimental critical function and/or characteristic proof of concept:** Proof of concept validation. Active research and development is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.
4	**Component/subsystem validation in laboratory environment:** Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.
5	**System/subsystem/component validation in relevant environment:** Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.
6	**System/subsystem model or prototyping demonstration in a relevant end-to-end environment**: Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.
7	**System prototyping demonstration in an operational environment:** System prototyping demonstration in operational environment. System is at or near scale of the operational system with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.
8	**Actual system completed and qualified through test and demonstration in an operational environment:** End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation (V&V) completed.
9	**Actual system proven through successful operations:** Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

Thirteen technologies have reached the pre-large scale demonstration phase (Table 90) with 10 technologies reaching a large-scale demonstration phase (Table 89). The six companies considered to be at the most advanced stages are:

1. Carnegie Wave Energy with the CETO technology (Australia).
2. Wello Oy with the Penguin technology (Finland).
3. Voith Hydro with the Limpet Wave Power Technology (Germany).
4. North West Energy innovations with the Azura Technology (Hawaii).
5. AW-Energy Oy with the Wave Roller Technology (Finland).
6. Ocean Power Technologies with the Power Buoy Technology (USA).

Table 89: WEC technologies at the large-scale demonstration phase.

Device	Country	Company	Operating principle	Location	TRL Phas	Power take-off	Prototype rating
Azura	Hawaii	North West Energy Innovations	Point absorber	Offshore	5 - 6	Hydraulic	500kW – 1MW
Limpet	Scotland	Voith Hydro	Oscillating Water Column	Onshore	7-8	Air turbine	500kW
Wave Roller	Finland	AW-Energy Oy	Point absorber	Near shore Depth 8-20m	3-4	Hydraulic	500Kw – 1 MW
Penguin	Finland	Wello Oy	Direct Conversion	Offshore	6-7	Direct Drive	300-700kW
Wave Dragon	Denmark	Wave Dragon ApS	Over topper	Offshore	3	Hydro turbine	4-11 MW
Power-bBuoy3	USA	Ocean Power Technologies	Point absorber	Offshore 20m to 1000m)	3	Hydro-electric	15kW
CETO 6	Australia	Carnegie Wave Energy Ltd	Point absorber	Offshore	5-6	Hydraulic	1 MW to 5MW with 15 MW planned
Bio Power	Australia	Bio Power Systems	Point Absorber	Near shore 30-45m	5	Hydraulic	1 x 250kW
Wave Star	Denmark	Wave Star A/S	Multi-Point absorber	Near shore	4-5	Hydro-electric	600kW
SSG	Norway	WAVEenergy	Multi-Level Water turbine	Onshore	2	Hydro-electric	200kW

Table 90: WEC technologies at the pre-large scale demonstration phase

Device	Country	Company	Operating principle	Location	Power take-off	Prototype rating
Anaconda	UK	Checkmate Sea Energy	Surface following	Offshore	Hydro Electirc	1MW
AquaBUOY	Ireland-Canada - Scotland	Finavera Renewables Inc.	Point absorber (Buoy)	Offshore	Hydro-electric	0.25 MW units, 0.75 MW
Cycloidal	USA	Atargis Energy Corp	Submerged turbine	Offshore 100m	Direct drive	0.8 MW
Wave Pio-	Belgium	FlanSea	Point absorber (Buoy)	Offshore	Hydro-electric	50kW
SDE Sea Wave	Israel	SDE Energy	Breakwater point absorber array	Nearshore - onshore	Hydro drive	250kW
SeaRaser	UK	Ecotricity	Point absorber (buoy)	Nearshore	Hydraulic – pumped to shore	0.25kW
CETO 5	Australia	Carnegie Wave Energy Ltd	Point absorber (submerged sea floor)	Offshore	Pump to shore – hydro turbine	3 x 240kW
Wave roller	Finland	AW-Energy Oy	Point absorber	Near shore Depth 8 – 20 m	Hydraulic	500kW
Sperboy	UK	Embley Energy	Oscillating Water Column	Offshore	Air turbine	50 kW
Seadog	USA	Inri	Point absorber	Offshore	Pneumatic pump to shore – hydro-electric	> 1 MW
OWEL	UK	Offshore wave energy Ltd	Floating overtopper	Nearshore	Air turbine	>1 MW
Seabased	Sweden	Seabased	Point absorber	Nearshore (< 20 m)	linear generator	10 kW to 1 MW arrays
DCEM	UK	Trident Energy	Point absorber		Linear generator	>10 MW arrays

Onshore and close inshore systems have the advantage of being close to the utility network, are easy to maintain, and as waves are attenuated as they travel through shallow water they have a reduced likelihood of being damaged in extreme conditions. But they have the disadvantages of shore mounted devices, as shallow water leads to lower wave power. For Mauritius, both onshore and nearshore (lagoon based) WEC systems are unlikely to be suitable for deployment due to both the low inshore wave resources and the impacts of these systems in terms of aesthetic values, biodiversity and sediment deposition.

6.5.3. Challenges

There can be many challenges to overcome when integrating new technologies into an existing energy system. Table 91 lists some of the typical challenges associated with wave energy projects that are likely to be encountered in Mauritius.

Table 91: Summary of likely challenges to be encountered by wave energy projects in Mauritius

Challenges	Discussion
Planning	As with all electricity generation technologies, the installation of wave power conversion devices faces competing land uses and environmental concerns that will need to be understood and alleviated. Wave energy developments have potential impacts on the many different activities that take place at the sea. The sea is usually a public space and the creation of zones for commercial uses, such as aquaculture and wave energy generation, compete with other activities, including commercial and recreational fisheries, navigation routes and safety, sand and gravel extraction, dumping, aquaculture, tourism and leisure. The installation of floating devices, submarine cables and mooring lines may pose risks to existing infrastructures. Human interference with the reefs and near shore waters affects biological productivity and the coastal sediment budget. Hence, management of the reefs and near shore waters is of fundamental importance to the maintenance of coastal biodiversity, as well as to the sustainability and well-being of the local fishing industry (Porte 2011). The environmental impact of wave energy devices and the extraction of wave energy are not well understood. For example, wave calming may have a positive or negative effect by offering protection from coastal erosion and/or changes to local current flows. The devices themselves may provide artificial reefs to the benefit of local marine creatures; on the other hand, they may under some circumstances promote the invasion of foreign species and reduce inshore sedimentation deposition. An advantage of having one of the leading wave conversion technology developers, Carnegie, based in Fremantle is that the Western Australia government has begun to look at these types of issues and a marine spatial planning process that would avoid or minimise future possible conflicts of use with other sectors and in minimising environmental impact problems, with the introduction of environmental criteria into plans and programs, although not yet in place, is more advanced than in many other locations.
Ability to find suitable site	Finding suitable onshore and close to shore sites is likely to be difficult for environmental reasons.
Integration with local grid	Grid integration should not be problematical as ocean wave systems tend to have low short term variability of output. There are frequency issues and the loads will determine what scale ocean power plant that can be built, which will impact on costs.
Tourism, recreation and visual amenity	Given the high recreational and tourism use, onshore and close to short systems may not be feasible in some areas around Mauritius. Visual amenity should not be an issue if offshore systems are used.
Parks and protected areas	Mauritius is fringed by sensitive coastline, has two marine parks and several national parks. Any wave farm will need to be located with consideration for such areas.
Wave variability and prediction	The advantage of ocean power systems is the low short term variability in output (unlike solar PV and wind). Oceanographic studies would need to be undertaken to determine the suitability of selected sites.
Financing new wave power projects	Banks are likely to be highly hesitant about financing ocean power projects until they are more proven. Grant funding is therefore likely to be required for the first systems.
Jobs	Ocean power systems have significant potential for local job creation as they require high maintenance.
Wildlife impacts	The potential impacts of fish species and other marine life will be a major issue and would need to be assessed.

6.5.4. Competitiveness

Because wave energy is so concentrated (2 to 3 kW/m^2 vertical plane at the surface) compared to solar energy densities of 0.1 to 0.3 kW/m^2 (of horizontal surface), it has been claimed that the cost of producing electricity from waves once commercialised will be around $45/MWh (Goldman 2012, Ocean Energy Council 2015). However, no wave energy conversion technologies are as yet fully commercialised and those at the demonstration stage are all supported by significant government funding. The successful commercialisation of WEC devices also faces many challenges that will increase their eventual costs. However, some WEC technology developers claim that the cost of producing electricity from WECs will be competitive with both wind turbines and conventional fossil fuels within 3 to 7 years.

The energy production cost estimates made by the IEA of around US$300 /kWh (2005 dollars) therefore appear more reliable and is an estimate that aligns well with the most reliable cost estimates for Australia are those that have been prepared by the CSIRO. The CSIRO's estimates were based on modelling Australian wave energy resources data and using cost data on actual costs published by WEC developers, which indicates that the levelised cost of electricity of different types of WEC devices installed in Australian waters ranges from $100 to $300 /MWh. It is also consistent with estimates made by the International Renewable Energy Agency (IRENA) in Europe, which estimate that the levelised cost of electricity produced from wave energy to be in the range $125 to $250 /MWh (2014 dollars) (Kempener and Neumann 2014). To achieve this, the costs of commercial WEC farms will need to be reduced to about one third of the large-scale demonstration project costs (Holmberg, et al. 2011). Data indicates that the most cost effective wave energy devices are likely to be point absorbers and terminators, and that the estimated LCOE is approximately $125 to $150 /MWh.

For a commercial operation, wave devices would need to be built in “wave farms” or collections of devices in specific areas. The areas can be quite large, for example, a 5 MW wave farm designed to extract only 10% of the incoming wave energy could occupy an area of 1 km^2.

Gaining access to these coastal waters for renewable energy development is at least as complex an issue as for land based sites. Considerations include marine protected areas, fishing, aquaculture and fisheries, shipping; tourism, recreation and visual amenity.

6.5.5. Summary

1. Wave energy conversion technologies are not yet commercialised. There are more than 200 different wave energy convertors (WEC) in various stages of development.
2. When they are commercialised, the cost of electricity may be similar to that of the cost of electricity from a wind farm
3. The nature of the seabed around Mauritius places significant constraints on the types of WEC devices that could be deployed:
    - **Onshore devices.** It is highly unlikely that onshore WEC devices could be deployed near to the National Parks or reefs. There are several reasons for this, including the limited number of suitable sites available, the impact on visual amenity, the impacts on localised marine biodiversity, and the attenuation of the wave energy by the time the waves reach the shore due to the islands, headlands and inner reefs.
    - **Nearshore.** It is possible to install WEC devices near the shore around Mauritius, but due to the visual impacts these would have to be submerged devices. This would minimise the visual impacts but other impacts would need to be assessed, including marine safety and impacts on water flows through the area to the shore.
    - **Offshore (3 to 8 km) and Far offshore (> 8 km).** The wave energy in the offshore waters is higher, making WEC devices more viable. The waters off Island of Mauritius become deep quite quickly starting less than 3 km offshore. Furthermore, the trade-off would be the longer underwater sea cables required to transport the electricity to shore. Also, the far offshore WEC devices tend to be large scale, and may produce more electricity than could be used by Mauritius where installed.

Table 92: Summary for wave energy

Technology risk	Wave Energy
Technology risk	Medium-High until fully commercialised around 2025-30
Difficulty of implementation	Moderate to High
Potential installed capacity implementation (MW)	High – Constrained potential for inshore and onshore systems. Potential for offshore systems is not constrained.
Potential annual output (MWh/year)	Unknown, but likely to be medium-high
Key Benefits	Ability to provide electricity on a more predictable (non-intermittent) basis Less of an impact on visual amenity
Capital Cost ($/kW)	Non-commercial
LCOE of point absorbers (US$/kWh)	Non-commercial – expected to be $0.30 to $0.30 by 2025-30 and $0.10 to $0.27 by 2025-30
LCOE of linear attenuators (US$/kWh)	Non-commercial
LCOE of terminators (US$/kWh)	Non-commercial

6.6. Ocean Current

The earth's oceans are constantly on the move with ocean currents carrying large amounts of water in complex patterns. The patterns are affected by wind, water salinity, temperature, topography of the ocean floor, and the earth's rotation. Ocean currents are relatively constant and flow in one direction, however, compared with wind speeds are much slower. Despite the slower speed of ocean currents, they can carry a great deal of energy due to the higher density of water (i.e. water is more than 800 times the density of air). For example, for the same surface area, water moving 19.3 kilometres per hour exerts the same amount of force as a constant 177 km/h wind. This has led to the development of technologies to extract energy from ocean currents and convert it to usable power (Bureau of Ocean Energy Management (BOEM) 2016).

Although not a focus of this section, tidal current technologies can also be grouped with ocean current as many of the technologies can be used for both ocean current and tidal energy resources. In addition, there are no available tidal energy resources at Mauritius and hence, tidal energy technology has not been considered.

6.6.1. Drivers of ocean current

There are two main drivers of ocean currents with the most common being wind and solar heating of surface waters near the equator and the other because of variations in salinity and temperature which lead to what oceanographers call thermohaline flow. When ocean water at polar latitudes is sufficiently cooled, it gets denser and sinks. This results in horizontal surface water movement as it replaces the sinking water (Gulf of Mexico Research Initiative (GoMRI) 2013). The global-scale flow pattern that results from this effect is called the oceanic conveyer belt, see Figure 66.

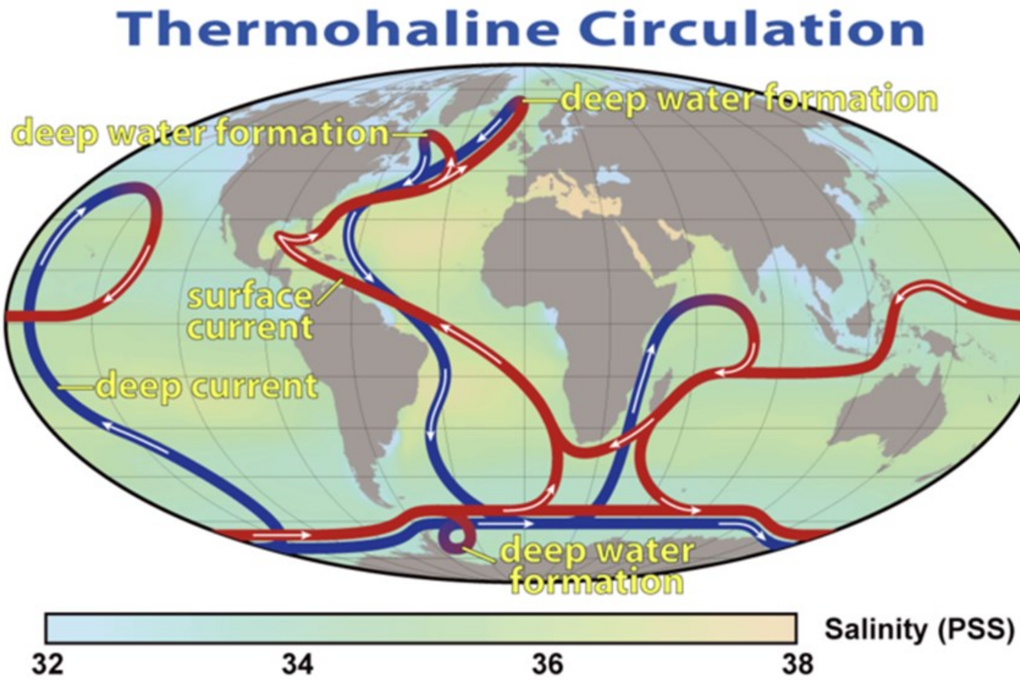


Figure 66: Oceanic conveyer belt (Rahmstorf 2002) (Source: Wikimedia

Ocean surface currents are a result of both main drivers of ocean currents, the major ocean surface currents are shown in Figure 67

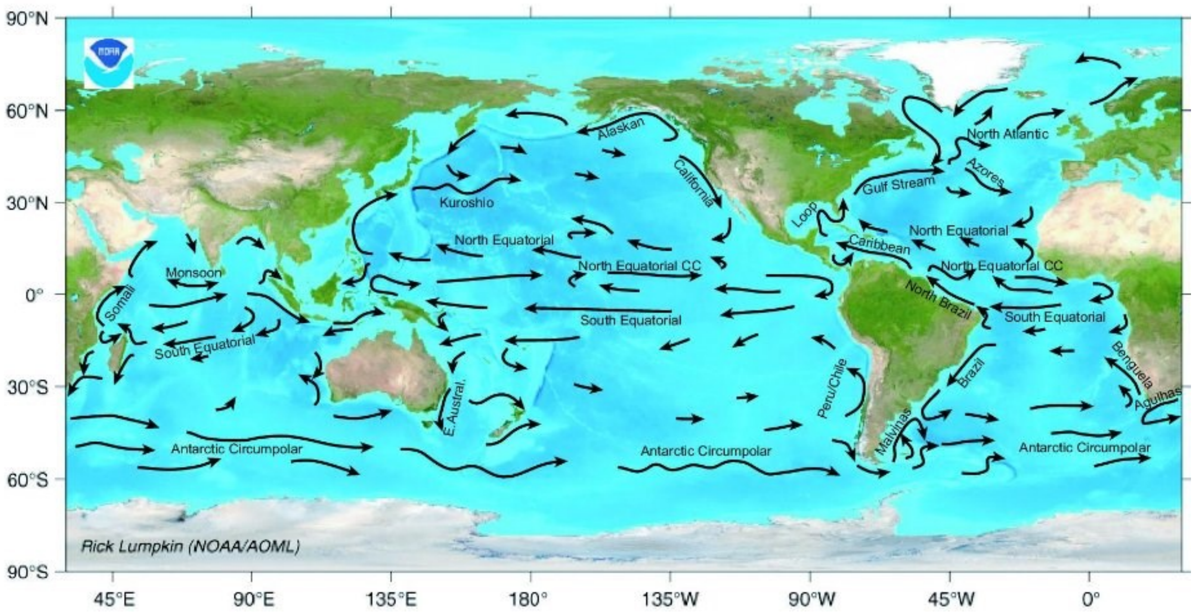


Figure 67: Major Ocean Surface Currents (Source: Wikimedia Commons, courtesy of NASA)

6.6.2. Ocean Current Technologies

Ocean current technology, also known as marine current power, is only at the concept development phase and thus is not currently in use. There are no commercial grid-connected ocean current turbines currently operating, and only a small number of prototypes and demonstration units have been tested. More advanced technologies have been developed for use with tidal currents in near-shore environments (Bureau of Ocean Energy Management (BOEM) 2016).

There are several technical factors that ocean current technology must address to become economically competitive, these include:

- Alteration of currents and waves
- Avoidance of cavitation (bubble formation)
- Prevention of marine growth build up
- High maintenance costs
- Corrosion resistance
- Generation of electromagnetic fields (EMF)
- Toxicity of paints, lubricants, and antifouling coatings
- Interference with animal movements and migrations, including entanglement and strike by rotating blades or other moving parts

There are four main types of devices being developed to convert ocean current energy:

- Horizontal Axis Turbines
  - Operates in the same fashion as a wind turbine in that it converts the kinetic energy from the moving water using a turbine that looks similar to a wind turbine.
- Ducted Horizontal Axis Turbines
  - Like the horizontal axis turbine except the turbine is housed inside a duct. This helps to concentrate the current flow through the turbine and may provide a better capacity factor.
- Vertical Axis Turbines
  - Operates is the same fashion as a vertical axis wind turbine which sits perpendicular to the ocean current flow.
- Oscillating Hydrofoils
  - Utilises an oscillating hydrofoil system to extract energy from moving water. The hydrofoil can be similar to a shark fin or wing that oscillates or flaps in the ocean current flow to capture the kinetic energy.

6.6.3. Available ocean current resource

Marine current energy is at an early stage of development. Relative to wind, wave, and tidal resources, the energy resource potential for ocean current power is the least understood, and its technology is the least mature. The deployment of technology to capture ocean current resources near Mauritius would likely occur at a much greater distance from shore than offshore wind or wave energy technologies, therefore, if commercially available, is likely to remain more expensive than near shore technologies.

Note that many of the technologies used to capture ocean tidal currents is very similar and in some cases, can be used for both applications. Some tidal energy technologies have progressed from concept development to demonstration. However, there are no tidal energy resources at Mauritius and therefore this technology has not been considered.

6.6.4. Summary

Ocean current technology is not recommended for Mauritius in the short to medium term. There are several reasons including:

- One of the least mature renewable energy technologies
- Because ocean current systems have not yet been widely deployed, cost estimates are uncertain and anticipated to be very high in the short to medium term
- One of the least well understood renewable energy resources
- Likely to remain a higher cost technology for Mauritius due to the greater distance offshore that the technology needs to be deployed than offshore wind or wave energy technologies
- Timeframe to develop the technology from concept to commercialisation and overcome technical factors that need to be addressed

6.7. Ocean Thermal

Ocean Thermal Energy Conversion (OTEC) is a process that exploits the thermal difference between the cold deep ocean and warm tropical surface seawater to produce electricity. OTEC can produce baseload electricity or electricity on demand. For the technology to be economically viable it is required that the temperature difference between the deep ocean and surface seawater be at least 20°C year-round, therefore limiting the technology primarily to the equatorial areas (OTEC Foundation 2016). The different types of OTEC technologies under development are given in Table 93. An OTEC plant can potentially be built on land, on the continental self at depths up to 100 m or as a floating facility that is operated offshore and connected to the local electricity grid via underwater cables. Land based facilities have greater advantages over the other facilities in that they don't need lengthy and costly under water electricity cables, maintenance associated with ocean environments, or require sophisticated mooring.

The world's largest grid connected OTEC plant in operation is the 100 kW Makai plant on the big island of Hawaii, see Figure 69. There are plans for a larger offshore 100 MW plant. The 100 kW plant has been developed as part of the Makai Ocean Energy Research Centre which is dedicated to demonstrating and improving technology to harness ocean thermal energy. The 100 kW demonstration plant is based on a closed cycle with ammonia as the working fluid. The system operates with a temperature differential of 20° C with an ocean surface water temperature of 25°C at the warm water intake and a deep ocean water temperature of 5°C at the cold-water intake.

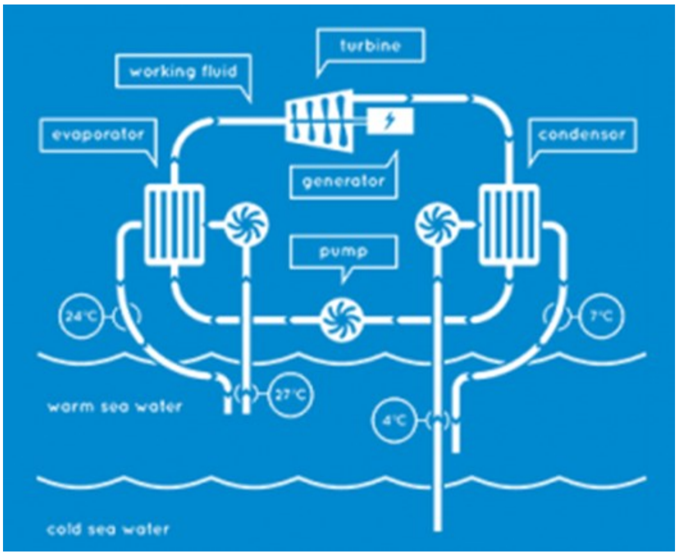


Figure 68: Open and closed cycle OTEC energy conversion process (OTEC Foundation 2016)

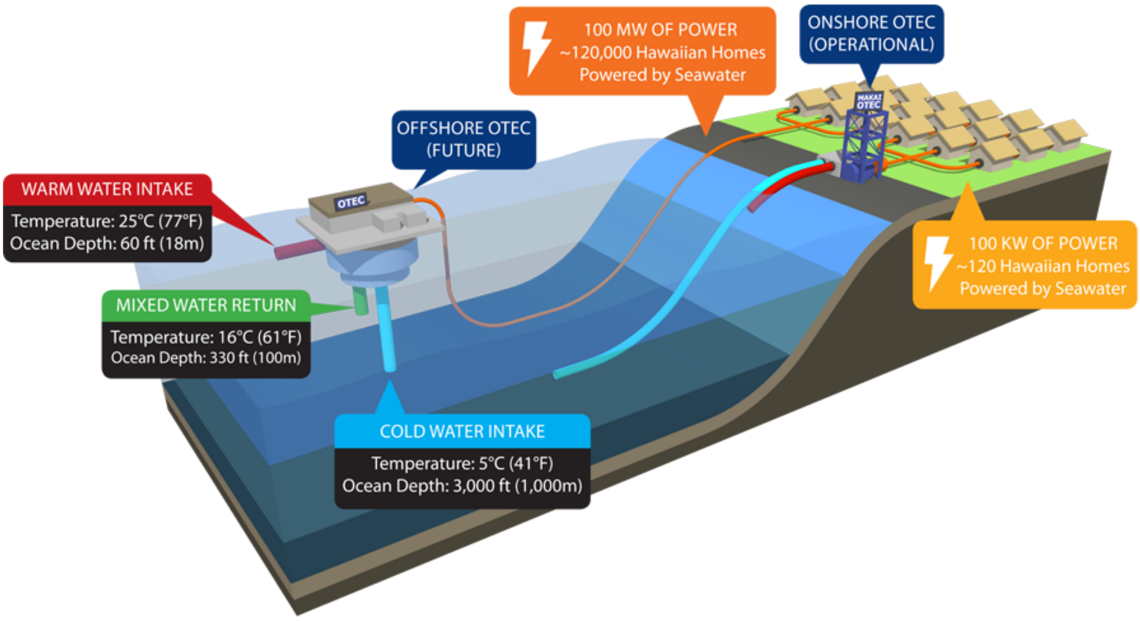


Figure 69: Overview of the operational 100 kW Makai OTEC plant and proposed offshore OTEC plant (Makai

Although further investigation of the local resource is required, the available resource maps for OTEC indicate that Mauritius has a monthly average temperature differential between ocean surface water and ocean water at a depth of 1,000 metres of between 19°C and 20°C, see Figure 70. The temperature differential is considered borderline for an economically viable application of OTEC technology.

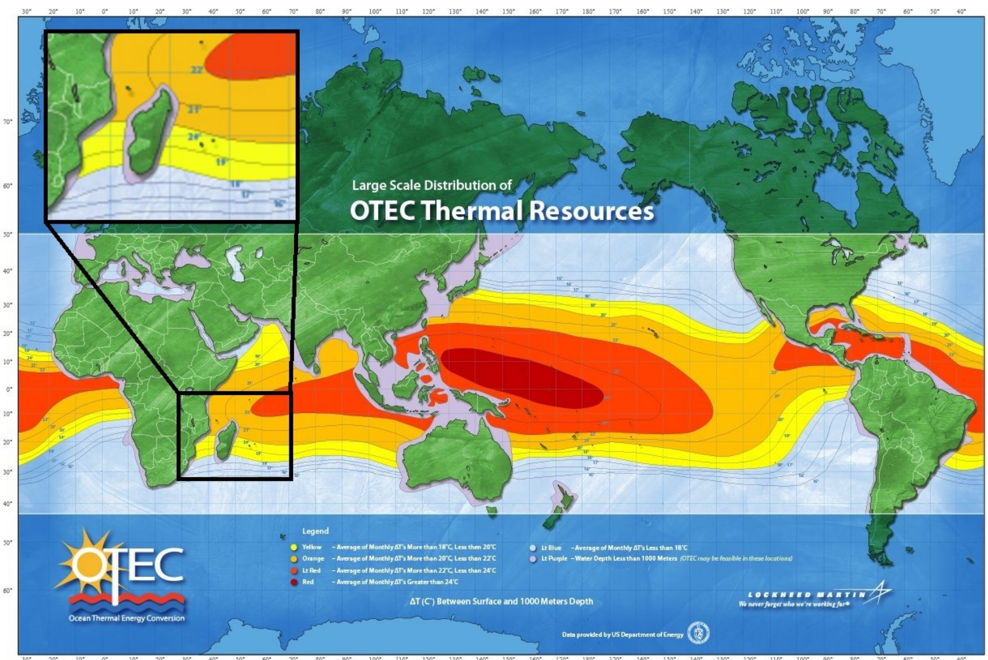


Figure 70: OTEC Resource Map (New Energy and Fuel 2013) – Image credit: Lockheed Martin composition, DOE data.

6.7.1. Complementary technologies

Both open cycle and hybrid OTEC technology can, in addition to electricity generation, supply cold water as a by-product for a range of complementary technologies such as (see Figure 71):

- Air-conditioning and refrigeration
  - Including chilled soil agriculture
- Fresh water from desalination plants

- Nutrient-rich deep ocean water can feed multi-species mariculture technologies
  - Potential for increased food security and export products

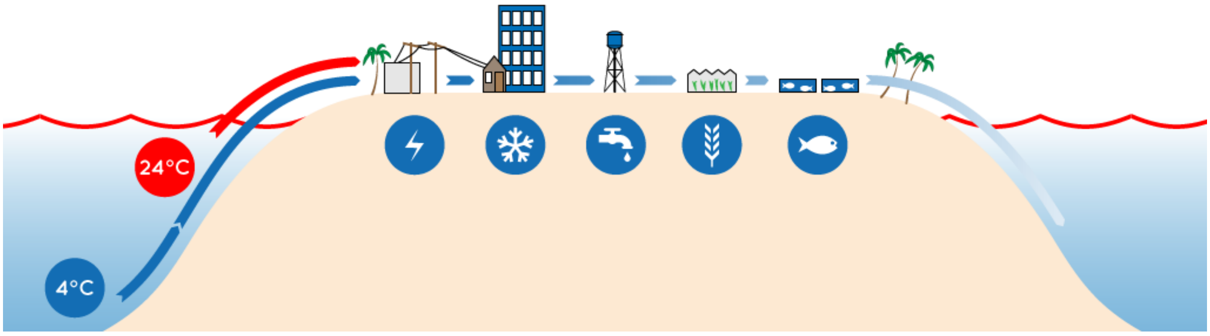


Figure 71: By-product applications of the OTEC technology

Table 93: Types of OTEC technologies in development (Ruud Kempener 2014)

Terminology	Working Fluid	Process	By-product
Open Cycle	Ocean surface water	Warm ocean surface water is introduced through a valve in a low-pressure compartment and flash evaporated. The vapour drives a generator and is condensed by the cold seawater pumped up from below (Figure 68).	The condensed water can be collected and because it is fresh water, used for various purposes
Closed Cycle	Ammonia or another refrigerant	Ocean surface water, with higher temperatures, is used to provide heat to a working fluid with a low boiling temperature, hence providing higher vapour pressure (Figure 68). Most commonly ammonia is used as a working fluid, although propylene and refrigerants have also been studied.	
Kalina Cycle	Mix of water and ammonia	The Kalina cycle is a variation of a closed cycle OTEC, where a mixture of water and ammonia is used as the working fluid. Such a mixture lacks a boiling point, but instead has a boiling point trajectory. More of the provided heat is taken into the working fluid during evaporation and therefore, more heat can be converted and efficiencies are enhanced.	
Hybrid System	Ammonia or another refrigerant for closed cycle and ocean surface water for open cycle	Hybrid systems combine both the open and closed cycles. First, electricity is generated in a closed cycle system as described above. Subsequently, the warm seawater discharges from the closed-cycled OTEC is flash evaporated similar to an open-cycle OTEC system, and cooled with the cold water discharge producing fresh water.	The condensed water can be collected and because it is fresh water, used for various purposes

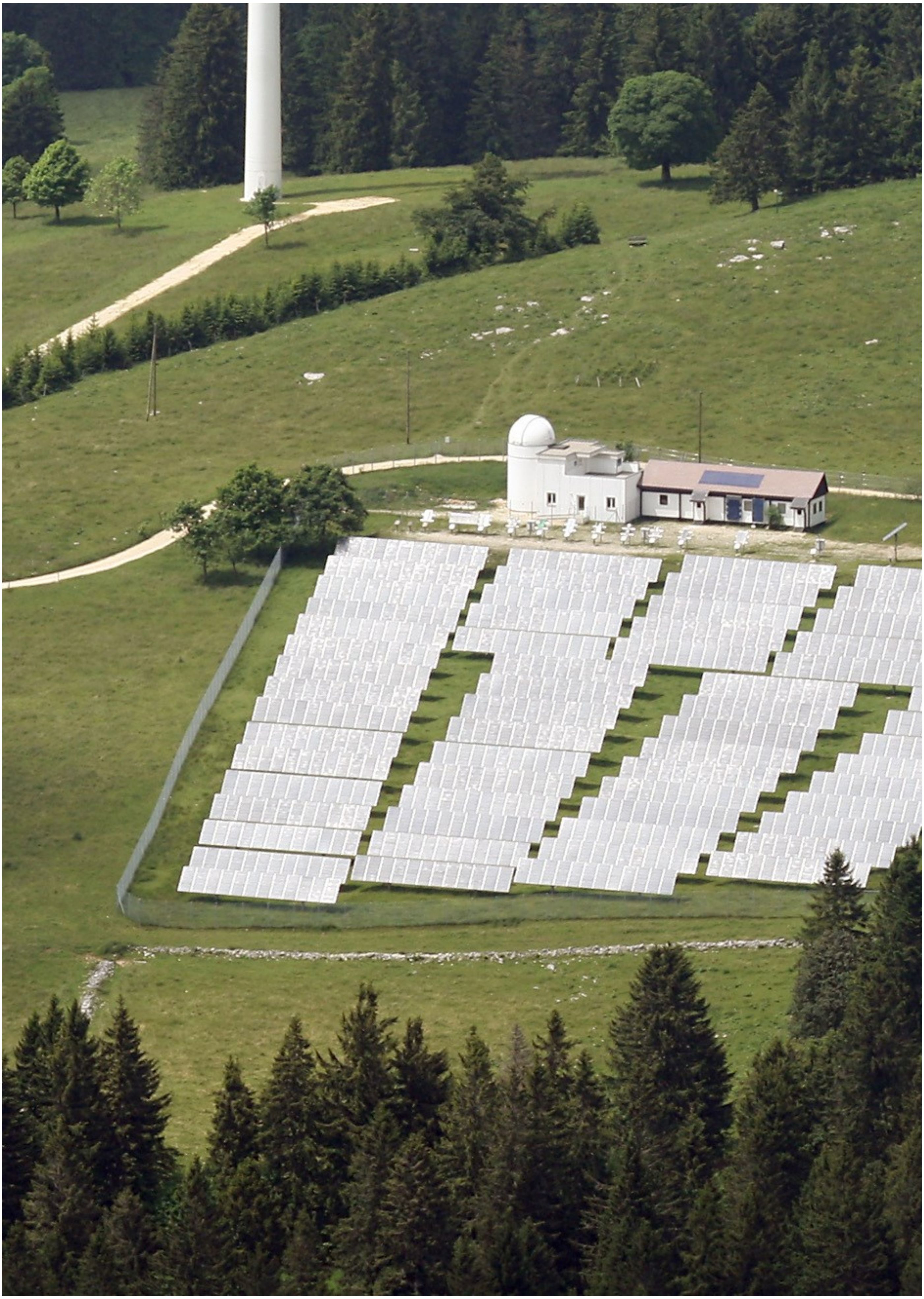
6.7.2. Summary

The biggest drawback of any OTEC technology is that it's relatively inefficient with an efficiency typically of just a few percent. OTEC plants have very high water pumping loads as they need to pump large amounts of water to produce even modest amounts of electricity. This means a significant amount of the electricity generated (typically about a third) must be used for pumping the water in and out of the plant. This also implies that the plants must be constructed on a relatively large scale, which makes the technology cost intensive. There are also potential environmental impacts from the large-scale OTEC plants when constructed onshore.

OTEC technology is not recommended for Mauritius in the short to medium term, however, if the technology does become commercially available and cost effective, the technology could be used to provide complementary industries such as food based mariculture production which has the added potential to increase Mauritius food security and provide export opportunities. A summary of each ocean thermal technology is provided in Table 94.

Table 94: Summary for ocean thermal energy

Technology risk	Open/closed cycle or hybrid system
Technology risk	High – the technology is not yet fully commercialised
Difficulty of implementation	High – depends on ability to access water at around 1,000 metres
Potential installed capacity implementation (MW)	Unknown, but likely to be low/medium
Potential annual output (MWh/year)	Unknown, but likely to be low/medium
Key Benefits	Ability to provide electricity on a continuous (non-intermittent) basis Complementary technologies
LCOE (US$/MWh)	Estimated to be $200-$300 per MWh – As OTEC systems have not yet been fully commercialised and are impact by economies of scale, cost estimates are uncertain
Capital Cost based on Capacity (US$/kW)	Estimated to be $5000-$35,400 per kW installed – As OTEC systems have not yet been fully commercialised and are impact by economies of scale, cost estimates are uncertain



7. Energy generation mix for a 60% Renewable Energy Target

Based on both the viable commercialised and emerging renewable energy conversion technologies, this chapter looks at potential scenarios for a future energy generation mix to meet a 60% renewable energy target. Each scenario is modelled to determine the likely contribution from each renewable energy source and likelihood of producing 60% or more energy from the most suitable renewable energy sources for Mauritius.

Based on the assessment of candidate renewable energy technologies as assessed in the previous sections, the following list of technologies will likely need to be used to reach a 60% RE target. The opportunities for utilising renewable energy sources on Mauritius are a function of the nature of the resources that are available and the stage of commercial development of the associated conversion technologies, and the costs. The recommended renewable energy technologies are summarised in Table 95 below.

Note that biomass generation from bagasse has been excluded as any increase in production will come about via incremental improvements and not through expansion of the industry. This industry is affected by climate change and coupled to the import of coal. Coal generation accounts for 40% of total electricity generation for the island and will need to be reduced to meet a higher renewable energy target and the goals of the MID initiative.

Table 95: Summary of renewable energy technologies and applicability to Mauritius

Technology	Resource	Sub-category	Recommended for region	Technology Risk	Challenge
Solar energy	Very good	Small scale distributed generation (SSDG) – solar PV	✓	Low (fixed, non-tracking)	Land and roof availability
		Medium scale distributed generation (MSDG) – solar PV	✓	Low (fixed, non-tracking)	Land and roof availability
		Utility scale solar PV	✓	Low (fixed, non-tracking)	Land availability
Onshore Wind energy	Good	Large wind turbine (LWT)	✓	Low but need to consider cyclone risk	Amenity, finding potential sites, land availability and cyclone risk
Offshore Wind Energy	Very good	Shallow Water	✓	Medium – cyclone risk to be resolved	Amenity, finding potential sites, network connection and integration and cyclone risk
		Transitional Depth	✓ (long term)		
Hydropower Pumped Storage	Limited	Conventional Pumped Storage	✓ (potential resource)	Low	Environmental impact, available/ reliable water source, and network connection and integration
		Seawater Pumped Storage	✓(potential resource)	Medium	Environmental impact particularly with the use of salt water, land availability, and network connection and integration
Wave energy	Good	Point absorbers	✓ (medium term)	High – until fully commercialised around 2025-30	Environmental impact
		Linear attenuators			
		Terminators			

7.1. Installed Generation Capacity and Type beyond 2025 – Island of Mauritius

Based on the available commercial and emerging renewable energy conversion technologies, there are several scenarios that Mauritius could pursue to move towards the 60% or greater target for renewable energy, see Figure 72. The scenarios will assume a business as usual (BAU) annual growth in electricity demand in line with demand growth scenarios used by the World Bank.

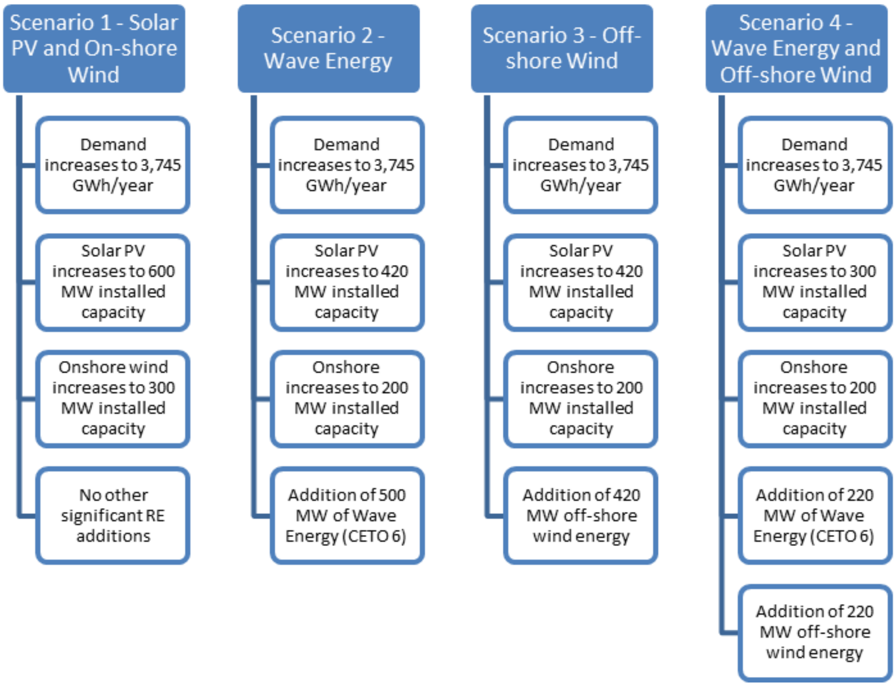


Figure 72: Proposed generation scenarios to reach a target of 60% beyond 2025

Under these scenarios, there are several established renewable energy technologies on Mauritius that are not expected to add any significant increase to generation capacity or annual output, see Table 96. CEB Thermal generation is expected to remain around the same capacity as forecast for 2025, plant upgrades will constitute the biggest change to this sector.

Table 96: Established renewable energy technologies where no significant change in generation capacity is expected beyond 2025

Technology	Changes to capacity	Capacity	Comments
IPP Bagasse/ Coal	Limited/ conflicts with other land use	No significant change	Incremental plant upgrades, crop changes etc. may increase annual generation through efficiency gains, ideal to reduce reliance on coal imports, sector at risk from climate change
CEB Hydro	Limited/ Fully exploited	No significant change – potential for pumped storage	Plant upgrades may increase annual generation through efficiency gains, generation at risk from climate change, potential for pumped water storage to enhance grid stability and reduce excess energy generation from renewables
WtE	Limited/ exploited	No significant change	Limited waste streams available on Island to produce significant generation
CEB Thermal	Replacement of old plant	Capacity to remain around 510 MW, sufficient capacity to manage peak periods	Efficiency improvements through plant upgrades, possible switch to LNG.

Some of these existing renewable energy technologies will manage to increase annual generation, however, these increases are not expected to be significant when compared to the amount of generation from renewable technologies that will be required to meet the 60% target. In addition, the annual average increase in demand is expected to be greater than any increase from any of these technologies over the 10-year period beyond 2025.

7.1.1. Demand Beyond 2025

Demand beyond 2025 with be dependent on population growth and the impact of any energy efficiency schemes/programs. Energy efficiency has seen demand in some western countries level off and even reduce. The 60% or greater renewable energy target would be expected to be set for around 2030, although it is assumed for this study that demand growth will stabilise around 2035 time due to the implementation of energy efficiency measures, see Table 97. The predicted annual electricity generation around 2030 is expected to be 3,745 GWh, an increase of 1,059 GWh versus 2015 demand. Refer to *Chapter 3 - Demand and Supply Beyond 2025* for more details of these projections.

Table 97: Projected electricity demand beyond 2025 (The World Bank 2015)

Year	2015	2025	~2030-35	Increase beyond 2025	
	(GWh)	(GWh)	(GWh)	(GWh)	%
Low Scenario	2,686	3,126	3,449	323	10.3%
Base Scenario (BAU)	2,686	3,240	3,745	505	15.6%
High Scenario	2,686	3,599	4,571	972	27.0%

7.1.2. Modelling Assumptions

The following key assumptions were made:

- Business as usual (BAU) growth in electricity continues to 2030-35 leading to a yearly demand of 3,745 GWh
  - The daily profile of the Mauritius load is assumed to remain the same
  - See Chapter 3 for further details of the projected growth forecast
- Existing IPP contracts are accounted as being permanently dispatched as required by the off-take agreements. The dispatch of the off-take is optimised to improve the penetration of solar and wind energy contribution.
- Network upgrades have been carried out to support the integration of intermittent renewable energy sources
  - Energy storage is assumed to be used in conjunction to the new installed renewable generation to balance the effects on voltage and frequency on the Mauritius grid
  - Network strengthening has occurred in some areas to support increased distributed generation
  - Prioritisation of SSDG and MSDG contracts to mitigate the effects to the power system
- Wave energy is commercialised around 2025 and CAPEX cost projection provided by Carnegie Clean Energy
- Offshore wind is commercialised around 2025 for areas subject to cyclonic conditions
  - Some form of storage has been integrated into the grid
  - Possible network strengthening in some areas to support increased distributed generation

7.1.3. Scenario 1

The energy generation mix for scenario 1 is presented in Table 98 with comments explaining the increase or not in each renewable energy technology.

Table 98: Scenario 1 - Electricity generation technology mix

Technology	Changes to capacity	Capacity	Comments
Onshore Wind energy	Increase	300 MW (up from 98 MW in 2025)	New onshore wind farms, will be limited by amenity and need to consider tourism industry. May help some farmers with additional income stream.
Solar PV	Increase	600 MW (up from 140 MW in 2025) Utility scale – 350 MW SSDG – 150 MW MSDG – 100 MW	Significant increase in utility scale and SSDG solar PV with additional capacity from MSDG, solar PV has good potential for local job development
Offshore Wind energy	Not implement-ed		Under this scenario, offshore wind remains too expen-sive versus solar PV and onshore wind
Wave energy	Not Implement-ed		Under this scenario, wave energy conversion technol-ogies remain too expensive versus solar PV and on-shore wind

Table 99: Total likely installed generation capacity by type in scenario 1

Fuel Type		Effective Capacity – Crop Season (MW)	Effective Capacity – Off-crop Season (MW)
Renewable	IPP Thermal - Bagasse	142.5	0
	CEB Hydro	56.3	56.3
	WtE	33.0	33.0
	Onshore Wind	300	300
	Solar PV	600	600
	Offshore Wind	0	0
	Wave Energy	0	0
Sub Total (Renewable)		**1,132**	**990**
Non-Renewables	CEB Thermal - Fuel Oil	510	510
	IPP Thermal - Coal	30	193
Total Electricity Generation Capacity		**1,672**	**1,693**

7.1.3.1. Scenario 1 – Modelling Results

Modelling was carried out using HOMER to determine the total electricity generation by each generation source based on the scenario generation capacity for Mauritius. The results of the modelling are listed in Table 100 which provides the total electricity generation for export to the grid broken down by fuel type for this scenario.

The total electricity generated, including the self-consumption total, is used to determine the total renewable energy generation for Mauritius, for this scenario the modelling results indicate that renewable energy will account for approximately 44.8% of total electricity generation on the Island, see Table 101 and Figure 73. This is well short of the 60% renewable energy target being proposed.

Table 100: Total electricity generated and exported to the grid by type as modelled for scenario 1

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse	427	11.2%
	Hydro	92	2.4%
	WtE	152	4.0%
	Onshore Wind	799	21.0%
	Solar PV	234	6.1%
	Offshore Wind	0	0.0%
	Wave Energy	0	0.0%
Sub Total (Renewable)		**1,704**	**44.8%**
Non-renewables	Fuel Oil	1,235	32.4%
	Coal	868	22.8%
Total Electricity Generated		**3,807**	**100.0%**

Table 101: Electricity exported to the grid and self-consumed by IPP generators as modelled for scenario 1

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse (crop season)	303	7.9%
	Hydro	92	2.4%
	WtE	152	4.0%
	Onshore Wind	799	21.0
	Solar PV	234	6.1%
	Offshore Wind	0	0.0%
	Wave Energy	0	0.0%
Sub Total (Renewable)		**1,580**	**41.5%**
Non-Renewables	Fuel Oil	1,235	32.4%
	Coal(non-crop season)	732	19.2%
Total Electricity Exported to CEB Grid		**3,547**	**93.2%**
IPP Self-consumption	Renewable—Bagasse (crop season)	124	3.3%
	Non-renewables—Coal (non-crop season)	136	3.6%
Total IPP self-consumption		**260**	**6.8%**
Total Electricity Generation		**3,807**	**100.0%**
Total Excess Electricity Generation		**62**	**1.6%**
Total Grid Load/Demand Serves		**3,745**	**98.4%**
Total Renewable Generation		**1,704**	**44.8%**
Total Non-renewable Generation		**2,103**	**55.2%**

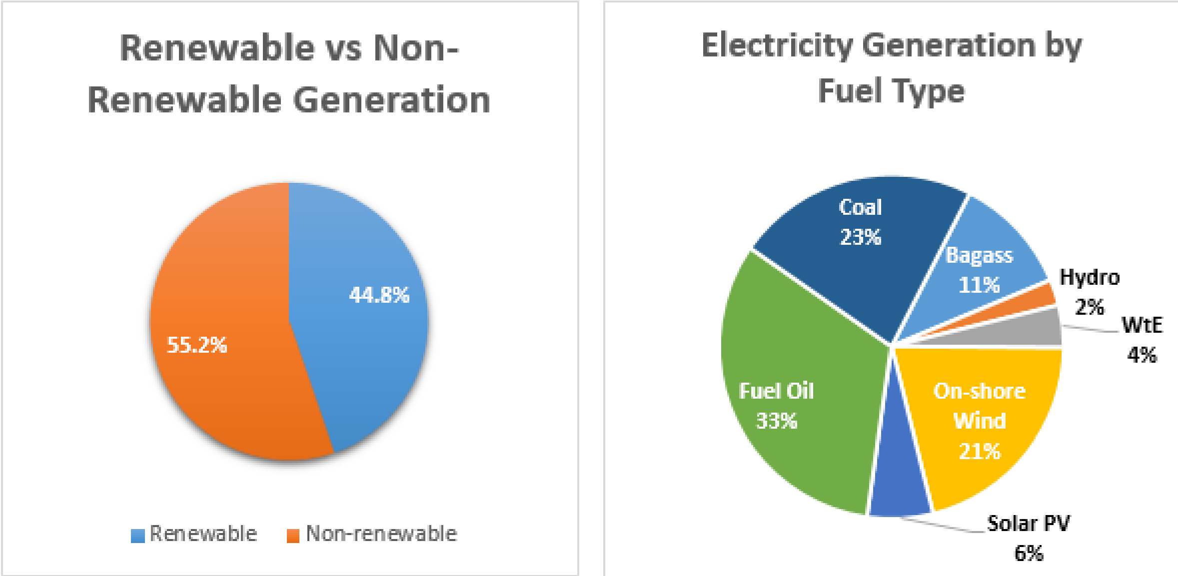


Figure 73: Electricity sources as modelled for scenario 1

7.1.3.2. Scenario 1A – No Pumped Hydro

This scenario examines what mix of onshore wind and solar PV would be needed to reach a 60% renewable energy target. The energy generation mix for scenario 1a is presented in Table 102 with comments explaining the increase or not in each renewable energy technology.

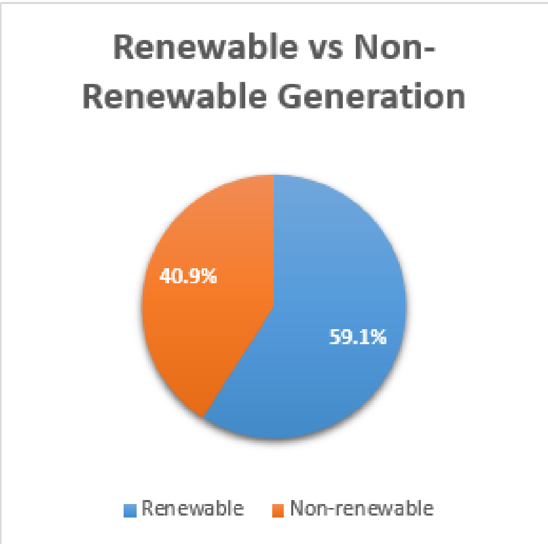
Table 102: Scenario 1a - Electricity generation technology mix without significant grid storage

Technology	Changes to capacity	Capacity	Comments
Onshore Wind energy	Increase	620 MW (up from 98 MW in 2025)	New onshore wind farms, will be limited by amenity and need to consider tourism industry. May help some farmers with additional income stream.
Solar PV	Increase	750 MW (up from 140 MW in 2025) Utility scale – 500 MW SSDG – 150 MW MSDG – 100 MW	Significant increase in utility scale and SSDG solar PV with additional capacity from MSDG, solar PV has good potential for local job development

Modelling was carried out using HOMER to determine the total electricity generation by each generation source based on the scenario generation capacity for Mauritius. The total electricity generated, including the self-consumption total, is used to determine the total renewable energy generation for Mauritius, for this scenario the modelling results indicate that renewable energy will account for approximately 59.1% of total electricity generation on the Island, see Table 103 and Figure 74. Adding additional wind or solar increases the excess generation at a higher rate than the percentage renewable energy at this point due to there being no grid storage available.

Table 103: Electricity exported to the grid and self-consumed by IPP generators as modelled for scenario 1a

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse (crop season)	259	6.1%
	Hydro	92	2.2%
	WtE	148	3.5%
	Onshore Wind	1653	38.9%
	Solar PV	234	5.5%
	Offshore Wind	0	0.0%
	Wave Energy	0	0.0%
Sub Total (Renewable)		**2,387**	**56.2%**
Non-Renewables	Fuel Oil	979	23.0%
	Coal(non-crop season)	625	14.7%
Total Electricity Exported to CEB Grid		**3,990**	**93.9%**
IPP Self-consumption	Renewable—Bagasse (crop season)	124	2.9%
	Non-renewables—Coal (non-crop season)	136	3.2%
Total IPP self-consumption		**260**	**6.1%**
Total Electricity Generation		**4,250**	**100.0%**
Total Excess Electricity Generation		**505**	**11.9%**
Total Grid Load/Demand Serves		**3,745**	**88.1%**
Total Renewable Generation		**2,511**	**59.1%**
Total Non-renewable Generation		**1,739**	**40.9%**



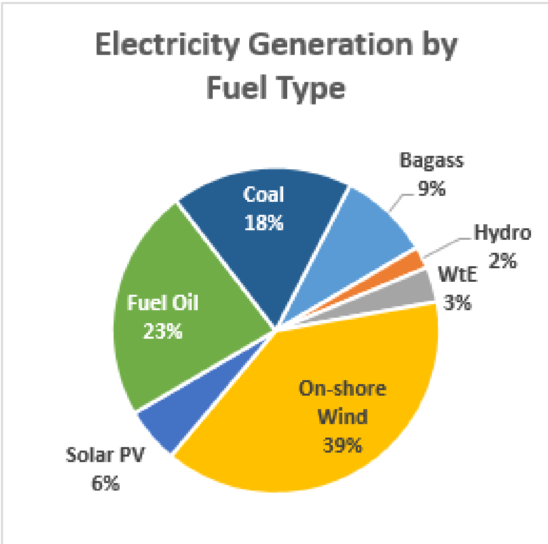


Figure 74: Electricity sources as modelled for scenario 1a

7.1.3.3. Scenario 1B – With Pumped Hydro

This scenario examines what mix of onshore wind and solar PV would be needed to reach a 60% renewable energy target. The energy generation mix for scenario 1b is presented in Table 104 with comments explaining the increase or not in each renewable energy technology.

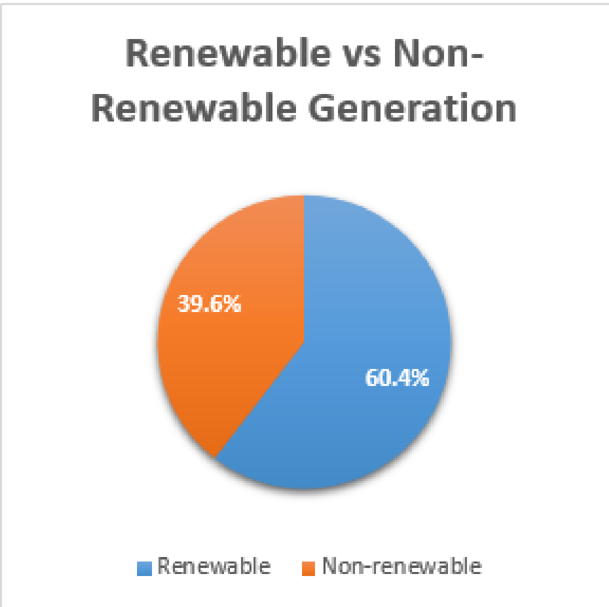
Table 104: Scenario 1b - Electricity generation technology mix

Technology	Changes to capacity	Capacity	Comments
Onshore Wind energy	Increase	620 MW (up from 98 MW in 2025)	New onshore wind farms, will be limited by amenity and need to consider tourism industry. May help some farmers with additional income stream.
Solar PV	Increase	750 MW (up from 140 MW in 2025) Utility scale – 500 MW SSDG – 150 MW MSDG – 100 MW	Significant increase in utility scale and SSDG solar PV with additional capacity from MSDG, solar PV has good potential for local job development
Pumped Hydro	New facility	70 MW capacity with 1 GWh of storage	This scenario proposes the addition of Pumped Hydro storage to help both in reducing the excess generation and in boosting the stability of the grid with high levels of intermittent renewable energy sources.

Modelling was carried out using HOMER to determine the total electricity generation by each generation source based on the scenario generation capacity for Mauritius. The total electricity generated, including the self-consumption total, is used to determine the total renewable energy generation for Mauritius, for this scenario the modelling results indicate that renewable energy will account for approximately 60.4% of total electricity generation on the Island, see Table 105 and Figure 75. Adding storage helps to better utilise the available renewable energy sources by storing energy during times of excess generation and shifting that generation to times of low renewable energy generation. Furthermore, the addition of Pumped Hydro storage adds significant grid stability with the proposed high levels of intermittent renewable energy sources.

Table 105: Electricity exported to the grid and self-consumed by IPP generators as modelled for scenario 1b

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse (crop season)	259	6.1%
	Hydro	92	2.2%
	WtE	148	3.5%
	Onshore Wind	1653	38.9%
	Solar PV	234	5.5%
	Offshore Wind	0	0.0%
	Wave Energy	0	0.0%
Sub Total (Renewable)		**2,387**	**56.2%**
Non-Renewables	Fuel Oil	979	23.0%
	Coal(non-crop season)	625	14.7%
Total Electricity Exported to CEB Grid		**3,990**	**93.9%**
IPP Self-consumption	Renewable—Bagasse	124	2.9%
	Non-renewables—Coal	136	3.2%
Total IPP self-consumption		**260**	**6.1%**
Total Electricity Generation		**4,250**	**100.0%**
Total Excess Electricity Generation		**505**	**11.9%**
Total Grid Load/Demand Serves		**3,745**	**88.1%**
Total Renewable Generation		**2,511**	**59.1%**
Total Non-renewable Generation		**1,739**	**40.9%**



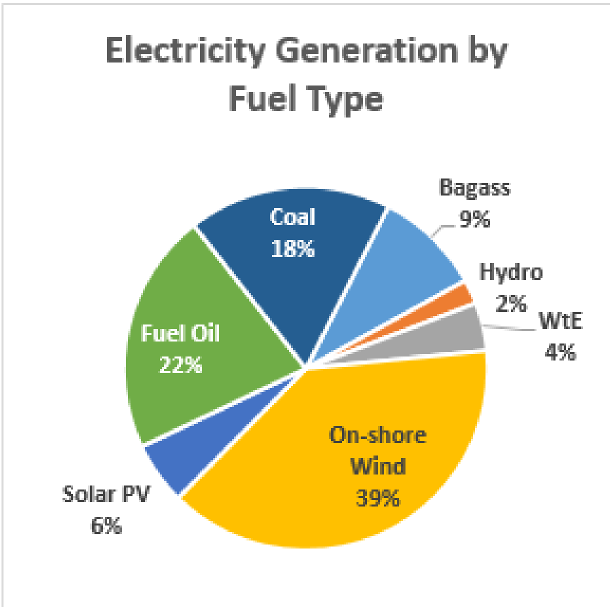


Figure 75: Electricity sources as modelled for scenario 1b

7.1.4. Scenario 2

The energy generation mix for scenario 2 is presented in Table 106 with comments explaining the increase or not in each renewable energy technology. Table 107 provides a list of likely installed generation capacity for each technology under this scenario.

Table 106: Scenario 2 - Electricity generation technology mix

Technology	Changes to capacity	Capacity	Comments
Onshore Wind energy	Increase	200 MW (up from 98 MW in 2025)	New onshore wind farms, will be limited by amenity and need to consider tourism industry. May help some farmers with additional income stream.
Solar PV	Increase	420 MW (up from 140 MW in 2025) Utility scale – 190 MW SSDG – 150 MW MSDG – 80 MW	Significant increase in utility scale and SSDG solar PV with additional capacity from MSDG, solar PV has good potential for local job development
Offshore Wind energy	Not implemented		Under this scenario, offshore wind remains too expensive versus solar PV, onshore wind and wave energy
Wave energy	Installation of CETO 6 or equivalent	500 MW (equivalent to 500 x 1 MW_e units)	Under this scenario, wave energy conversion technologies become cost competitive with fossil fuel generation

Table 107: Total likely installed generation capacity by type in scenario 2

Fuel Type		Effective Capacity – Crop Season (MW)	Effective Capacity – Off-crop Season (MW)
Renewable	IPP Thermal - Bagasse	142.5	0
	CEB Hydro	56.3	56.3
	WtE	33.0	33.0
	Onshore Wind	200	200
	Solar PV	420	420
	Offshore Wind	0	0
	Wave Energy	500	500
Sub Total (Renewable)		**1,352**	**1,210**
Non-Renewables	CEB Thermal - Fuel Oil	510	510
	IPP Thermal - Coal	30	193
Total Electricity Generation Capacity		**1,892**	**1,913**

7.1.4.1. Scenario 2 – Modelling Results

Modelling was carried out using HOMER to determine the total electricity generation by each generation source based on the scenario generation capacity for Mauritius. The results of the modelling are listed in Table 108 which provides the total electricity generation for export to the grid broken down by fuel type for this scenario.

The total electricity generated, including the self-consumption total, is used to determine the total renewable energy generation for Mauritius, for this scenario the modelling results indicate that renewable energy will account for approximately 62.8% of total electricity generation on the Island, see Table 109 and Figure 76. This exceeds the 60% renewable energy target being proposed.

Table 108: Total electricity generated and exported to the grid by type as modelled for scenario 2

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse	386	10.0%
	Hydro	92	2.4%
	WtE	148	3.8%
	Onshore Wind	533	13.8%
	Solar PV	221	5.7%
	Offshore Wind	0	0.0%
	Wave Energy	1,048	27.1%
Sub Total (Renewable)		**2,429**	**62.8%**
Non-renewables	Fuel Oil	699	18.1%
	Coal	744	19.1%
Total Electricity Generated		**3,872**	**100.0%**

Table 109: Electricity exported to the grid and self-consumed by IPP generators as modelled for scenario 2

	Fuel Type	Units Generated (GWh)	%
Renewable	Bagasse (crop season)	262	6.8%
	Hydro	92	2.4%
	WtE	148	3.8%
	Onshore Wind	533	13.8%
	Solar PV	221	5.7%
	Offshore Wind	0	0.0%
	Wave Energy	1,048	27.1%
	Sub Total (Renewable)	**2,305**	**59.5%**
Non-Renewables	Fuel Oil	699	18.1%
	Coal(non-crop season)	608	15.7%
	Total Electricity Exported to CEB Grid	**3,612**	**93.3%**
IPP Self-consumption	Renewable—Bagasse	124	3.2%
	Non-renewables—Coal	136	3.5%
Total IPP self-consumption		**260**	**6.7%**
Total Electricity Generation		**3,872**	**100.0%**
Total Excess Electricity Generation		**127**	**3.3%**
Total Grid Load/Demand Serves		**3,745**	**96.7%**
Total Renewable Generation		**2,429**	**62.7%**
Total Non-renewable Generation		**1,443**	**37.3%**

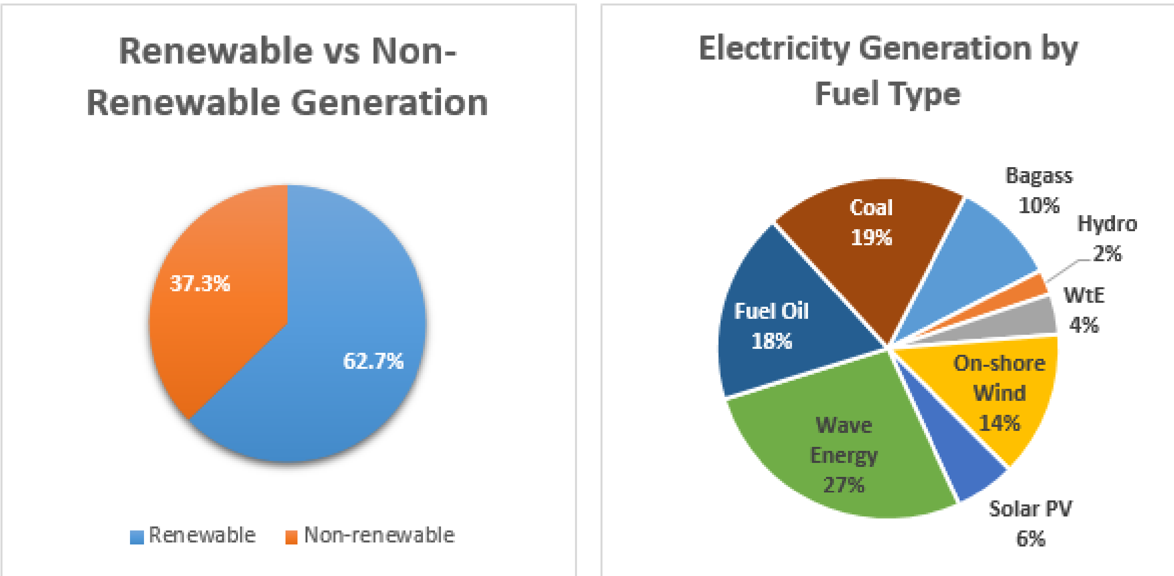


Figure 76: Electricity sources as modelled for scenario 2

7.1.5. *Scenario 3*

The energy generation mix for scenario 3 is presented in Table 110 with comments explaining the increase or not in each renewable energy technology. Table 111 provides a list of likely installed generation capacity for each technology under this scenario.

Table 110: Scenario 3 - Electricity generation technology mix

Technology	Changes to capacity	Capacity	Comments
Onshore Wind energy	Increase	200 MW (up from 98 MW in 2025)	New onshore wind farms, will be limited by amenity and need to consider tourism industry. May help some farmers with additional income stream.
Solar PV	Increase	420 MW (up from 140 MW in 2025) Utility scale – 190 MW SSDG – 150 MW MSDG – 80 MW	Significant increase in utility scale and SSDG solar PV with additional capacity from MSDG, solar PV has good potential for local job development
Offshore Wind energy	Installation of wind turbines in shallow depth areas	420 MW	Under this scenario, offshore wind becomes cost competitive with fossil fuel generation
Wave energy	Not Implemented		Under this scenario, wave energy conversion technologies remain too expensive versus solar PV and onshore wind

Table 111: Total likely installed generation capacity by type in scenario 3

Fuel Type		Effective Capacity – Crop Season (MW)	Effective Capacity – Off-crop Season (MW)
Renewable	IPP Thermal - Bagasse	142.5	0
	CEB Hydro	56.3	56.3
	WtE	33.0	33.0
	Onshore Wind	200	200
	Solar PV	420	420
	Offshore Wind	420	420
	Wave Energy	0	0
Sub Total (Renewable)		**1,272**	**1,130**
Non-Renewables	CEB Thermal - Fuel Oil	510	510
	IPP Thermal - Coal	30	193
Total Electricity Generation Capacity		**1,812**	**1,833**

7.1.5.1. *Scenario 3 – Modelling Results*

Modelling was carried out using HOMER to determine the total electricity generation by each generation source based on the scenario generation capacity for Mauritius. The results of the modelling are listed in Table 112 which provides the total electricity generation for export to the grid broken down by fuel type for this scenario.

The total electricity generated, including the self-consumption total, is used to determine the total renewable energy generation for Mauritius, for this scenario the modelling results indicate that renewable energy will account for approximately 60.2% of total electricity generation on the Island, see Table 113 and Figure 77. This matches the 60% renewable energy target being proposed.

Table 112 : Total electricity generated and exported to the grid by type as modelled for scenario 3

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse	378	8.8%
	Hydro	92	2.2%
	WtE	147	3.4%
	Onshore Wind	533	12.4%
	Solar PV	221	5.1%
	Offshore Wind	1,218	28.4%
	Wave Energy	0	0.0%
Sub Total (Renewable)		**2,589**	**60.2%**
Non-renewables	Fuel Oil	964	22.4%
	Coal	745	17.3%
Total Electricity Generated		**4,298**	**100.0%**

Table 113: Electricity exported to the grid and self-consumed by IPP generators as modelled for scenario 3

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse (crop season)	254	5.9%
	Hydro	92	2.2%
	WtE	147	3.4%
	Onshore Wind	533	12.4%
	Solar PV	221	5.7%
	Offshore Wind	1,218	28.4%
	Wave Energy	0	0.0%
Sub Total (Renewable)		**2,465**	**57.4%**
Non-Renewables	Fuel Oil	964	22.4%
	Coal(non-crop season)	609	14.2%
Total Electricity Exported to CEB Grid		**4,038**	**94.0%**
IPP Self-consumption	Renewable—Bagasse	124	2.9%
	Non-renewables—Coal	136	3.2%
Total IPP self-consumption		**260**	**6.0%**
Total Electricity Generation		**4,298**	**100.0%**
Total Excess Electricity Generation		**553**	**12.2%**
Total Grid Load/Demand Serves		**3,745**	**87.1%**
Total Renewable Generation		**2,589**	**60.2%**
Total Non-renewable Generation		**1,709**	**39.8%**

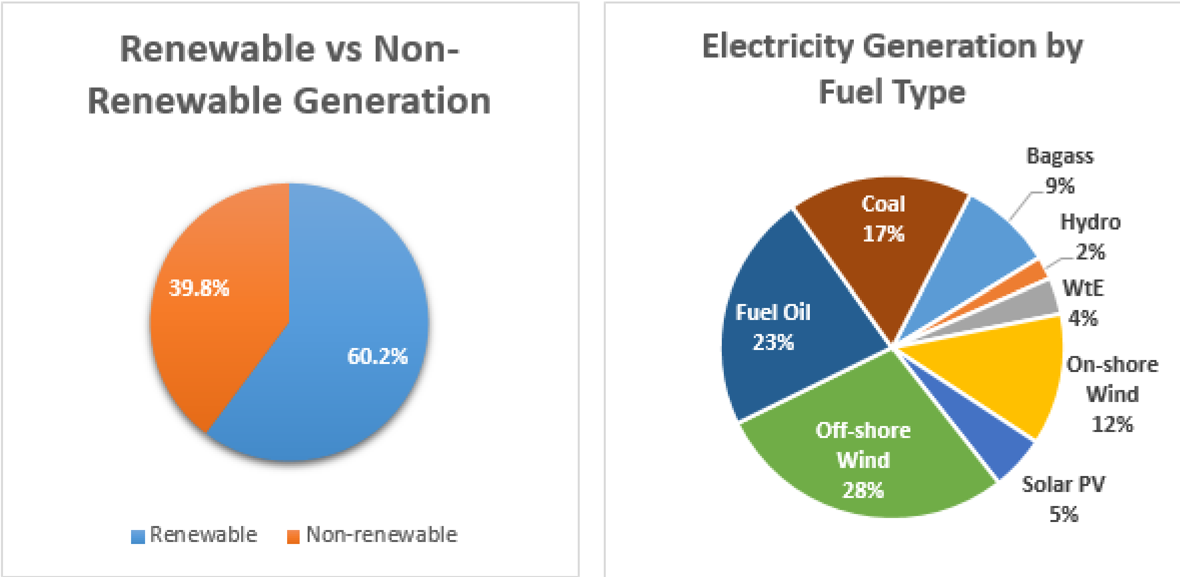


Figure 77: Electricity sources as modelled for scenario 3

7.1.6. Scenario 4

The energy generation mix for scenario 4 is presented in Table 114 with comments explaining the increase or not in each renewable energy technology.

Table 115 provides a list of likely installed generation capacity for each technology under this scenario.

Table 114: Scenario 4 - Electricity generation technology mix

Technology	Changes to capacity	Capacity	Comments
Onshore Wind energy	Increase	200 MW (up from 98 MW in 2025)	New onshore wind farms, will be limited by amenity and need to consider tourism industry. May help some farmers with additional income stream.
Solar PV	Increase	300 MW (up from 140 MW in 2025) Utility scale – 110 MW SSDG – 130 MW MSDG – 60 MW	Significant increase in SSDG solar PV with additional capacity from utility scale and MSDG, solar PV has good potential for local job development
Offshore Wind energy	Installation of wind turbines in shallow depth areas	220 MW	Under this scenario, offshore wind becomes cost competitive with fossil fuel generation
Wave energy	Installation of CETO 6 or equivalent	220 MW (equivalent to 220 x 1 MW_e units)	Under this scenario, wave energy conversion technologies become cost competitive with fossil fuel generation

Table 115: Total likely installed generation capacity by type in scenario 4

Fuel Type		Effective Capacity – Crop Season (MW)	Effective Capacity – Off-crop Season (MW)
Renewable	IPP Thermal - Bagasse	142.5	0
	CEB Hydro	56.3	56.3
	WtE	33.0	33.0
	Onshore Wind	200	200
	Solar PV	300	300
	Offshore Wind	220	220
	Wave Energy	220	220
Sub Total (Renewable)		1,172	1,030
Non-Renewables	CEB Thermal - Fuel Oil	510	510
	IPP Thermal - Coal	30	193
Total Electricity Generation Capacity		1,712	1,733

7.1.6.1. Scenario 4 – Modelling Results

Modelling was carried out using HOMER to determine the total electricity generation by each generation source based on the scenario generation capacity for Mauritius. The results of the modelling are listed in Table 116 which provides the total electricity generation for export to the grid broken down by fuel type for this scenario.

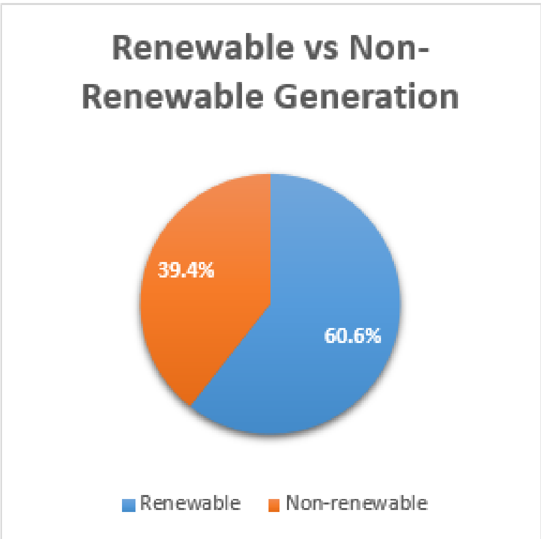
The total electricity generated, including the self-consumption total, is used to determine the total renewable energy generation for Mauritius, for this scenario the modelling results indicate that renewable energy will account for approximately 60.6% of total electricity generation on the Island, see Table 117 and Figure 78. This exceeds the 60% renewable energy target being proposed.

Table 116: Total electricity generated and exported to the grid by type as modelled for scenario 4

Fuel Type		**Units Generated (GWh)**	**%**
Renewable	Bagasse	384	9.5%
	Hydro	92	2.3%
	WtE	148	3.7%
	Onshore Wind	585	14.5%
	Solar PV	200	5.0%
	Offshore Wind	579	14.3%
	Wave Energy	461	11.4%
Sub Total (Renewable)		**2,449**	**60.6%**
Non-renewables	Fuel Oil	843	20.8%
	Coal	750	18.6%
Total Electricity Generated		**4,042**	**100.0%**

Table 117: Electricity exported to the grid and self-consumed by IPP generators as modelled for scenario 4

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse (crop season)	260	6.4%
	Hydro	92	2.3%
	WtE	148	3.7%
	Onshore Wind	585	14.5%
	Solar PV	200	5.0%
	Offshore Wind	579	14.3%
	Wave Energy	461	11.4%
Sub Total (Renewable)		**2,325**	**57.5%**
Non-Renewables	Fuel Oil	843	20.8%
	Coal(non-crop season)	614	15.2%
Total Electricity Exported to CEB Grid		**3,782**	**93.6%**
IPP Self-consumption	Renewable—Bagasse	124	3.1%
	Non-renewables—Coal	136	3.4%
Total IPP self-consumption		**260**	**6.4%**
Total Electricity Generation		**3,807**	**100.0%**
Total Excess Electricity Generation		**296**	**7.3%**
Total Grid Load/Demand Serves		**3,745**	**92.7%**
Total Renewable Generation		**2,449**	**60.6%**
Total Non-renewable Generation		**1,592**	**39.4%**



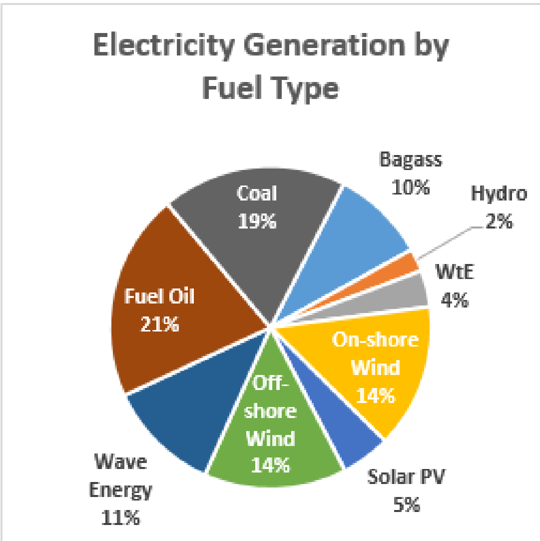


Figure 78: Electricity sources as modelled for scenario 4

7.2. Summary of Modelling Results for Generation Scenarios beyond 2025

Four primary renewable energy generation mix scenarios where proposed to reach a renewable energy target of 60% beyond 2025, see Figure 79. The first relied entirely on the expansion of solar PV and on-shore wind technologies. The second assumed that wave energy would be competitive with other generation technologies and due to its suitability for Mauritius would be installed with some additional solar PV capacity. Offshore wind was assumed to be competitive with other generation technologies for scenario 3 including the resolution of installing turbines in areas subject to cyclonic wind conditions such as Mauritius, the turbines would be installed in combination with some additional solar PV capacity. The last scenario involved the installation of both wave energy and offshore wind with some additional solar PV capacity.

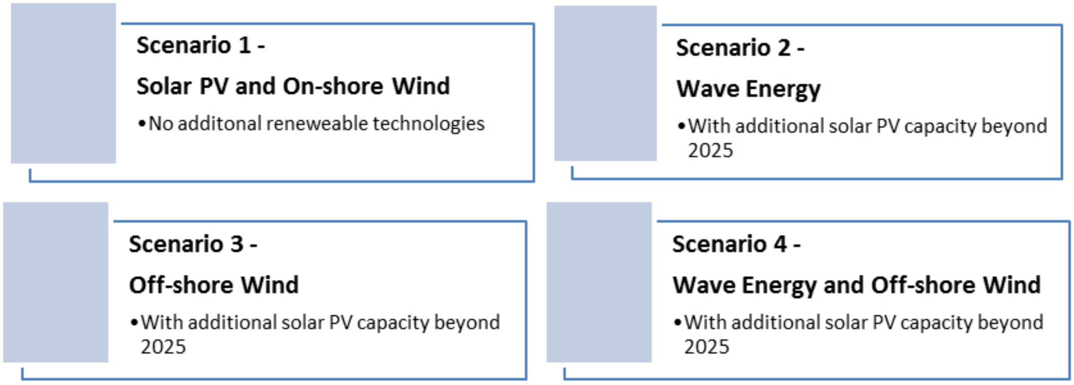


Figure 79: Proposed generation scenarios to reach a target of 60% beyond 2025

A summary of the modelling results by technology capacity for each scenario are presented in Table 118 along with the baseline years 2015 and 2025 for comparison. Note that scenario 1 did not achieve the 60% target by a considerable 15%, as a result additional scenarios were considered to determine how much solar PV and onshore wind would be required to achieve a 60% renewable energy target. The modelling was carried out and detailed in scenarios 1a and 1b. Scenario 1b demonstrates how Pumped Hydro can improve renewable energy penetration and reduce excess generation while also benefitting network stability.

Table 118: Summary of modelling for generation scenarios beyond 2025 by technology capacity

Scenario	% Renew - able Energy	Solar PV Capacity (MW)	On- shore Wind Capacity (MW)	Off- shore Wind Capacity (MW)	Wave Energy Capacity (MW)	Pumped Hydro (MW)	Excess Energy (%)
2015 Baseline	22.9%	140	100	-	-	-	0%
2025 Baseline	35.0%	140	100	-	-	-	0%
Scenario 1	44.8%	600	300	-	-	-	1.6%
Scenario 1a	59.1%	750	620	-	-	-	11.9%
Scenario 1b	60.4%	750	620	-	-	70 (1 GWh)	10.1%
Scenario 2	62.7%	420	200	-	500	-	3.3%
Scenario 3	60.2%	420	200	420	-	-	12.2%
Scenario 4	60.6%	300	200	220	220	-	7.3%

A summary of the modelling results by RE capacity for each scenario is presented in Table 119 along with the baseline years 2015 and 2025.

Table 119: Summary of modelling for generation scenarios beyond 2025 by RE capacity

Scenario	% Renewable Energy	RE Capacity – Crop Season (MW)	RE Capacity – Off-crop Season (MW)	Excess Energy (%)	Demand (GWh)	Demand Growth (%)
2015 Baseline	22.9%	220	77	0%	2,956	-
2025 Baseline	35.0%	471	328	0%	3,505	18.6%
Scenario 1	44.8%	1,132	990	1.6%	3,745	6.8%
Scenario 1a	59.1%	1,602	1,460	11.9%	3,745	6.8%
Scenario 1b	60.4%	1,602	1,460	10.1%	3,745	6.8%
Scenario 2	62.7%	1,352	1,210	3.3%	3,745	6.8%
Scenario 3	60.2%	1,272	1,130	12.2%	3,745	6.8%
Scenario 4	60.6%	1,172	1,030	7.3%	3,745	6.8%

7.2.1. Geographic Analysis

A geographic analysis was conducted to determine the likely area required for the installation of the renewable energy options presented in scenario 4, see Table 120.

Table 120: Renewable Energy Options for Scenario 4

Scenario	Solar PV Capacity (MW)	On- shore Wind Capacity (MW)	Off- shore Wind Capacity (MW)	Wave Energy Capacity (MW)
Scenario 4	300	200	220	220

7.2.2. Solar PV

A survey of solar PV farms constructed revealed a large range of installed power densities due to both the panel type, thin film versus crystalline silicon, and size and whether the farm employed single-axis tracking (East-West) or not, see Table 121. Figure 80 shows the relative area required for the installation of a 500 MW solar PV farm overlaid with a map of Mauritius. This clearly demonstrates that there will be more than sufficient space available on the Island of Mauritius to accommodate a significant expansion in the installation of utility scale solar PV. Note that it may be best to distribute the utility scale solar PV over a large geographic area (10 km or more apart) in order to reduce the variability in output from the solar PV farms due to cloud cover, see section 8.5.4 for a case study of these benefits.

Table 121: Average solar PV farm installed density

	Utility Scale Solar PV
Solar PV Rated Power (MW)	1 MW to 1,000 MW
Average Installed Power Density (W/m^2)	50 (range 22 to 100)

Table 122: Results for solar PV farm geographic analysis

Scenario	Utility Scale Solar PV required (MW)	Average Installed Power Density (W/m^2)	Area required (km^2)
Scenario 1	350	50	7.0
Scenario 1a & 1b	500	50	10.0
Scenario 2 & 3	190	50	3.8
Scenario 4	110	50	2.2

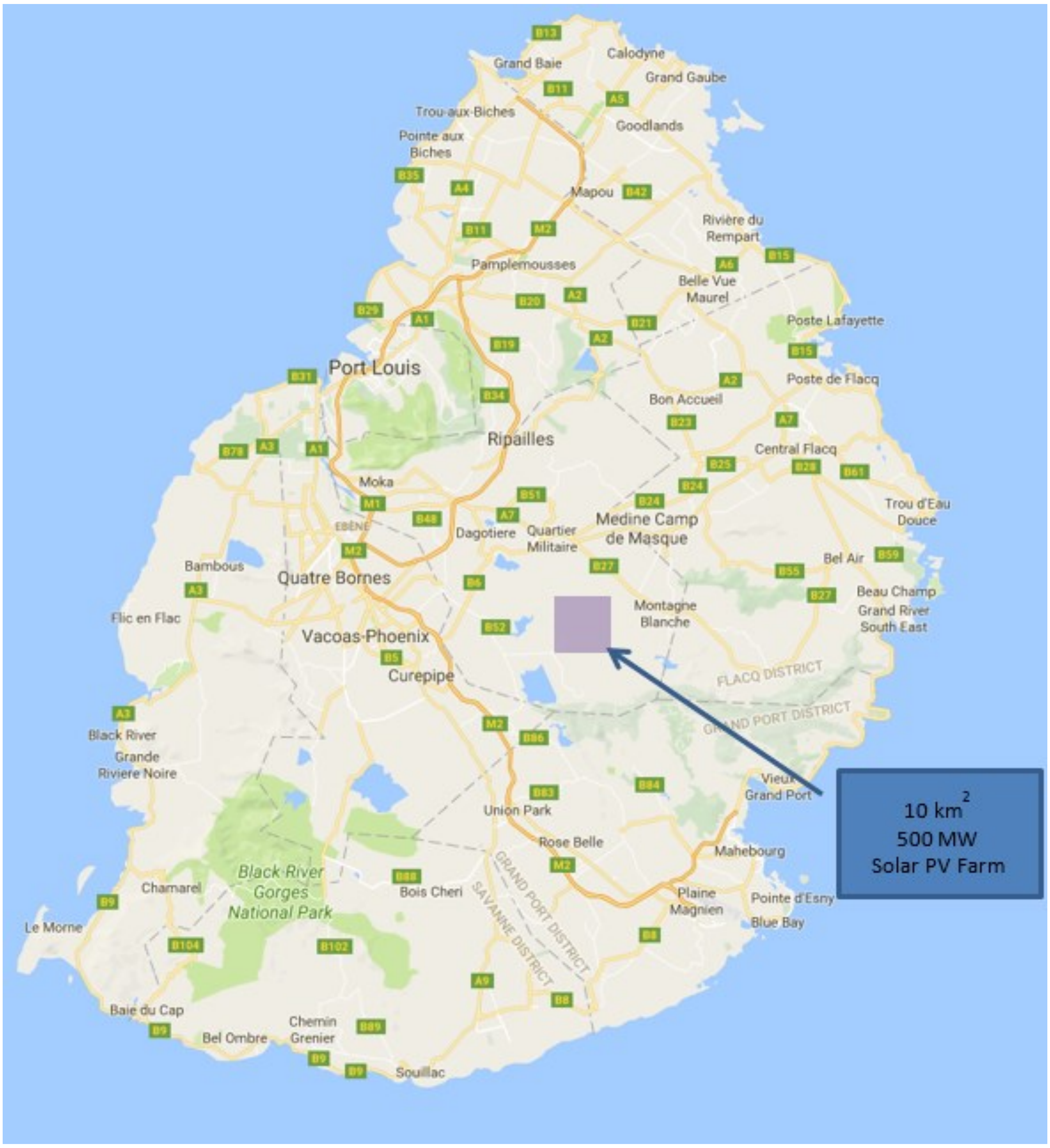


Figure 80: Results of geographic analysis for onshore wind energy

7.2.1.2. *Onshore & Offshore Wind Energy*

The potential for any wind farm is based on several factors including wind power density, wind turbine technology, land type for onshore farms and turbine layout. Turbine layout, known as array orientation, is important as it considers prevailing winds and wake losses due to nearby turbines. Although we will apply average power densities to determine the required space for both onshore and offshore wind farms as proposed for Mauritius, actual site array designs may differ due to local variations in one or more of these factors.

A study of operating European wind farms indicated that the power density of onshore wind farms with turbines of a rated power of 2 MW to be approximately 8 MW/km^2 and as low as 4 MW/km^2 for more mountainous areas (4). This same study estimated that the power density for offshore wind farms in 2020 and 2030 will be 12 and 15 MW/km^2 with a rated power per turbine of 8 and 10 MW respectively. This compares to a range of 3.5 to 8.8 MW/km^2 and a mean of 6.0 MW/km^2 for 18 existing and under construction projects that were assessed as part of a National Renewable Energy Laboratory (NREL) study conducted for offshore wind energy leasing areas for BOEM New Jersey wind energy area in 2013 (5), see Figure 81. The study was based on a 5 MW reference turbine with 126 m diameter rotor. Of note, the study found that some offshore wind farms where not achieving the capacity factors estimated due to poor array design resulting from wake losses of up to 10%.

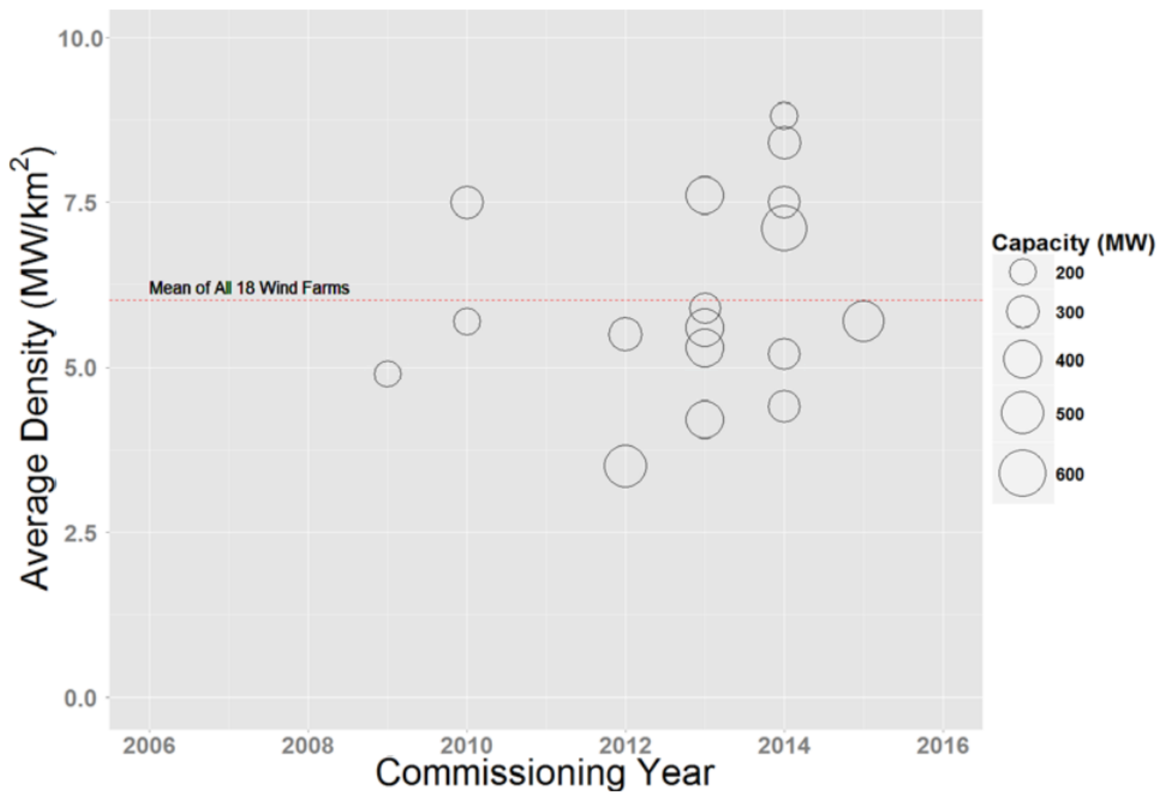


Figure 81: Average turbine array density for 18 large (>200 MW capacity) offshore wind power projects (mean of all 18 wind farms = 6 MW/km^2), adapted from (5)

Offshore array design is complex with the optimum array density considering many variables including wake losses, bottom conditions, distance to shore, competing use issues (such as shipping lanes) as well as cable cost. Although wider turbine spacing reduces wake losses and potentially reduces turbine maintenance costs, it increases cable costs and other costs associated with development. Although some studies are indicating a doubling or more in power density for future offshore wind development, primarily due to the increase in turbine rated power, the historical data and complexity in designing the optimum array does not provide any trends to indicate that this will be the case. This study will use the lower power densities for both onshore and offshore wind as this is more likely to find the worst case (i.e. largest area required), see Table 123.

Table 123: Average wind farm power densities for both onshore and offshore

	Onshore Wind (as built)	Offshore Wind (as built)	Offshore Wind - 2030
Turbine Rated Power (MW)	2	3-6	6-10
Average Power Density (MW/km^2)	8	6	10

7.2.1.3. Onshore Wind

The following geographic analysis was conducted for onshore wind to determine the likely area required for the various options proposing onshore wind farm, see Table 124 and Figure 82. The analysis indicates that the required space, even for the largest proposal, could easily be accommodated when spread across agricultural areas of Mauritius. It should be noted that the agriculture impact is relatively small and can continue in parallel with wind farms in place with the only reduction in agricultural land due to access roads to turbines for maintenance and tower foundations.

Table 124: Results for onshore geographic analysis

Scenario	Onshore Wind Capacity (MW)	Turbine Average Rated Power (MW)	Average Power Density (MW/km^2)	Area required (km^2)
Scenario 1	300	2	8	37.5
Scenario 1a & 1b	620	2	8	77.5
Scenario 4	200	2	8	25

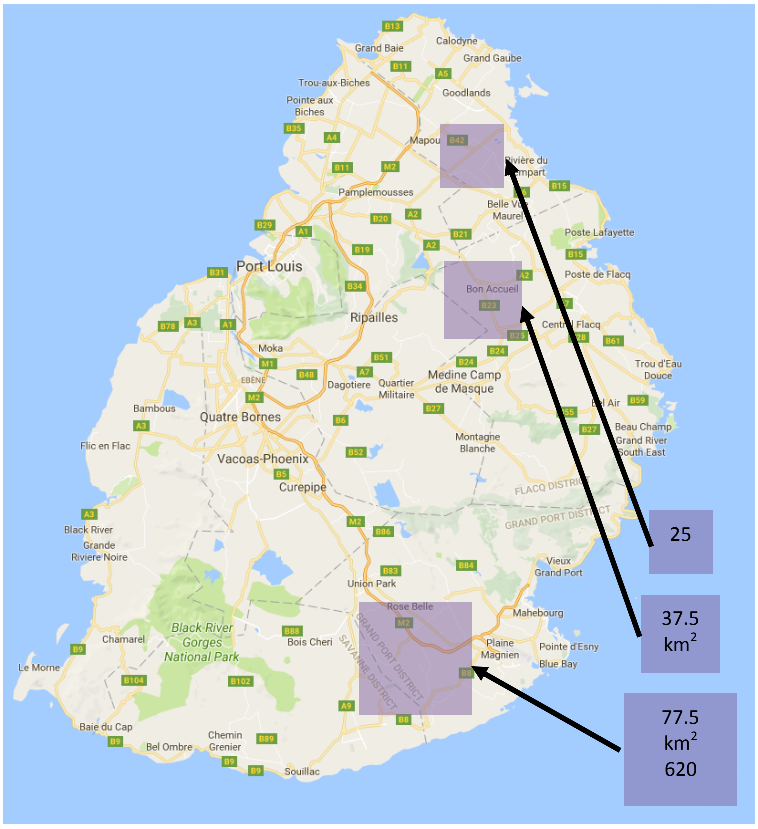


Figure 82: Results of geographic analysis for onshore wind energy

7.2.1.4. Offshore Wind

The following geographic analysis was conducted for offshore wind to determine the likely area required for the various options proposing offshore wind farms, see Table 125 and Figure 83. The analysis indicates that the required space, even for the largest proposal, could be accommodated when spread across multiples site around Mauritius. It should be noted that the analysis is considered worst case for the sized turbines proposed (6 MW – 1 turbine per square km) to allow for site conditions and optimum array design.

Table 125: Results for offshore geographic analysis

Scenario	Offshore Wind Capacity (MW)	Turbine Average Rated Power (MW)	Average Power Density (MW/km^2)	Area required (km^2)
Scenario 3	420	6	6	52.2
Scenario 4	220	6	6	36.7

Figure 83: Results of geographic analysis for offshore wind energy

7.2.1.5. Wave Energy

There are currently no commercial wave energy plants in operation. A wave energy farm design will need to consider similar variables to that of an offshore wind farm to achieve an optimum array design. These variables will include but are not limited too; bottom conditions, distance to shore, competing use issues (such as shipping lanes and tourism) as well as cable cost.

This study will use the estimated power density for a point absorber type wave energy generator, see Table 126 and Figure 84. The analysis indicates that the required space, even for the largest proposal, could be accommodated when spread across multiple sites around Mauritius. The analysis assumes that there would be equivalent of 5 MW of wave energy generation per square km allowing for differing site conditions, optimum wave energy array design, and that there is no data available for large scale commercial implementation.

Table 126: Estimated average wave energy farm power density and results for offshore geographic analysis

Scenario	Wave Energy Capacity (MW)	Wave Energy Generator Rated Power (MW)	Average Power Density (MW/km^2)	Area required (km^2)
Scenario 2	500	1	5	100.0
Scenario 4	220	1	5	44.0

Figure 84: Results of geographic analysis for wave energy

7.2.1.6. Bathymetry Data for Offshore Wind and Wave Energy

Bathymetry data for the area surrounding the Island of Mauritius was obtained from the National Centres for Environmental Information administered by the National Oceanic and Atmospheric Administration (NOAA), see Figure 85. This information shows that the ocean floor falls away very quickly in most of the areas surrounding Mauritius, quickly reaching depths of up to 3,000 metres. Only the red coloured areas immediately surrounding the island are less than 500 metres in depth. Therefore, the placement of both offshore wind turbines and wave energy converters will need to be spread out over a significant area along the coastline to ensure placement in water that are relatively shallow, typically less than 100 metres is ideal. Floating offshore wind turbines can operate in deeper waters, however, costs for anchoring to the sea floor and running connecting high voltage cables will increase. One of the recommendations of this report is to fund a study to gather more detailed bathymetry data around both the island of Mauritius and Rodrigues to determine the best locations for the installation of these offshore technologies. This type of study could be combined with other marine studies that require bathymetry data to save costs.

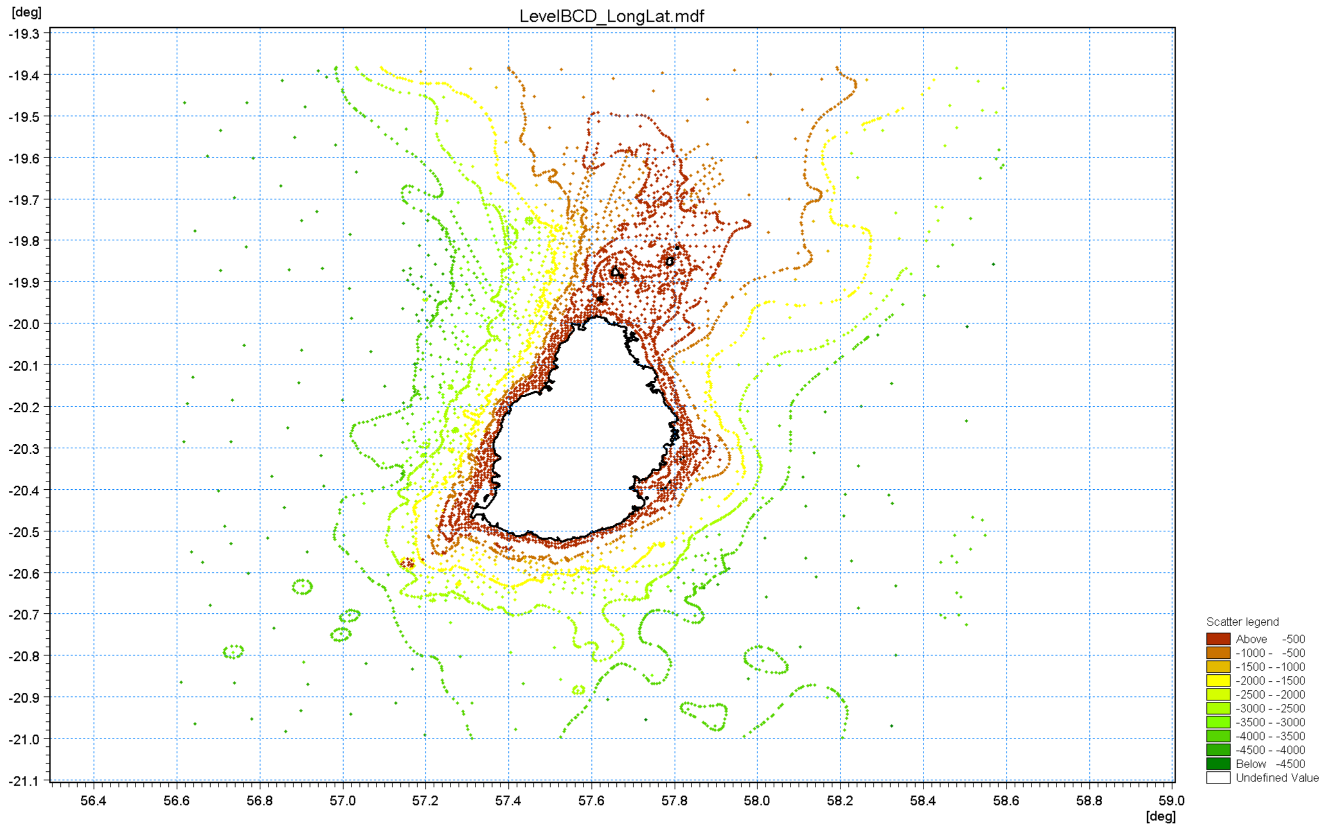


Figure 85: Bathymetry data for Mauritius and surrounding area

7.3. Conclusions

The modelling revealed that to achieve a renewable energy contribution higher than 45% required offshore wind and wave technologies to be considered. One of the recommendations of this report is to fund a study to gather more detailed bathymetry data around both the island of Mauritius and Rodrigues to determine the best locations for the installation of these offshore technologies.

Scenario 4 meets the target renewable energy penetration with low excess energy production while offering a diverse mix of renewable energy generation sources. This scenario comprises an increase in both solar PV and onshore wind over the 2025 target plus the addition of 220 MW of offshore wind and 220 MW of wave energy. This scenario is reliant on the CEB to expand the solar PV schemes to increase the total solar PV from an estimated 140 MW in 2025 to 420 MW around 2030. Similar, onshore wind energy needs to expand from an estimated 100 MW in 2025 to 200 MW around 2030. With the right incentives in place along with falling prices for both solar PV and onshore wind, these targets should be easily achievable within a 10-year timeframe out to 2030.

The most significant generation change will require the installation of 220 MW of both offshore wind and wave energy. As the installation is due to occur sometime after 2025, there is sufficient time for the technology to mature and for Mauritius to play a part in the development of these technologies by participating in research and development. This could involve the deployment of offshore wind and/or wave energy technology as a demonstration project over the next 5-year period prior to the roll-out of 220 MW of both offshore wind and wave energy to meet the 60% renewable energy target.

It is also important to note that due to the longer-term time frame of the proposed 60% renewable energy target, there are many other policies, schemes, and local changes that could impact the percentage of renewable energy achieved in a 10 plus year timeframe. For example, should an effective energy efficiency scheme be rolled out across Mauritius, the anticipated growth in demand may be curtailed and therefore, instead of achieving the 60% target it may be possible to achieve a higher percentage of 65% or 70%.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8. Managing Power System Integrity with High Levels of VRE Sources into a Common Grid

The intermittency of Variable Renewable Energy (VRE) has been well studied and documented in many papers and journals over the years. Many electrical utilities around the world including the CEB have expressed concerns over high penetration of VRE into the distribution grid. The concerns relate to grid management, operation and generation planning for the local grid, in particular, how to address variability in solar PV generation caused by cloud effects and wind generation due to varying wind conditions.

Network problems occur when VRE generation variability (seen as negative loads) could not be accommodated by the baseload generation in the required step change (both amplitude and duration). The potential mismatch in the response in the existing mix of baseload generation and the dynamic load pattern of the VRE can lead to power quality issues and even network outages. Potential effects include voltage peaks and troughs, harmonic distortions, inadequate spinning reserve capacity of existing generators leading to generator trips, step load requirement exceeding current energy generation mix and inability to plan generation capacity due to the variability.

There is potential for local feeders and substations to experience specific power system issues, something that this study has not attempting to identify and resolve. Further power systems modelling would be required to specifically deal with local effects.

This study details the effects of both solar and wind integration to the existing Mauritius grid, identifying which further studies are required to maximize the amount of solar and wind energy that can be integrated into the Mauritius grid firstly without integrating battery energy storage systems and determine some economic scenarios that would allow higher penetration of VRE into the grid. This study also reviews the possible effects of wave generation systems such as the CETO system and the possible effects caused by the inclusion of wave generation into the 2025 Mauritius grid.

This section will focus on the following:

- Current Planning Criteria's
- Mauritius network current architecture and upgrades in planning to achieve 35% renewable target.
- Total variability effects on integrating solar energy systems by distributing the systems geographically in the grid.
- The role of battery storage in the network.
- Control System Architecture.
- Wave generation effects on the grid.

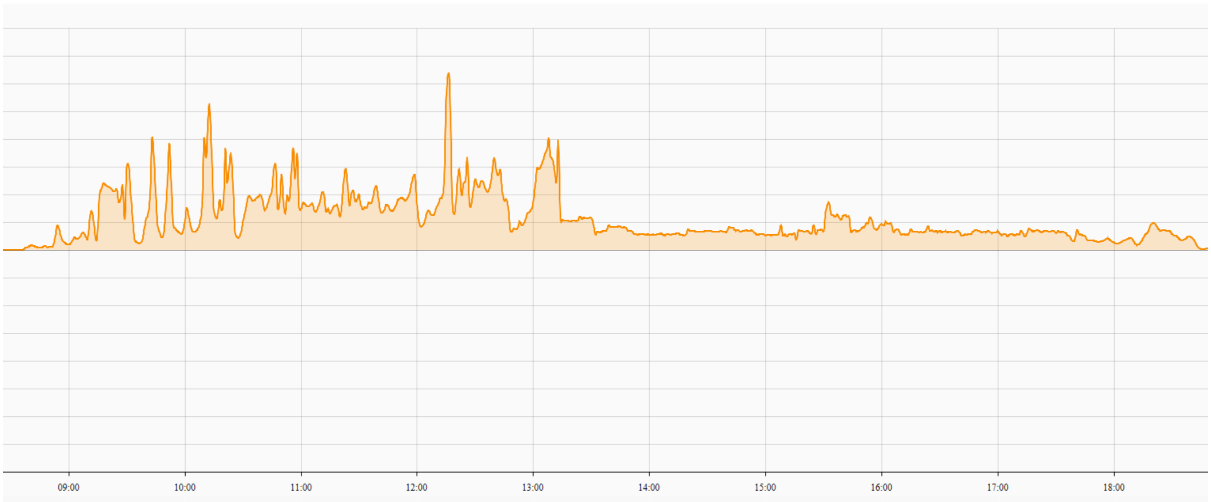
To determine the total wind and solar capacity of a grid requires complicated networks studies to be carried out using sophisticated power systems tools. The CEB is currently undertaking these studies for the Mauritius electricity grid and expects the results to be available in 2017.

8.1. Baseload Vs Variable Renewable Energy (VRE)

Baseload power plants are an energy source designed to produce constant power output reliably from fuel sources that can be stored and dispatch in a managed process. Baseload plants are the production facilities used to meet some or all of Mauritius's continuous energy demand, and produce energy at a flat predictable rate, designed to be at a low cost relative to other production facilities available to the system. Examples of baseload plants using non-renewable fuels include diesel and coal-fired plants. Baseload plants typically run at all times through the year except in the case of repairs or maintenance. These plants are often designed for relatively high efficiency, and may be combined cycle plants, but may take several minutes/hours/days to start up and shut down. Most of the baseload comes from the IPP power plants with coal producing 40%, Bagasse producing 17.3% and CEB diesel at 37.1%. Traditional base load plants have high carbon emissions and technological development to produce cleaner, low carbon energy is being investigated.

A large electricity grid, such as the Australian grid, has been developed in a fairly ad-hoc manner as the country was industrialised, new generation was added and grid extensions were required. This is the case for all developed and developing countries such as Mauritius.

The variation in solar power without cloud cover during a typical day of the year is highly predictable. This is because the movement of the sun is very well understood. However, the presence of clouds that can pass over solar power plants makes the modelling less predictable and this results in limited generation for short periods of time. Cloud movements can be fast and this results in changes in the output of individual PV systems, but the impacts on the electric grid are minimized when solar projects are spread out geographically. The variability of a cumulative solar capacity spread over a large area can smooth out the cloud effects as studied in Alice Springs, Australia, see case study in Chapter 8.5. For MW scale photovoltaic (PV) plants, clouds typically affect only a portion of the solar modules at a given time while the clouds travel through the entire solar plant layout. Typically, the cloud effects are not as severe for large utility scale PV systems due to the physical area covered by the solar panels compared to smaller systems. On an overcast day, the solar irradiance % on the solar cells can be between 20% to 120% instantaneously due to direct and indirect sunlight. The graph below shows the typical variability in solar production from a 10kW site in Western Australia from 9am to 6pm.



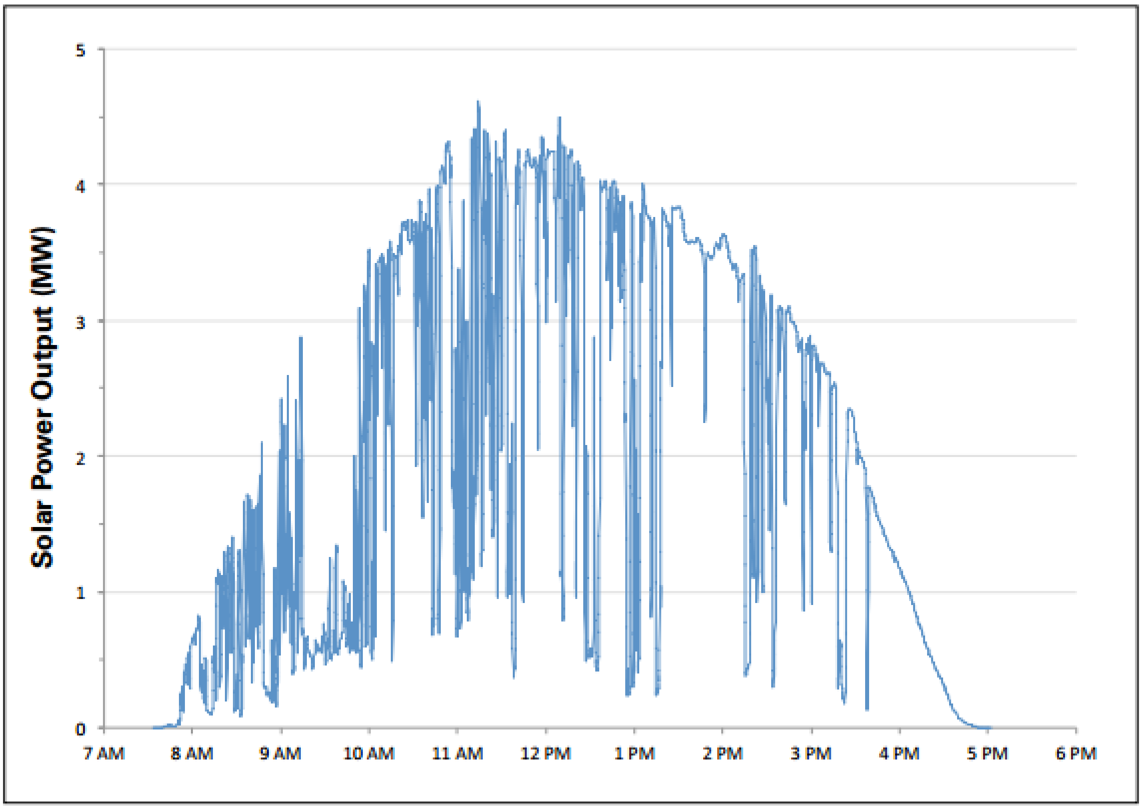


Figure 86: 10 second output from a solar PV plant in Arizona which has an installed capacity of 4.6MW.

Figure above shows that a large 5MW plant has the potential to vary in output from 4.6MW to 1MW in a matter of minutes. This variability poses challenges for a traditional grid and the operators to manage the fluctuations. Typically, this type of fluctuation is only considered for thermal generation failures which only occur 1-2 times a year with an output feeder protection trip. The challenge is then for a power system to be able to continuously balance these solar power effects with traditional generation sets by maintaining adequate spare capacity (called Spinning Reserve) and adequate step load capacity. Typically, a change of over 50% in output level for a diesel generator can be challenging and inadequate delivery of power in time could lead to system failures.

Wind energy is the least predictable of all of the variable renewable energy sources. Some grid authorities use day ahead forecasting to determine which of the available power sources to use the following day. The differing correlation between wind output and prediction can be relatively high, with an average uncorrected error of 8.8% in Germany over a two-year period (Bernhard Ernst 2002). Where predictions are possible, a historical analysis can be used to model the output of a selected wind farm based on past wind data performance information. Historical wind data is typically used to calculate possible renewable energy annual yield and can also be used to evaluate the dynamic effects of an installed plant. Figure 87 shows the variability of wind power output over a 5-minute period (Left) and over a 24 hour period (Right).

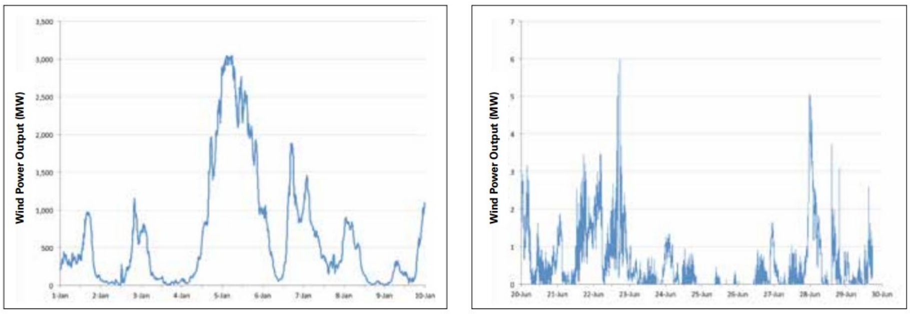


Figure 87: Example of wind power output 5-minute data on the left and second data over a 10-day period on the right.

Wind energy needs to be considered as just one aspect of a variability in a dynamic electricity system. At modest penetration levels, the variability of a wind turbine is dwarfed by the normal variations of the system load. Since the variations are masked by the system load variations, it can be difficult to isolate wind power variation and its particular effects to the baseload generation. The size and the inherent flexibility of a power system are crucial aspects in determining the power system's capacity to absorb large amounts of wind power.

The variability of wind power needs to be examined in the wider context of the power system instead of individual site analysis. The wind resource is not consistent over any island and there can be little impact if the wind stops blowing in a particular site. This is because the variation again would be masked by the system load variation. This lack of correlation between locations means that at a system level, wind can be used to provide stable output even though the wind resource is inconsistent at a given location. In the case of Mauritius, it is particularly important, as analysis has shown, that the natural movement of the wind on the island varies across parts of the island. This would result in a lower effect on the overall power system.

In terms of overall power system, it is not relevant to consider the case when a wind plant varies its output, due to local wind conditions. Earlier studies have been performed that shows that until wind power exceeds 10% of total electricity demand, there is a little impact on combined load variability. Additional fast acting power sources must be included to achieve power system stability with higher installed wind capacity.

Understanding the reasons for variations and their predictability is key to optimal integration and utilisation of wind power in the power system. Power systems are variable both in terms of demand and supply and they are to be designed to manage these variations through their configuration control, dynamic control and network design.

Figure 88 and Figure 89 below shows two full days of irradiance data from the same monitoring location (site in northern Australia). The samples are 5 second averaged values taken across the daylight hours. One day shows a clear sky and therefore a full irradiance profile and the other day with highly variable irradiance due to intermittent cloud cover. These two days represent the extreme ends of the spectrum in terms of irradiance variability and are a useful starting point to understand its impact on PV generation (CAT Projects & ARENA for public distribution 2015).

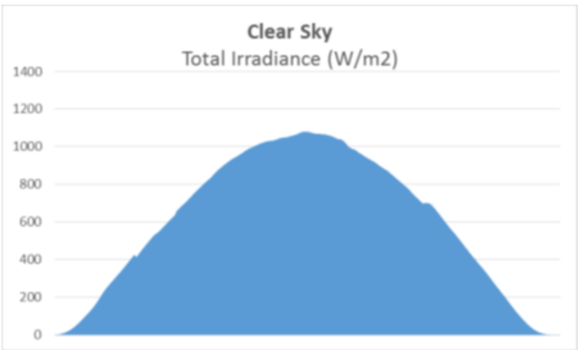


Figure 88: Total Irradiance Clear Sky

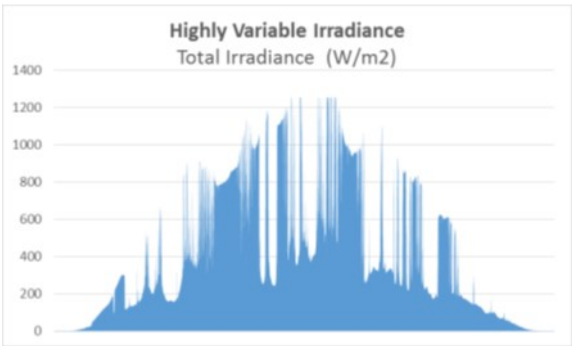


Figure 89: Total Irradiance Cloudy Sky

The traditional grid is designed such that power generation output is regulated in a planned manner and is generally not reactive. In this regard, the Mauritius grid comprises the components as shown in Figure 91.

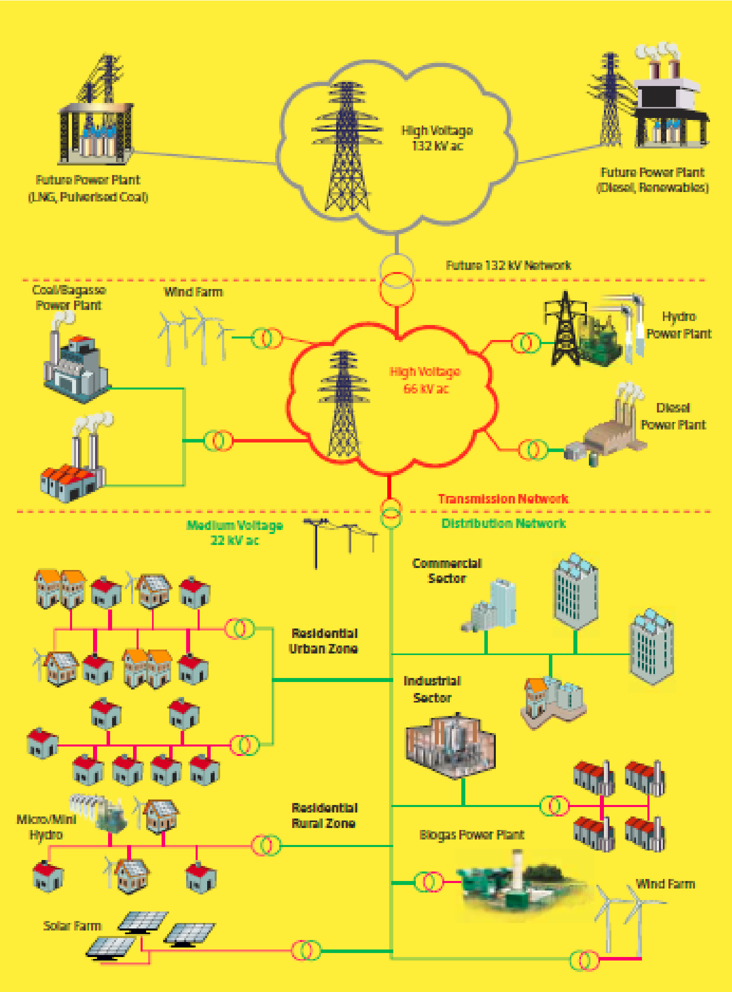


Figure 90: Mauritius Electricity Network (CEB 2012)

Over time the CEB has carefully planned and constructed a number of baseload and peaking plants. The network has grown to include 66kV transmission lines and plans are in progress to consider higher voltage levels to 132kV.

Table 127: Baseload Coal and Bagasse power plants

Name of Power Station	Location	Year of Operation	Installed capacity (MW)	Effective capacity – bagasse	Effective capacity – coal (MW)	Energy Source Used	Cold to full Load startup time
Consolidated Energy Limited (CEL)	Beau Champ	1997	24.5	12	22	Coal/ Bagasse (to 2015)	12 Hours
Alteo Energy Limited (ex	FUEL	1998	36.7	20	27	Coal/ Bagasse	12 Hours
Terragen Ltd	Mapou	2000	71.2	46	62	Coal/ Bagasse	12 Hours
OTEOSA (ex	Saint Aubin	2005	34.5		30	Coal	12 Hours
OTEOLB (ex	L'escalier	2007	90	65.5	74	Coal/ Bagasse	12 Hours
MSML (ex Me-	Bambous	2015	21.7	11		Bagasse	12 Hours
Total			**278.6**	**142.5**	**215**		

Table 128: HFO diesel and Kerosene power plants.

Power station	Unit	Technology	Date Commissioned	Capacity [MW]	Operation Schedule	Is AGC Installed	Year AGC on-line	Cold to full load startup time
Fort George	G1	Thermal, plant, diesel engine, slow speed	1992	127	Frequency and Load Control	No	2017	<20 mins
	G2		1993					
	G3		1997					
	G4		1999					
	G5		2000					
Saint-Louis	G1	Thermal, plant, diesel engine	1978	25				
	G2		1978					
	G3		1979					
	G4		1979					
	G5		1981					
	G6		1981					
	G7	Thermal, plant, diesel engine, medium speed	2006	40				
	G8		2006					
	G9		2006					

Power station	Unit	Techn-ology	Date Commi-sioned	Capac-ity [MW]	Operation Schedule	Is AGC Installed	Year AGC on-line	Cold to full load startup time
Fort Victo-ria	G1	Thermal, plant, die-sel engine medium speed	2010	28	Frequency and Load Con-trol	No	2017	<10 mins
	G2		2012					
	G3		2012	56				
	G4		2012					
	G5		2012					
	G6		2012					
	G11		1989	28	Load Control			
	G12		1989	28	Load Control			
Nicolay	G1	Thermal , plant, open-cycle gas turbine	1988	72	Used for peaking and emergency condition on last priority (Frequency and Load control availa-ble)	No	N/A	<1 min
	G2		1991					
	G3		1995					
Total				364				

Table 129: WTE power plants

Name of Power Station	Location	Year	Installed Capacity (MW)	Effective capacity (MW)	Operation Schedule	Cold to full load startup time
Sotravic Ltee	Mare Chicose	2011	3.3	3.0	Scheduled on 24/7	>10 mins
Total			**33.3**	**33.0**		

Table 130: Hydro Power Plants

Name of Power Station	Location	Year of Commis-ioning	Installed capacity (MW)	Effective capacity (MW)	Operation Schedule	Cold to full load startup time
Champagne	Mahebourg	1984	30	28	Requirement for peak-ing and emergency condition	2 Mins
Ferney	Mahebourg	1971	10	10	Depending on water availability	2 Mins
Tamarind Falls	Henrietta	1945	11.7	9.5	Depending on water availability	2 Mins
Magenta	Henrietta	1960	0.94	0.9	Depending on water availability	2 Mins
Le Val	Riche en Eau	1961	4	4	Depending on water availability	2 Mins
Cascade Cecile	Surinam	1963	1	1	Depending on water availability	2 Mins
A.I.A (Reduit)	Reduit	1984	1.2	1	Depending on water availability	2 Mins
La Ferme	La Ferme	1988	1.2	1.2	Depending on water availability	2 Mins
La Nicoliere F.C	Nicoliere	2010	0.35	0.35	Depending on water availability	2 Mins
Midlands	Midlands	2013	0.35	0.35	Depending on water availability	2 Mins
Total			**60.74**	**56.3**		

One of CEB's objectives has been to increase the population's confidence in its capability to ensure reliable, affordable and sustainable electricity supply for Mauritius and Rodrigues. After ten years, CEB has been successful in delivering projects and policies that deliver on its objective (CEB 2012). CEB is proud of its recent performance achieving almost 100% grid availability for the last 4 years which is an achievement.

CEB must maintain enough supply from this very complex system, within a narrow range of frequencies and voltages, to meet constantly fluctuating demand at all times. The CEB strategy to date has been to be risk-averse, preferring to stick with what they know to be reliable, and avoiding untested power sources and unproven technology which is typical of most utilities.

The generation profile and load profile for Mauritius is set to increase steadily as detailed in Chapter 3, with the total installed effective capacity projected to increase from about 672MW to 1031MW from 2015 to 2025. With the changes to the energy generation mix detailed in Chapter 7 to achieve a 60% renewable energy contribution to load, it is crucial for the CEB to develop renewable energy sources to deliver the increase in installed capacity, while achieving this target.

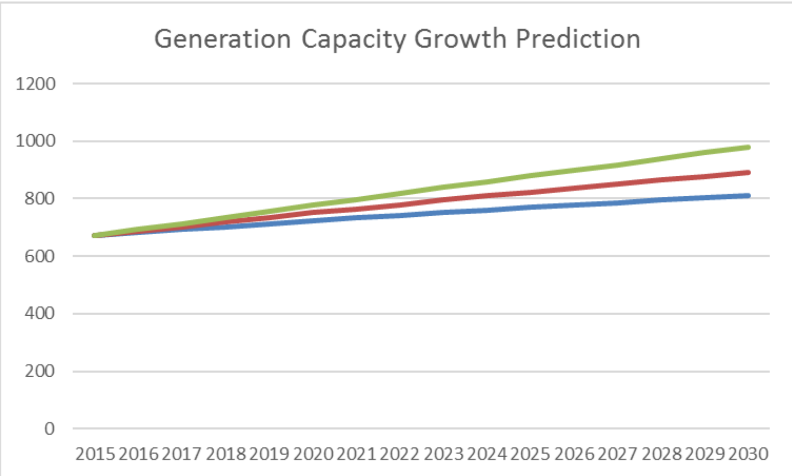


Figure 91 : Generation Capacity Increase based on 4% median growth to 2030

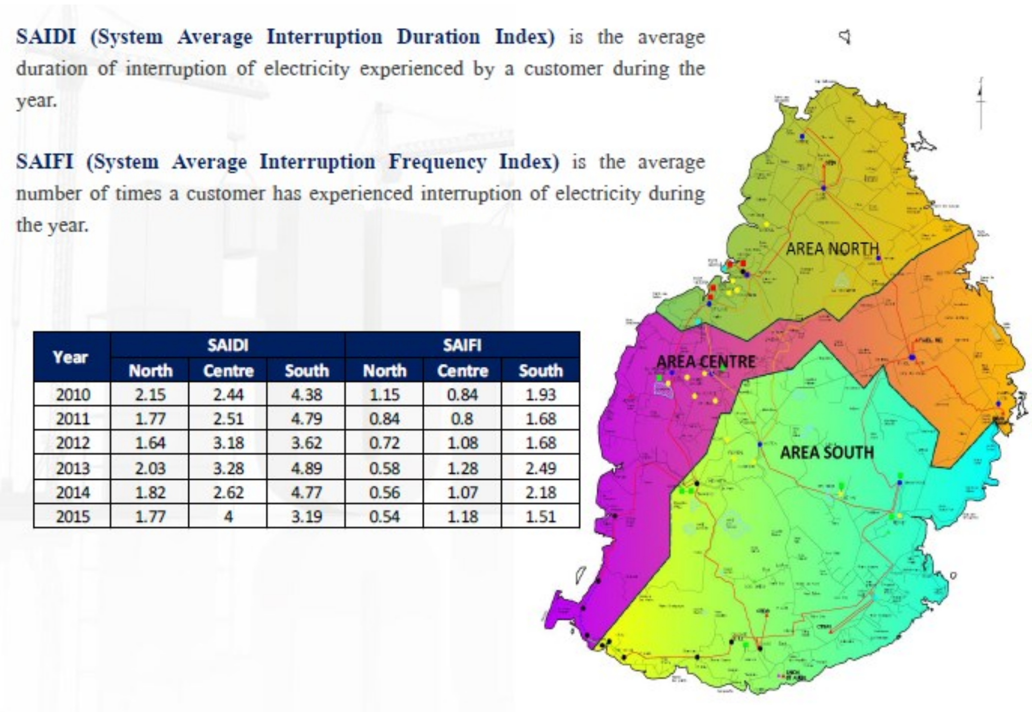
8.2. CEB Planning Criteria

The CEB consider the following as factors in considering the network planning to meet the future demands and higher penetrations of VRE (Mr. Shamshir Mukoon 2016):

- First and foremost N-1 planning criteria
- Power Transfer Requirements
- Location and Size of major loads
- Location and size of local generation
- Location and size of new generation including VRE sources
- Expected retirement of generation
- Least cost network augmentation while minimizing network losses
- Environmental constraints

Table 131: Mauritius Grid Availability 2008-2015

Grid availability		
Year	Time grid Not Available, Hr	% Availability
2008	2	99.98
2009	0	100.00
2010	3	99.97
2011	5	99.94
2012	0	100.00
2013	0	100.00
2014	0	100.00
2015	0	100.00



SAIDI (System Average Interruption Duration Index) is the average duration of interruption of electricity experienced by a customer during the year.

SAIFI (System Average Interruption Frequency Index) is the average number of times a customer has experienced interruption of electricity during the year.

Year	SAIDI			SAIFI		
	North	Centre	South	North	Centre	South
2010	2.15	2.44	4.38	1.15	0.84	1.93
2011	1.77	2.51	4.79	0.84	0.8	1.68
2012	1.64	3.18	3.62	0.72	1.08	1.68
2013	2.03	3.28	4.89	0.58	1.28	2.49
2014	1.82	2.62	4.77	0.56	1.07	2.18
2015	1.77	4	3.19	0.54	1.18	1.51

Figure 92: SAIDI and SAIFI figures for Mauritius

8.3. The Mauritius Grid Architecture

The Mauritian transmission network, consists of sixteen major substations and 300 kilometres of single-circuit transmission lines. The transmission network is made up of a mix of underground cables and overhead lines. Figure 93 shows a high-level representation of the transmission network.

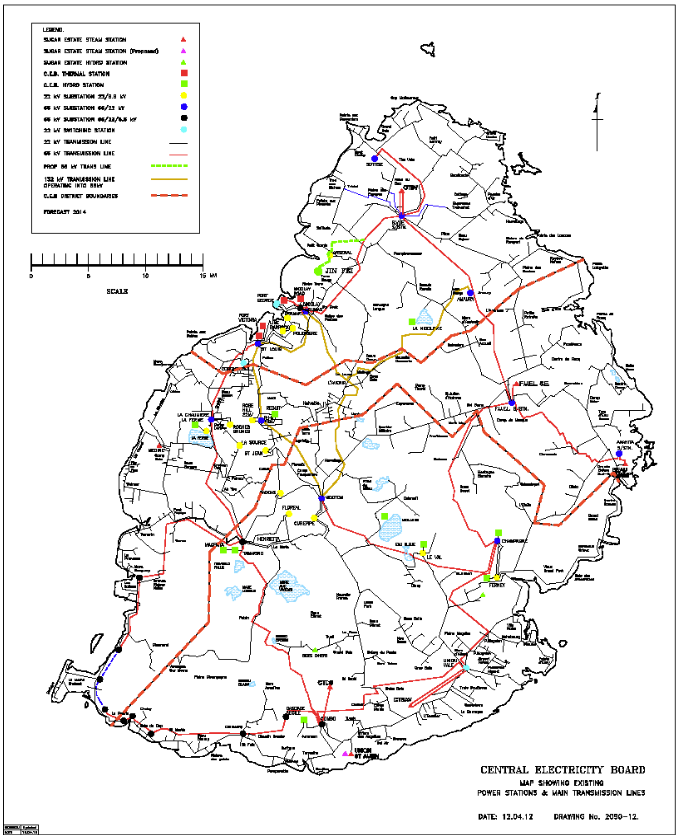


Figure 93: Mauritius Electricity Network – Geographic representation.

Today, CEB delivers electricity to approximately 422,000 customers across the island through its distribution system, which operates at medium voltages of 66kV, 22 kV and 6.6 kV and low voltages of 230 V single-phase and 400 V three-phase. As at 2011, CEB had approximately 8,450 kilometres of electric distribution lines. The break-down of the line length, in terms of different voltages and types of cable, is shown in Figure 85.

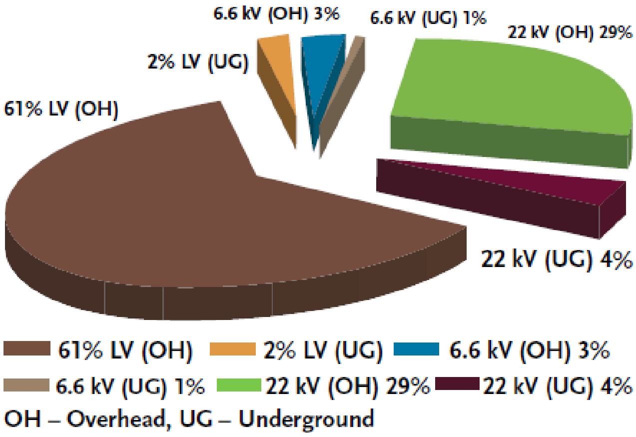


Figure 94: Mauritius Electricity Network – Voltage Distribution.

Investigations performed to date ((CEB 2012) seems to suggest that an additional 100MW of baseload generation would require the existing 66kV network to be upgraded to 132kV Transmission System. This would mean significant investment in upgrading the current lines, substations and protection systems.

The CEB has made a strategic decision to avoid an upgrade the current transmission network to 132kV, instead the CEB are planning to meet demand using distributed generation means, however, the CEB have challenges to overcome before the upgrade to 132kV can be avoided.

8.4. Current network strategies planned to meet the 2025 target.

As described in Chapter 4 of this report, the CEB is progressing well to achieving the 35% target well ahead of the targeted 2025 aim.

Strategies by the CEB to boost the spinning reserve and step load capacities of the power system include a number of planning areas:

1. Network upgrade to 66kV and 132kV to create a large interconnected system;
2. Increasing the N+1 security for radial feeders and substations;
3. Increased voltage regulation in the network using tapped transformers;
4. Studies related to Grid Absorption Capacity;
5. Review of Grid Codes;
6. Implementing Battery Spinning Reserve in the network; and
7. Upgrading existing Power Station dispatch strategies.

This report supports further strategies to address the goal to higher renewable penetration of the network. This report also identifies that optimising the renewable energy output to load usage is crucial to increasing the energy penetration without the use of batteries to shift excess renewable energy to loads at a delayed timeline.

8.5. Strategies to enhance current planned upgrades

Strategies 1-5 in Section 8.4 are current network strategies planned to meet the 2025 target. These strategies are also part of the overall plan to achieve higher renewable energy penetration by the CEB and these are not elaborated further as part of this report. This report specifically considers enhancements to Strategies 6 & 7 and a new strategy to deploy distributed VRE to mitigate any intermittency effects of

VRE. This looks at the benefits of distributed VRE with the support of a detailed study commissioned in Australia by a common body called CAT.

Strategy 6 looks into the roles of battery storage in Mauritius. This report identifies two specific areas where battery storage can be deployed. First, on the grid with large grid connected energy storage systems providing short term spinning reserve and peak lopping functions on the grid. Second, is the role of advanced energy storage systems with ability to island from the main grid and form a smaller gird (Microgrid) in the main grid. The move to “island-able” grids are being trialled in Australia and throughout the globe. Western Power, a utility in Australia, published its concept of the state of the future grid

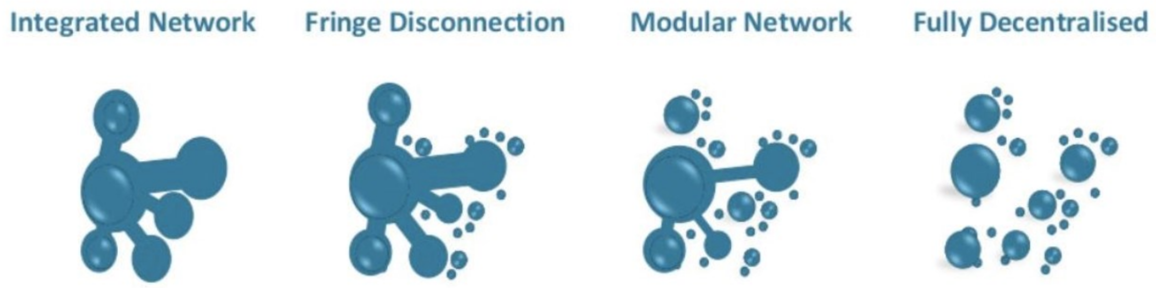


Figure 95: Future Electricity Grid – Western Power

This concept believed that the current model of central dispatching and transmission of energy is a concept of the past and the modern grid is moving towards a model with load centres and generation matched to those load centres. The concept also supports the islanding of smaller loads (especially in unpopulated areas) to exist with hybrid (solar/battery/diesel) solutions to avoid inefficient CAPEX and also reduce transmission loses. There are a number of cultural, legal and political hurdles that need to be overcome to progress to such a model and Western Power are one of the pioneers in the world to have undertaken such a trial in 2016. Refer to “Case study of Western Power Fringe of Grid Trial 2016”.

8.5.1. The Role of Battery Storage beyond 2025

8.5.1.1. Battery Technologies

Battery technology has been around for many years. The world now is familiar with the batteries used in many day-to-day applications such as phones and cars. Larger scale batteries have been commonly used in commercial applications such as telecom and sea vessels as UPS backup systems for emergency power. Five years ago (2011), the most common batteries used for power generation in remote off-grid solutions have been lead acid batteries. Companies like EMC has been a pioneer with deploying off-grid solutions and have a deep understanding of the technological and commercial breakthroughs that is needed to make batteries viable for off-grid and on-grid applications.

Six potential benefits of bulk energy storage systems into the electricity grid are:

1. Allowing time shifting of energy to balance electricity supply and demand at a reduced cost;
2. Supplying capacity credit to delay investments in generating capacity;
3. provide grid voltage and frequency support to facilitate smooth, coordinated operation of the components of the electricity supply system;
4. providing peak lopping support to delay investment of the transmission and distribution system;
5. Power quality support by supplying energy to the system with very short response times; and
6. Allow integration of VRE by smoothing their energy output.

Dual aspects of electricity are important to understanding technology and applications of storage: power and energy. Energy can be thought of as a volume (i.e. a kilowatt-hour), while power can be thought of as a rate of flow (i.e. a kilowatt). Some applications, such as load shifting across hours, require a large volume of energy storage capacity. A storage device like pumped hydroelectric power is well suited for this type of application. Other applications, such as real-time voltage stabilization, require a large responsive power capacity. A storage device like a flywheel is well suited for this type of application. So, it is important to match the application with the storage technology, Figure 96 shows the discharge rate of different storage technologies.

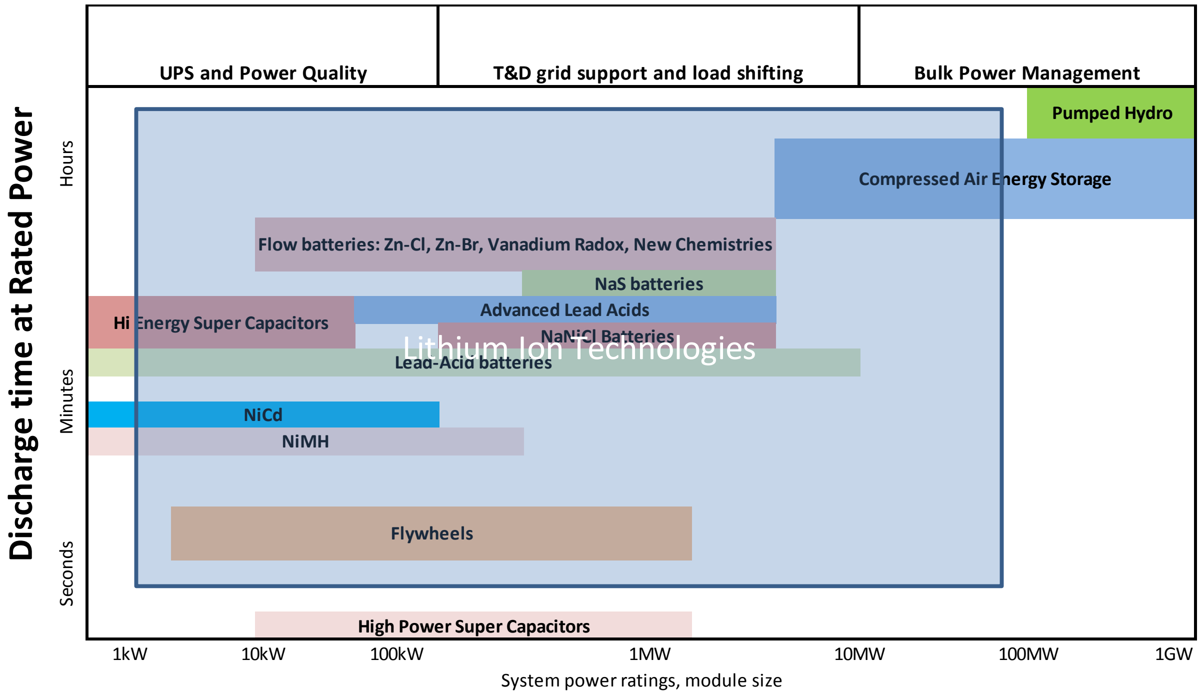


Figure 96: Characteristics of different energy storage technologies

Spinning reserve is the main functionality required by the grid and therefore any technology that is capable of delivering approximately 2 minutes of energy at a very fast step response has been considered. For VRE management a fast step response is required and therefore a source needs to be able to discharge its energy quickly.

Flywheels, Super Capacitors, and Batteries have been considered. Flywheels and super capacitors are fast acting and can deliver up to 30 seconds of energy however this is not sufficient time to start up a HFO generator and have therefore been discounted. Battery storage is capable of operating over a wide range of operations, as such both Lead Acid and Lithium Ion batteries have been considered. Lead Acids while cost effective don't have a very long cycling life and can be quickly damaged if overused. Lithium Ion batteries are a more expensive option but are capable of long cycle lives and are more resistant to damage.

The Lithium Ion technology is chosen because of its wide range of operations (seconds to hours of energy, 1kW to 30MW of power) and its commercialisation forecast. This technology is predicted to the best option for static large scale energy storage systems providing high energy density and the relative cost predictions.

	Cost	Capacity (KWh)	Includes inverter?	Cost/KWh	
				With inverter	After deducting inverter cost
Tesla Powerwall2	$5,500	13.5	Yes	$407	$259
LG Chem RESU	$4,000	6	No	n/a	$667
Orison	$1,600	2.2	No	n/a	$727
Sonnen	$5,950	4	No	n/a	$1,488
Sunverge (small)	$8,000	6	No	n/a	$1,333
Sunverge (large)	$20,000	23	No	n/a	$870
Powervault (UK)	$3,000	6.6	No	n/a	$455
ElectrIQ	$10,000	10	Yes	$1,000	$800
Nissan	$4,500	4.2	No	n/a	$1,071

Figure 97: Comparison prices for Lithium Ion in 2016 (Tesla's Powerwall 2: The Right Product At The Right Time n.d.).

8.5.1.2. Lead Acid Battery

In 1859, a French physicist called Gastom Plante invented the lead acid battery and it's the oldest type of rechargeable battery. It typically has a low energy to weight and volume ratio however its capacity for power to weight ratio was high. This made it attractive to be used in motor vehicles to provide the high currents for the stating mechanisms. The mass production of these batteries for cars resulted in the low cost of these batteries we see today.

Lead Acid batteries are lower cost than newer technologies such as Lithium Ion technologies, they are widely used also when surge currents are not important and other technologies provide higher energy densities. Large battery designs are now widely used for storage in backup power supplies in telecommunications, critical infrastructure such as hospitals, and access to remote community power in stand-alone power systems. For these applications, modifications are needed to improve storage cycles and reduce maintenance. VRLA (valve-regulated lead-acid) is a commonly used term to describe Gel-cells and absorbed glass-mat batteries that are commonly used in these sorts of applications.

VRLA is a specially designed deep-cycle lead-acid battery with cells that are less susceptible to degradation due to cycling needed for applications such as stand-alone PV and diesel systems, electric vehicles (forklift, golf cart, electric cars and other) and uninterruptible power supplies (UPS). The batteries have thicker plates that can deliver less peak current, but can withstand frequent discharging.

Some VRLAs are designed as a compromise between high-power and deep cycle characteristics. They are able to be discharged to a greater degree than automotive batteries, but less so than deep cycle batteries.

8.5.1.3. Lithium Ion Batteries

The concept of Lithium Ion battery was invented in the 1970's and saw widespread adoption in the 1990's. The mechanism is that a charged ion of lithium is gravitated back and forth between the cathode and the anode during charge and discharge.

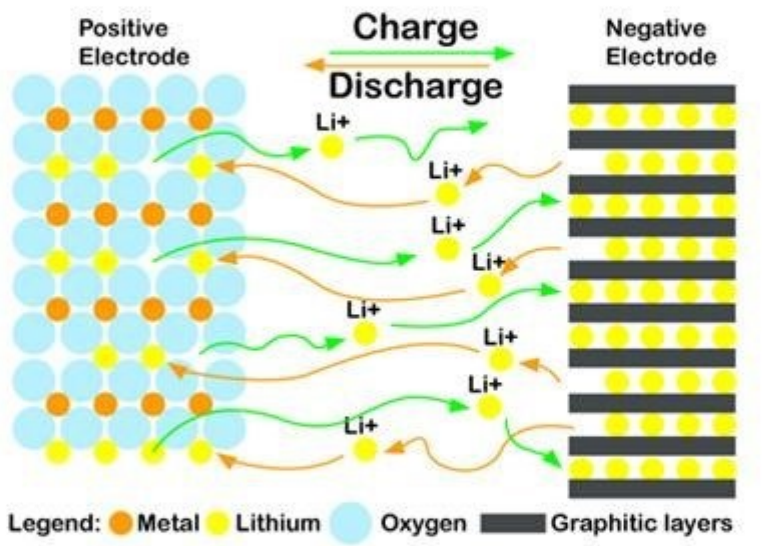


Figure 98: Cell Schematic of a Lithium Ion battery, Source Clean Energy

8.5.1.4. Comparison between Lead Acid and Lithium Ion technology for Mauritius VRE purpose

Battery Energy Storage Systems (BESS) used for renewable capacity using Lithium Ion started around late 2011. A relevant comparison of the lead-acid *to* Lithium Ion technology was made by All Cell group in 2012 and concluded the following (AllCell Technologies LLC 2012):

"Chemistry differences in the cathode, anode, and electrolyte influence cell performance, as does packaging geometry. The cathode chemistry is the factor most commonly altered from cell manufacturer to cell

manufacturer with terms like LFP, NCM, NCA, Cobalt, and Manganese reflecting the cathode chemistry class. Over 90% of Lithium Ion anodes are comprised of graphite; silicon and titanium based materials are occasionally used to get better life and power performance in exchange for significantly higher cost."

Table 132: Lithium Ion Cell Comparison (AllCell Technologies LLC 2012).

	LFP	LiNCM
Voltage	3.3 V nominal (2-3.6 V/cell)	3.7 V nominal (2.7-4.2 V/cell)
Energy Density	300 Wh/L	735 Wh/L
Specific Energy	128 Wh/kg	256 Wh/kg
Power	1000 W/kg	512 W/kg
Cycle Life	2,000 @ 100% DoD 3,000 @ 80% DoD	750 @ 100% DoD 1,900 @ 80% DoD
Calendar Life	6 years	8 years
Max recommended temperature	40°C	55°C
Safety	High	Moderate
Commercial Suppliers	A123, Valence, BAK, BYD, K2, Lishen, many Chinese vendors	Sanyo, Panasonic, Samsung, DowKokam, Sony, LG Chem, Moli

The electrolyte exists in liquid form, but for "lithium polymer" cells, the electrolyte is absorbed in a polymer membrane. This allows for cell manufacturers to use a pouch enclosure on the cell rather than the metal casing used when liquid electrolyte is present in cylindrical and prismatic shaped cells. Each of these variations influences the performance of a Lithium Ion cell. Despite the various chemical variations, Lithium Ion batteries can generally be separated into two groups: lithium iron phosphate (LFP, $LiFePO_4$) and metal oxides (NCM, NCA, Cobalt, Manganese). Table 121 outlines the differences between the two chemistry classes on a cell level. The values in the table reflect average values as there is variation in each class.

All Lithium Ion cells are "deep cycle" meaning that they have the ability to be fully charged and discharged. The life of the battery will significantly increase if the depth of each discharge is limited to 80% of the rated capacity.

Since 2012 companies like EMC has been deploying Lithium Ion technology based standalone systems using Lithium Ion technologies. The transition to lithium Ion was made based on the technology being widely accepted as the commercial choice for static energy storage systems and for use in electric vehicles by major manufacturers in 2012.

Technically the Lithium Ion cells presented a lower weight, wider range of charge/discharge profile and a better performance in life when cycled at both micro level cycling and deep discharge cycling (greater than 90%)

Table 133: Lead Acid to Lithium Ion comparison (AllCell Technologies LLC 2012).

	Flooded lead acid	VRLA lead acid	Lithium-ion (LiNCM)
Energy Density (Wh/L)	80	100	250
Specific Energy (Wh/kg)	30	40	150
Regular Maintenance	Yes	No	No
Initial Cost ($/kWh)	65	120	600[1]
Cycle Life	1,200 @ 50%	1,000 @ 50% DoD	1,900 @ 80% DoD
Typical state of charge window	50%	50%	80%
Temperature sensitivity	Degrades significantly above 25°C	Degrades significantly above 25°C	Degrades significantly above 45°C
Efficiency	100% @20-hr rate 80% @4-hr rate 60% @1-hr rate	100% @20-hr rate 80% @4-hr rate 60% @1-hr rate	100% @20-hr rate 99% @4-hr rate 92% @1-hr rate
Voltage increments	2 V	2 V	3.7 V

In regards to life, the Lithium Ion technology has a far better performance profile compared to Lead-Acid batteries.

Figure below shows cycle life data for a Lithium Ion pack compared to an AGM style VRLA battery in a moderate climate (average temperature of 77°F). As cycle life is influenced by depth of discharge, the figure shows multiple DoD percentages for the lead acid. It can be seen that the AGM pack must be limited to a 30% depth of discharge to get comparable life to a Lithium Ion that is at 75% depth of discharge. This means that the AGM battery must be 2.5 times larger in capacity than the Lithium Ion to get comparable life (AllCell Technologies LLC 2012).

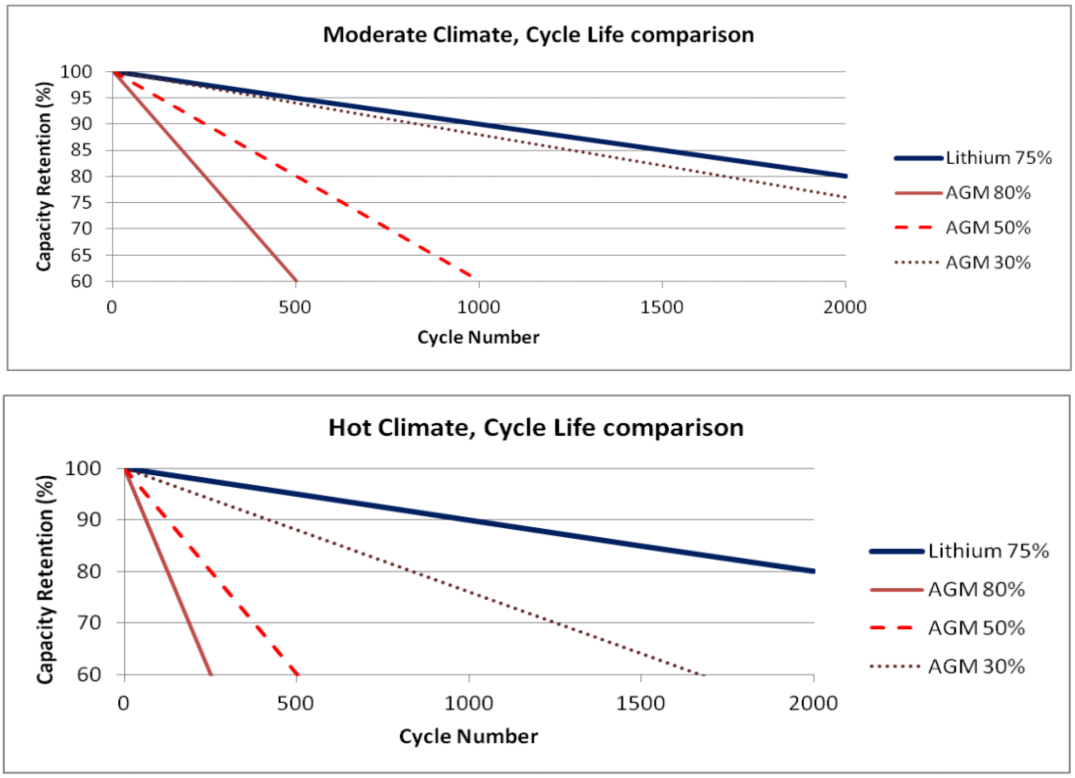


Figure 99: Cycle Life (AllCell Technologies LLC 2012).

The Lithium Ion cell performs better in a number of other factors:

- Discharge rate performance, if fast discharge is required then lead-acid batteries perform poorly.
- Cold weather performance, not applicable for Mauritius
- Environmental Impact. The lead acid battery requires more raw materials (per kwh) and require higher processing. Lithium is not without its own environmental problems. The major components of a Lithium Ion cell require the mining of lithium carbonate, copper, aluminium, and iron ore. Lithium mining specifically is resource intensive, but lithium is only a minor portion of the battery cell by mass, so the aluminium and copper environmental impacts are much more significant.
- Recyclability, the Lithium Ion recycling industry is only in its infancy right now, but the cell materials have shown high ability for recovery and recyclability, so it is expected that Lithium Ion recycling rates will rival lead acid (AllCell Technologies LLC 2012).

Lithium does present a higher density of energy in a smaller volume however now most tier 1 Lithium Ion battery producers have safety systems designed into the battery to prevent “thermal runaway”. EMC has found that experiences with Sony, Samsung, LG, Kokam and Saft have been positive in regards to quality of products supplied, compliance to Australian standards and delivery commitments. Technical and service support has also been good to date.

8.5.1.5. Market moves with Lithium Ion Technology

The take up of Lithium technology has soared since 2012

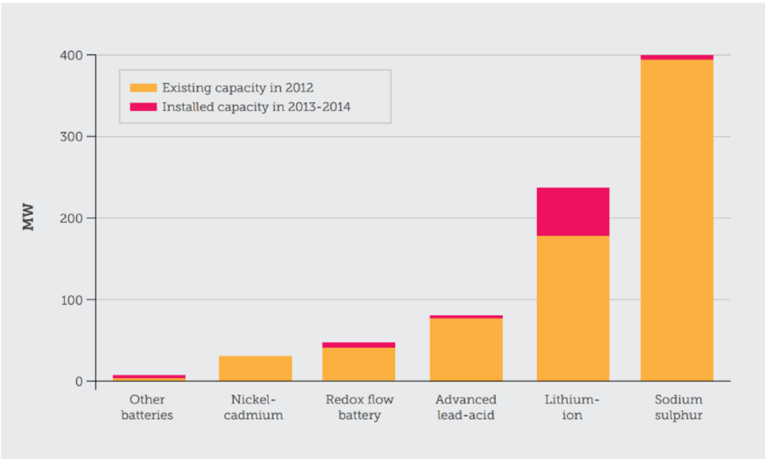


Figure 100: Estimated installed global battery capacity by type for the electricity sector. Source: Navigant Research

Due to the high level of take up of the lithium ion batteries the price trend for this technology has come down enormously over the last 5 years and is expected to continue to decline for the next 20 years in the same rate as PV modules over the last 10 years.

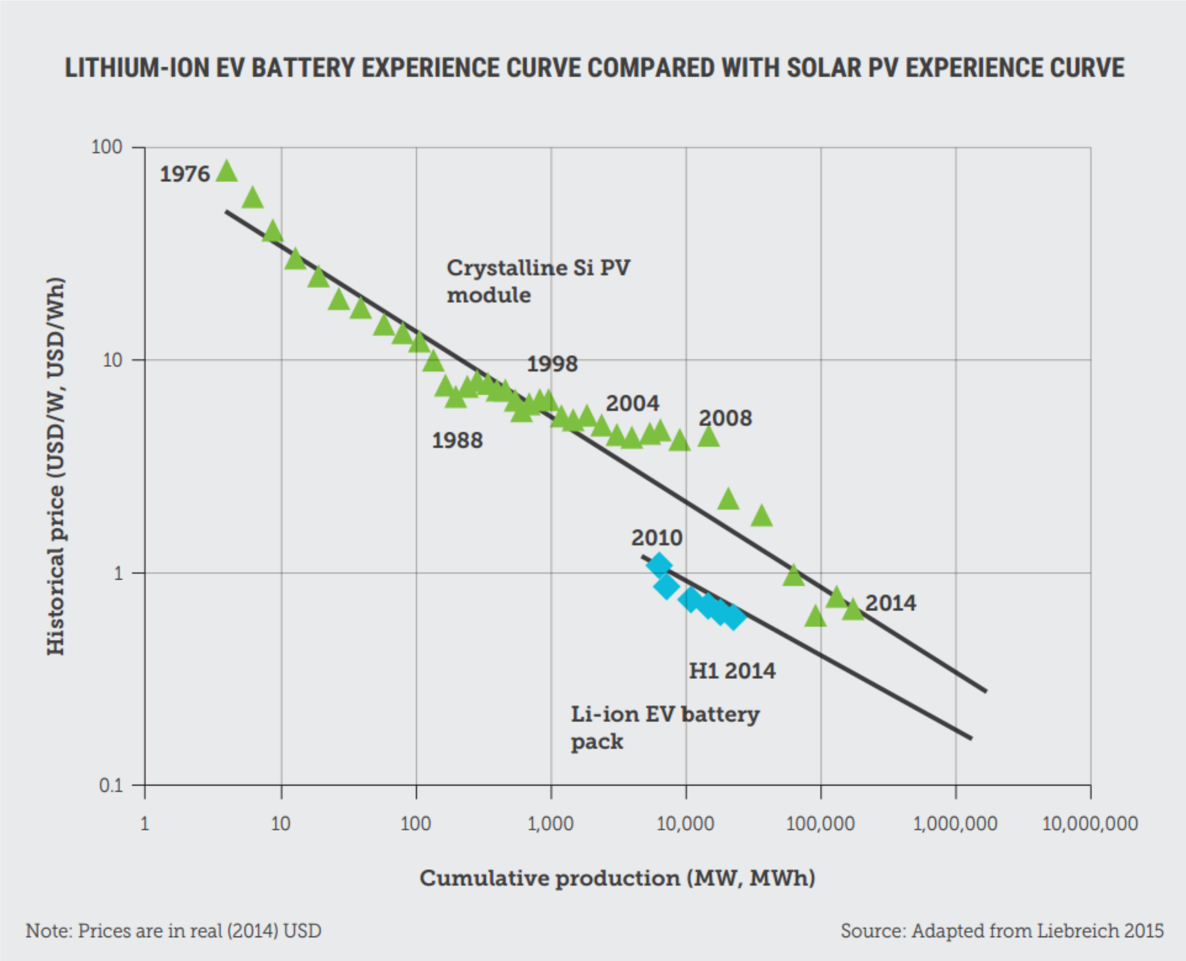


Figure 101: Lithium Ion batteries and solar PV modules are on very similar learning curves for cost reductions.

With new global multinationals like Tesla entering the electric vehicle market and the large scale battery market, the price trend for Lithium Ion batteries are predicted to keep falling which offers great potential and many cost benefits to business cases for the renewable energy industry.

8.5.1.6. Importance of understanding the whole Battery Energy Storage System (BESS)

The requirements of a battery energy storage system is often misunderstood and the total scope of works included in the delivery of such as system. It is commonly observed in industry forums that only the cost of the batteries, are discussed in regards to suitability to the application. Comparisons are made on LCOE based on battery market pricing only. This is a concern as the total cost of the project can be up to 2.5 times more compared to the cost of the batteries.

The battery inverter, containment systems and advanced battery control systems play an important role in the development of renewable energy integration solutions worldwide.

All other generations apart from rotating machines use power electronics to convert the energy to the correct frequency and voltage of the grid. For grid interface inverter technology, two different operating modes are known. The inverter can act as a current source mode inverter (CSI) or as a voltage source mode inverter (VSI) on the grid. It has become standard for inverters to have active front ends and the energy source on the dc link defines the dc voltage.

CSIs inject balancing current into the grid with a reference frequency needed from another source. They are very fast in response but they also need a diesel or grid impedance to work against as the CSI can't establish a grid. On the other hand, VSIs can create a frequency reference of a certain magnitude and frequency. The output current can be 3 Phase balanced or unbalanced and is entirely defined by the requirement from the load. To create an islanded grid a VSI is required to create a grid reference in the event that all other generating sources are offline.

The majority of solar inverters available work in CSI mode only and are designed to convert renewable energy to usable energy with the reference provided by the grid. Even with a constant load it is almost impossible to run a standalone system based on solar or wind CSI inverters only. There still is a need for providing a grid reference and stabilizing the system using a diesel generator. An alternative is to use a VSI with built in inertia that can replicate the grid or diesel generator.

Let's assume the renewable generation capacity is 20% at maximum compared to the diesel generation is used. In this scenario, the diesel generator(s) would still be able to maintain the power system. As the renewable installed capacity increases beyond 20%, advanced control systems are required to dynamically match the renewable output power to the available load or dispatch new loads. Increasing renewable penetration further (>50%), a traditional diesel generator set won't be able to deliver a stable response. Another form of grid stabilization is needed such as a dynamic energy storage system where it will be capable of delivering real and reactive power at rapid step change. Typically, a reaction time of <200mS is required to hold the stability of the system and could extend to several seconds to allow for the start-up time of traditional generators. Approximately 20-60 seconds are usually sufficient for that purpose but the cycle rate can be very high. When the cycle rate is very high, storage technologies like flywheels or super capacitors have a real advantage here over batteries due to the high cycling life. The inverter used must be a Voltage Source Inverter (VSI) as the system itself must maintain voltage by delivering reactive power and maintain frequency by real power support in real time.

The need of grid stabilization support for renewables is often misunderstood and assumed to be some kind of storage system is part of the project specification. Typically, a functional description of how to control and how to manage the grid is not available. This is an area that is commonly misunderstood and in some cases, there is an expectation that the energy storage system will take care of the network control.

While other storage technologies could increase autonomy and allow bridging longer periods of time, a storage system alone would not be the answer. A storage systems need to be supervised as well and must be based on a VSI that operates in V/f (voltage/frequency) mode to stabilize the grid. Due to the high variability with VRE additional software controls also need to be implemented to maintain the longevity of the battery system connected. Excessive charge/discharge cycles will degrade the batteries quickly and also unplanned charge and discharge commands could result in insufficient energy capacity to absorb and inject power into the system leading to underloading of generators.

Therefore, the selection of a high end VSI Component and a sophisticated control software is needed to adequately perform the battery storage functions needed in a renewable integration project. The table 134 below shows a CAPEX breakdown for a 1C and a 4C battery solution specifically designed for the renewable energy integration market for a system size of 1MW.

A typical battery storage system comprises the following components:

1. AC Customer Main CB board with protection systems and synchronisation schemes.
2. AC protection for the battery inverter
3. Battery inverter (VSI)
4. DC marshalling, protection and controls
5. Batteries
6. Auxiliary systems (transformer, distribution boards)
7. Containers for Safety, Ambient and Fire protection.

Relative costs of each component are shown in Figure 102.

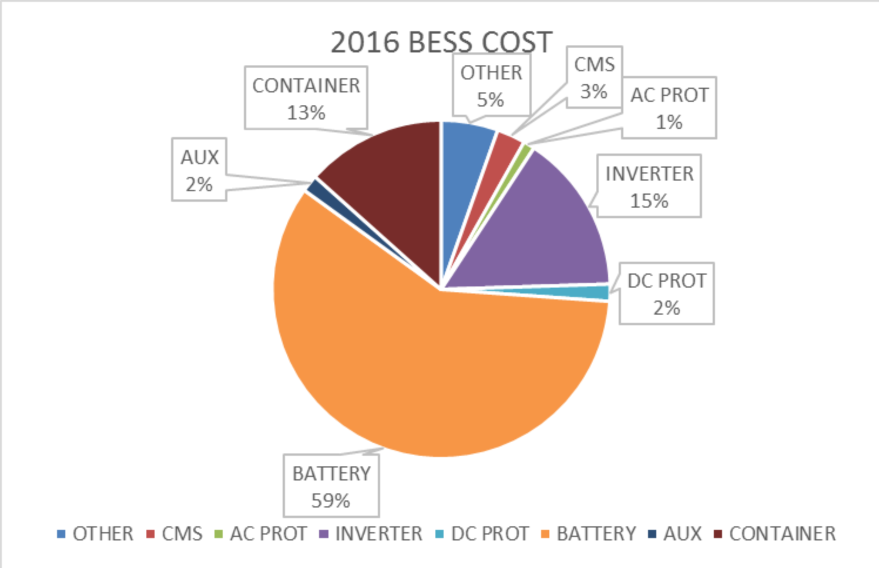


Figure 102: Battery Energy Storage Component Costs (2016)

Projected costs of battery storage systems as the battery price reduces is estimated as shown in Figure 103.

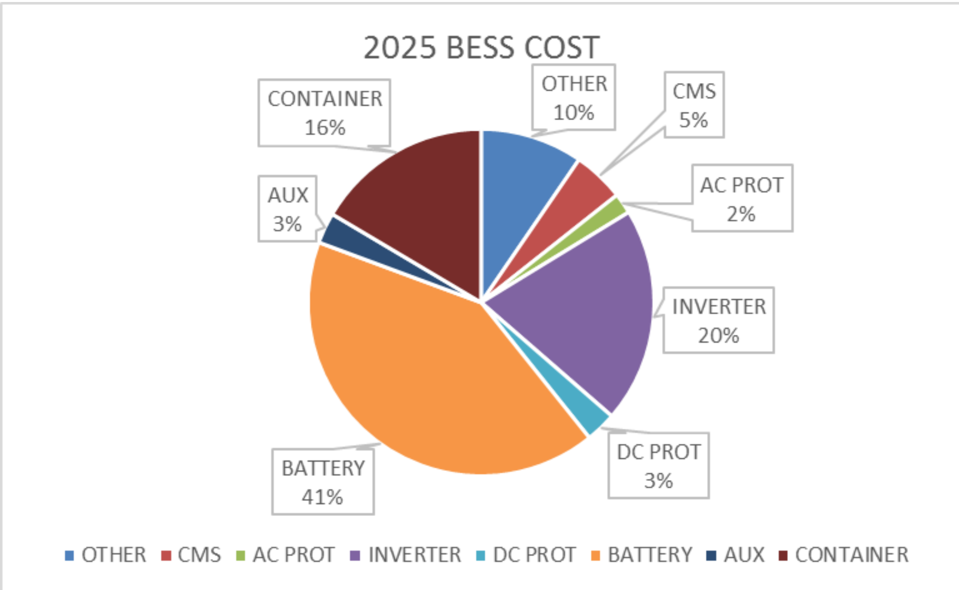


Figure 103: Battery Energy Storage Component Costs (Forecast 2025)

Table 134: Comparative Costs between 1C and 4C Energy applications

Parameters	Samsung SDI – 1C	Kokam – 4C
Footprint	1 x 40ft container for bigger battery	1 x 20ft container
Runtime	56.7 minutes	16.7 minutes
Size (kW)	1MW @ 1C	1MW @ 4C
Size (kWh)	902.5 kWh	252.7 kWh
CAPEX – Battery Storage	$968 kUSD	$605.5 kUSD
CAPEX – Elect. Network	100-500kUSD	100-500kUSD
OPEX	$5,700 to $7,000 USD	

8.5.1.7. Case Studies of battery storage solution in Australia in 2016

The optimal economic case for battery systems in 2016 for renewable energy capacity firming applications on the grid is a 4C solutions. This is because the costs of batteries in 2016 are still high and the most viable trials are focussing on testing the operational functions on the grid that require only short bursts of energy. There has been trials undertaken is NaS batteries for extended battery discharge times however this has not proved economical to date. In 2016 technology developments have allowed EMC to deploy 4C (4 times the power compared to the energy rating, e.g. 1MW/0.25MWh) systems that delivers peak power for 15 mins. This allows for the battery size to be reduced substantially compared to solutions based on 1C applications and lead-acid, for example, that require even higher energy capacities. By reducing the battery size EMC has been able to reduce the solutions CAPEX substantially in order to meet and exceed business cases for spinning reserve and standalone applications throughout Australia and New Zealand.

8.5.1.8. Case study of Western Power Fringe of Grid Trial 2016

The 2015 Esperance bushfires in Western Australia was a devastating fire that burnt 15 to 26 November and affected the entire region south of Perth in the Australian state of Western Australia. This horrific fire, the worst for 50 years in Western Australia, began on 15 November as a result of lightning strike in crown land around the area of Cascade and Scaddan to the north of Esperance. Over the days there was three major fires: the Cascade-Scaddan fire of some 137,000 hectares, the Merivale fire to the east of Esperance of some 18,000 hectares and, further to the east, the Cape Arid National Park, which was the subject again of lightning strike and fire of some 160,000 hectares—totalling in excess of 300,000 hectares burnt. To put that into context, this area is approximately 150% of the entire island of Mauritius, but it is only about six per cent of the entire area of the Esperance shire. (Hansard 2015)

Figure 104 : Photo from Esperance Fire of the damaged poles and wires

The Cascades fire destroyed the Scaddan town hall, one house, 16 other non-residential structures and dozens of vehicles in the communities of Grass Patch, Salmon Gums and Scaddan. In addition, the Merivale fire destroyed 2 houses in Stockyard Creek. Roads and utilities infrastructure was also damaged within the fire ground; the destruction of 320 power poles and hundreds of kilometres of power lines caused a week long power outage for 400–500 residents in the region.

Emergency response was undertaken to reconnect lost power to clients, 400 of which were re-instated within 10 days, there was a significant number of clients who live remotely, that many months of work was required to establish power to their homes. Temporary measures were taken while the restoration was being evaluated which included temporary diesel generators.

Another traditional option is to install a diesel generator to the remote loads. If the business cases were compared over a 20-year operational life, the advantages of a solar/diesel hybrid systems become more significant for a larger load (~50kVA).

Table 135: Financial Analysis Results for use of Solar/Battery Systems in remote sites

50kW variable load 24/7	EMC - Micro Grid	Diesel Generators
System Capex ($)	$584,800	$58,200
Total Cost of Ownership ($)	$670,000.00	$2,700,00
LCOE ($/kWh)	**$0.31**	**$1.27**
Fuel Cost	$1.20	$1.20
Escalation	5%	5%
Generator Replacement (hours)	17,520	17,520
Generator Service (hours)	500	500

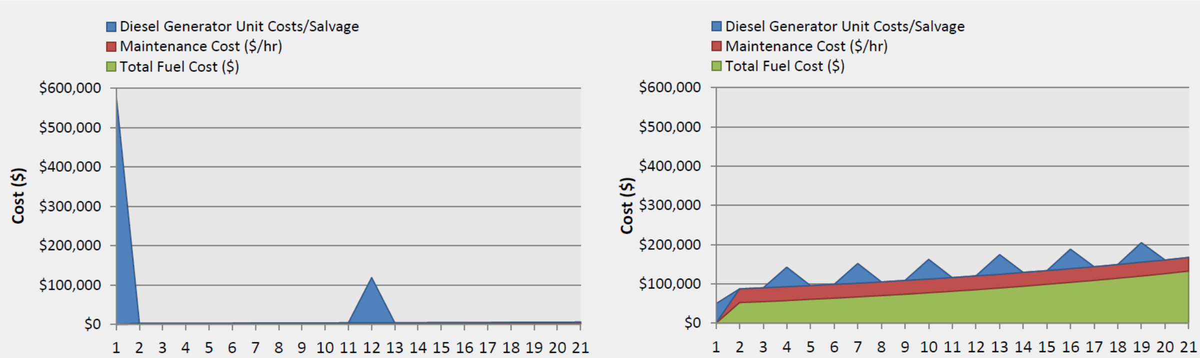


Figure 105: Business Case for use of Solar/Battery Systems in remote sites

In response to the bushfire and the damage caused to the electrical grid, the Western Australian Government and Western Power (utility in Australia) undertook a pilot program to address the issue of long radial power lines providing power to a handful of houses. Both from a power security perspective and best economic business case to establish power to these homes, the parties undertook a trial to use SPS (Standalone Power Systems) using solar, battery and diesel system to provide power to 5 houses in the Esperance region.

The aim of the trial was to address the following areas:

1. Avoid future fires causing power outages in such wide scale.
2. Economic advantages to traditional poles and wires solution.
3. Cultural acceptance to non-network solution to provide power.
4. Rapid deployment of infrastructure in case of emergency response.
5. Opportunity to overcome grid-codes and policy hurdles to implement a non-network solution to homes.

The trail was undertaken with an agreement in place with the households, that they would pay the same rate for electricity and that the SPS would achieve higher power availability then their previous supply.

EMC was contracted to construct and install the SPSs as well as to provide support for these systems 24/7.

These SPS units generate and store electricity without being connected to the existing electricity network. With its own solar panels, batteries, inverters and back-up diesel generator, it supplies continuous power 24 hours a day, regardless of the weather. SPS units include solar panels to generate electricity during daylight hours. If the homes are not using as much electricity as the solar cells are generating, the batteries will charge up until they are full. The SPS batteries discharge power at night. A diesel generator provides backup power if energy use is higher than the solar panels and battery can supply, or if the weather is overcast for a long time. One of the benefits of the SPS units is they replace long powerlines which are vulnerable to reliability issues caused by faults or severe weather events. SPS units can be used to power homes, sheds, workshops, offices and farm worker accommodation.

These systems ranged from:

- Solar Systems (5kW to 20kW)
- Battery System (24kWh to 96kWh)
- Generator (12kVA to 48kVA)
- EMC designed containers and balance of plant.
- EMC Control System (local and remote)

Figure 106: Power On Demand – Package delivered to Western Power

Figure 107: Esperance Installation images

For islands like Rodrigues, systems such as SPSs provide a good alternative to traditional poles and wires solution because of the difficulty in the terrain and the costs associated with new lines. Larger loads in the system that can be dispatched on demand when there is excess renewable energy can be isolated from the distribution network to provide more renewable penetration to the island. An ideal load is water pumps and desalination plants that can run 24/7 when there is sufficient solar power without the impact of additional costs associated with diesel power.

8.5.1.9. Case study of Alkimos BESS

Synergy, a distribution utility in Australia, was successful in obtaining a grant from the Australian Renewable Energy Agency (ARENA) for an Energy Storage Trial (EST). The EST project involves the installation of an Energy Storage System within metropolitan Perth. The storage system will be connected to Western Power's electrical distribution network.

EMC in Western Australia was selected as the supplier of the 1.1 MWh energy storage system for the trial at Alkimos Beach.

Synergy CEO Jason Waters reinforced the strategic significance of the battery storage trial as investments and enhancements in distributed generation and the next wave of renewable energy technology rapidly transform the energy industry and reshape customer expectations.

The Australian Renewable Energy Agency has contributed significant funding towards the trial, which is thought to be the first of its kind on a community scale in Australia. The trial will offer participating residents virtual energy storage; rebates for solar PV, solar hot water system and other energy efficient appliances; an in-home energy display unit monitoring generation and usage; variable price plans; and, an education program to help residents maximise their potential to save money and better manage their energy usage.

Figure 108: Synergy Battery Energy Storage – Artist Impression

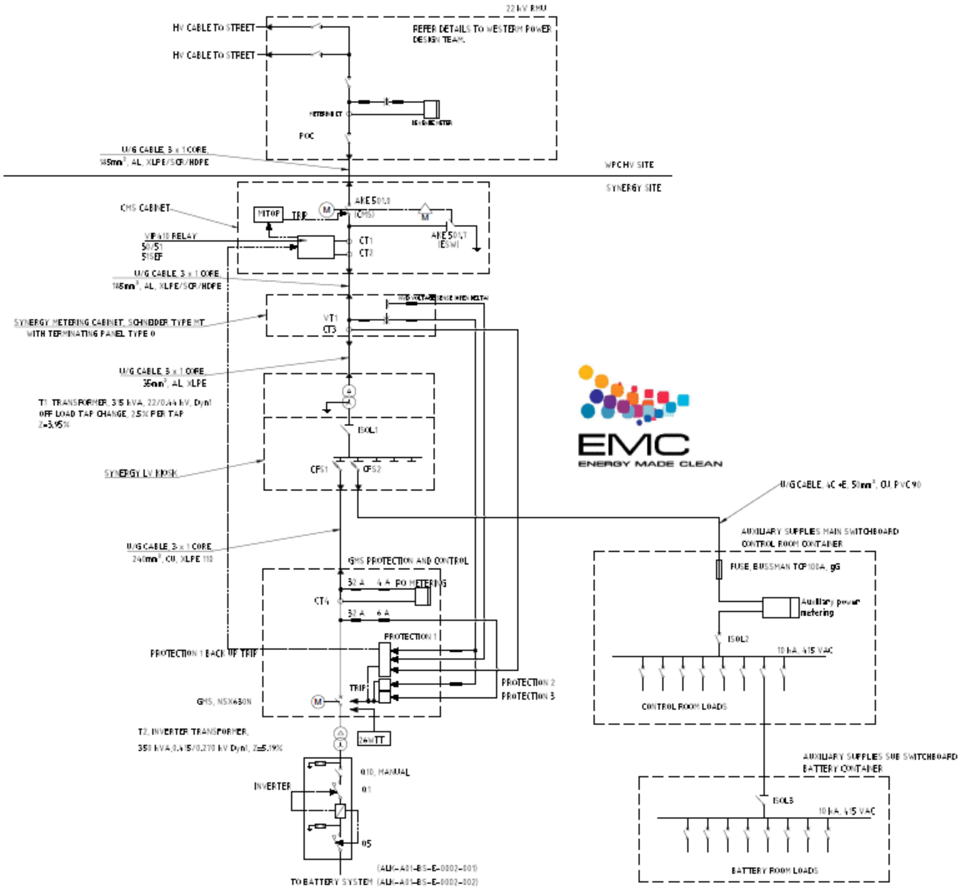


Figure 109: Typical Grid connected BESS SLD

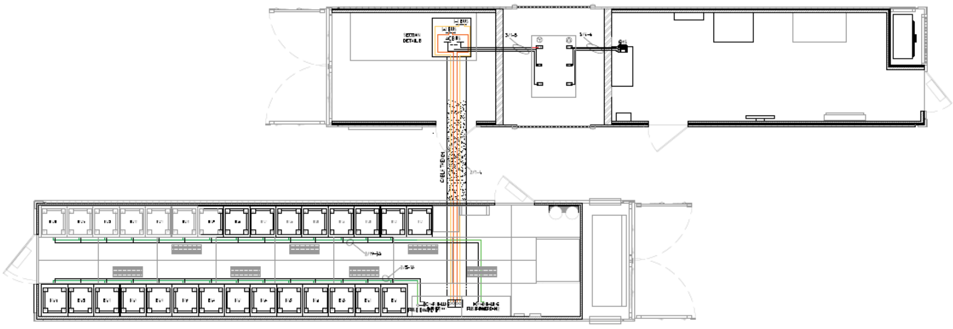


Figure 110: Synergy BESS General Arrangement

The EST project aims to answer a number of questions about the potential for energy storage systems to be deployed within metropolitan regions as a way to provide multiple benefits to many different parties. Some of the key questions that the project seeks to gather further information on include:

1. What barriers exist to the design, supply, installation and operation of an energy storage system in a metropolitan region and how can these barriers be overcome?
2. What is the optimum ratio of storage capacity to power (i.e. MWh to MW) for a storage system installed in Perth where there are two distinct peaks in the overall demand profile?
3. What benefits does an energy storage system offer parties including: the energy retailer, the distribution company and nearby customers?
4. What are the short and long-term economic benefits from this kind of storage installation?
5. How does a “community” scale battery installation compare to individual (i.e. household) battery storage systems?

As the BESS will be installed on a metropolitan grid where the load profile contains two distinct peaks most days of the year, the envisaged charge/discharge cycles required are:

1. Overnight – charge to full capacity
2. Morning peak – two hour discharge at peak power rating (approximately 7 – 9 a.m.)
3. Daytime – recharge to full capacity
4. Evening peak – 2- 4 hour discharge at 50 – 100% of the peak power rating (approximately 5 – 9 p.m.)

Whilst the above cycle is only indicative, a key point is that this energy storage system is predominantly designed for 2 – 4 hours of storage. It is not designed to be a project where the primary role of the storage system is to provide short-term (less than a few minutes) charge/discharge functionality to stabilise the distribution network.

Table 136: - Specification Table of Systems delivered

EST Component	Specification/Description
Energy Storage Capacity (usable at maximum DoD)	~ 2 x 550 kWh (~ 1100 kWh total)
Charge Rate	350 kW (per system)
Discharge Rate	350 kW (per system)
Connection Voltage	415 V
Design Life	Energy Storage = 5 years All other components = 10 years
Control System	Autonomous operation with remote control of charging/discharging rates Peak lopping and load levelling capabilities based on voltage algorithm or actual feeder load signal Inverter/Statcom capability
System Data	All hardware and software required to display and log real time plant performance data and interface with the control system including: Battery State of Charge Charge/Discharge Rate Self-discharge rate Ancillary power use Protection Status Alarms
Anticipated Charge Cycle	7 – 14 hours/day @ 50 – 150 kW (per system)
Anticipated Discharge Cycle	~ 6 hours/day @ 125 kW (per system)
Physical configuration	2 x containerised solutions installed on site within 50 km of Perth CBD

The project became operational in 2015 and expected to release performance outcomes by 2019.

8.5.2. Power Station Dispatch Strategies

Majority of the baseload (57% of baseload power) generation in Mauritius is provided by the 6 coal, bagasse and coal/bagasse power plants that are all IPP plants. The availability of power from bagasse IPPs currently vary between crop and off-crop seasons with 56MW of generation capacity available from bagasse during crop season and the bagasse contribution in off crop season increasing the production capacity to 215MW. These are slow start up units and the current strategy is to use these units as baseload which is key to the ultimate control strategy.

Refer to Table 137 and Table 138 for current dispatch strategies deployed by the CEB in 2016. CEB is intending to improve the automated dispatch capability of their diesel generation system by implementing AGC control to the current equipment.

Table 137: Coal/Bagasse Power Plants (2015)

Name of Power Station	Location	Year of Operation	Installed capacity (MW)	Effective capacity – bagasse (MW)	Effective capacity – coal (MW)	Energy Source Used	Cold to full Load startup time
Consolidated Energy Limited (CEL)	Beau Champ	1997	24.5	12	22	Coal/ Bagasse (to 2015)	12 Hours
Alteo Energy Limited (ex FSPG)	FUEL	1998	36.7	20	27	Coal/ Bagasse	12 Hours
Terragen Ltd	Mapou	2000	71.2	46	62	Coal/ Bagasse	12 Hours
OTEOSA (ex CTDS)	Saint Aubin	2005	34.5		30	Coal	12 Hours
OTEOLB (ex CTSav)	L'escalier	2007	90	65.5	74	Coal/ Bagasse	12 Hours
MSML (ex Medine)	Bambous	2015	21.7	11		Bagasse	12 Hours
Total			**278.6**	**142.5**	**215**		

Table 138: Diesel and HFO Power Plants (2015)

Power station	Unit	Technology	Date Commissioned	Capacity [MW]	Operation Schedule	Is AGC Installed	Year AGC on-line	Cold to full load startup time
Fort George	G1	Thermal, plant, diesel engine, slow speed	1992	127	Frequency and Load Control	No	2017	<20 mins
	G2		1993					
	G3		1997					
	G4		1999					
	G5		2000					
Saint-Louis	G1	Thermal, plant, diesel engine	1978	25				
	G2		1978					
	G3		1979					
	G4		1979					
	G5		1981					
	G6		1981					
	G7	Thermal, plant, diesel engine, medium speed	2006	40				
	G8		2006					
	G9		2006					

Power station	Uni t	Techn-ology	Date Commi-sioned	Capac-ity [MW]	Operation Schedule	Is AGC Installed	Year AGC on -line	Cold to full load startup time
Fort Victo-ria	G1	Thermal, plant, die-sel engine medium speed	2010	28	Frequency and Load Con-trol	No	2017	<10 mins
	G2		2012					
	G3		2012	56				
	G4		2012					
	G5		2012					
	G6		2012					
	G11		1989	28	Load Control			
	G12		1989	28	Load Control			
Nicolay	G1	Thermal , plant, open-cycle gas turbine	1988	72	Used for peaking and emergency condition on last priority (Frequency and Load control availa-ble)	No	N/A	<1 min
	G2		1991					
	G3		1995					
Total				364				

The remainder of the baseload in Mauritius comes from the fuel oil power plants.

Maintaining a constant system frequency is commonly known as Automatic Generation Control (AGC). It has got other nomenclatures such as Load Frequency Control, Power Frequency Control, Real Power Frequency Control and Automatic Load Frequency Control. This control function is performed manually in Mauritius.

The basic role of AGC is:

1. Provide input to the generator to match the output of the generator to the variable load.
2. Maintain frequency of the power system in the network.
3. In the event of a system with multiple generators, the AGC control, facilitates the seamless sharing of the load between the generators.

Automating this function achieves a faster dynamic response and less iterative delays associated with making changes and allowing system inertia to settle. The current strategy is to start to upgrade the current manual process to an AGC in 2017.

8.5.3. *Control System Architectures and Functions*

8.5.3.1. Station Management Systems

Traditionally control systems for power stations can be divided into two areas:

1. Unit Control
2. SCADA System

Unit control systems are typically provided by generator set manufacturers and typical well known systems are:

1. ComAp
2. Woodward
3. ABB
4. Siemens
5. GE
6. Alstom
7. CAT
8. Cummins PowerStart
9. Kohler etc

The functionality of these controllers is to control and protect the individual units themselves so that the unit life is extended, operated safely within its load range and manage start/stop. Typical functions include:

1. Start/Stop sequences
2. Automatic Synchronisation and breaker control
3. Speed Control
4. Voltage Control
5. Baseload, Import / Export, TempByPower, Peak shaving, Voltage and PF control (AVR)
6. Generator measurement, Mains measurement
7. Inputs and outputs configurable for various customer needs
8. Controller redundancy
9. Event-based history with timestamp to perform diagnostics and maintenance.
10. Integrated PLC programmable functions
11. Integrated fixed and configurable protections etc

Modern Controllers also include

1. Parallel Load Sharing
2. Spinning Reserve Management
3. Renewable Management

The SCADA acronym stands for supervisory control and data acquisition, a computer system for gathering and analysing real time data. SCADA systems are used to monitor and control a plant or equipment in industries such as telecommunications, water and waste control, energy, oil and gas refining and transportation. A SCADA system gathers information, such as power output and operational status of a generator and communicates this remotely to operators in a central control facility. SCADA allow remote operation of unmanned sites. SCADA systems were first used in the 1960s.

Both Unit Controllers and SCADA systems can be customised with additional PLC control algorithms to achieve the integration of renewable energy and load management. Typically, these systems are central controllers and are called Station Management Systems (SMS).

8.5.3.2. Microgrid Control Systems

The SMS control system can be expanded to provided strong control algorithms that maximized the renewable input to microgrids while assuring stability of the power system. However, it has been recognized that a central control system has several downsides in a microgrid environment (Microgrids n.d.):

1. A failure of the central master controller can be catastrophic
2. Redundancy of central master is often very expensive
3. Large hardware requirements for a central master controller (memory and CPU)
4. System maintenance requires complete shutdowns
5. Scalability and expansion is a complex and expensive task
6. Hard to fault find bugs due to complex isolation of code blocks
7. System relies more on security as attacks on a central controller would be catastrophic
8. Modification requires lots of testing
9. Limited options for network redundancy
10. Works against the nature of a microgrid which is often distributed

Electrical devices in a microgrid environment are usually distributed. A centralized control system works against this very nature by trying to remove the distribution.

The logical solution to this issue was to develop a control system which is local to the various electrical devices. The idea is that every node (generator, wind turbine, etc.) is autonomous. But all these nodes together build a network of peers that represents the whole power system. To overcome the lack of the central decision making engine (master controller) the peers communicate together. With communication they are able to make the correct control decision in every particular situation.

The advantages of having the control system distributed and split up in individual peers are:

1. Each electrical device can be fitted with a separate, less complex controller that:
    a. Mirrors the already existing redundancy of electrical devices back to the control system level. If one generator controller fails, it appears to the system as if one generator has failed, therefore the next generator starts as replacement.
    b. Is easy to maintain. Parts of the system can be shut down while the rest of the system continues to operate independently. Upgrades and updates can happen on one diesel generator while the rest of the power station is still operating in automatic.
2. The failure of one controller doesn't have catastrophic impact since replacement capacity can be brought online immediately
3. The system is more scalable and extendable, not limited to on-board I/O of central master controller
4. It is a more cost-effective solution
5. It is easier to develop upgrades thanks to independence and modularity
6. Communication redundancy can be easily achieved
7. Each node is autonomous and yet closely integrated with its peers

The communication in such a distributed environment works through exchanging messages between the individual controllers.

ABB Microgrids have acquired and developed such a platform of controllers that can be deployed to an island system such as Mauritius. Below in Figure 112: Concept Microgrid Architecture for Rodrigues is a typical example of how this can be deployed in Mauritius. A system such as this is optimal for Mauritius as the geographic area is small and the numbers of generation sources are small. With a distributed architecture, combined with a state of the art communication network, the entire island can be integrated with an advanced control system that would provide the best platform for Mauritius to achieve the goal of maximum renewable integration. The term Smart Grid is also interchanged with Microgrid type of control however the speed of control action is much slower with Smart Grid controls.

The advantage of such a distributed system is that individual sites can be upgraded without impacting the power system or any other component in the system. Modularity allows for planned upgrades through the entire system while maintaining system availability. Parts of the network could be upgraded first, then proved over a 3 to 6-month operational period then proceed to further upgrades.

Advantage of such systems is that these controllers can be retrofitted to existing systems (either using Modbus or hardwired I/Os), run in parallel to existing controls to test its operation and brought on line when the confidence of the operation is satisfied.

This allows time for the operators and CEB to get comfortable with the quality of operation from the advanced control system.

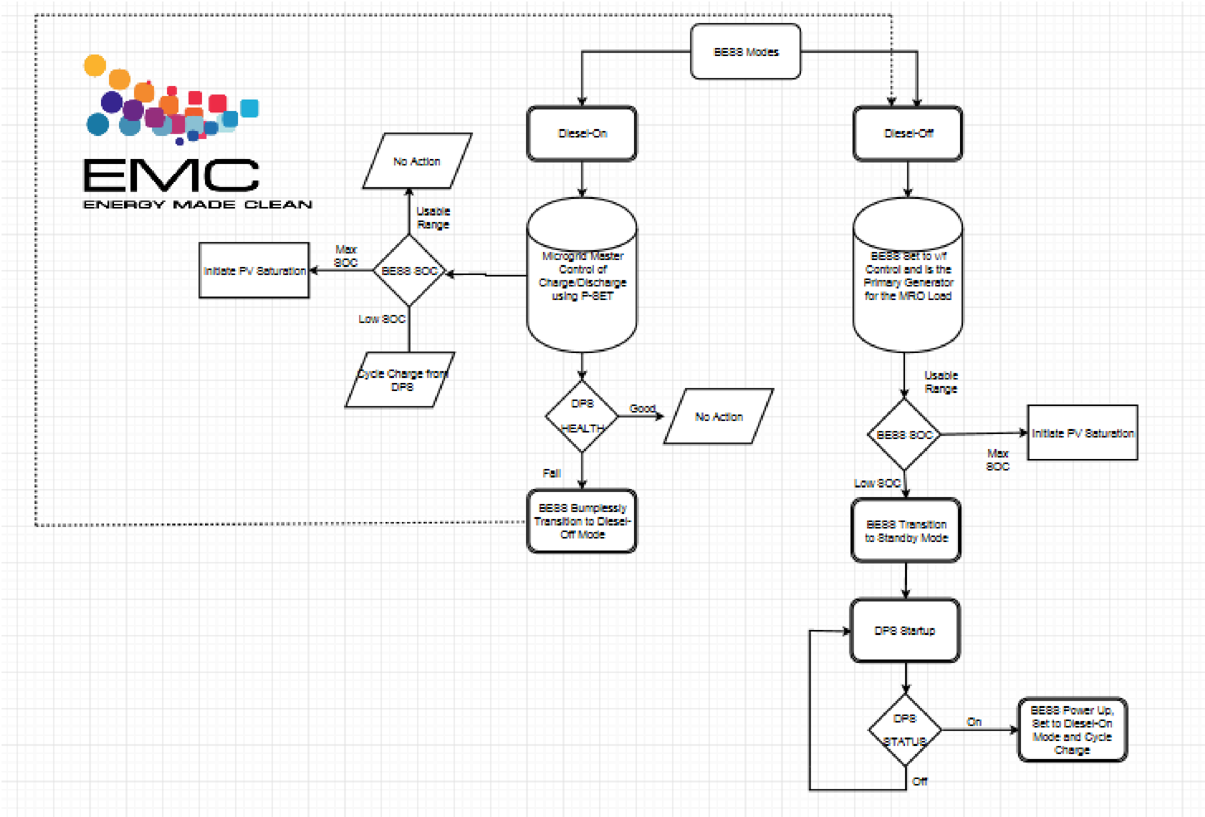


Figure 111: Sample flow diagram of an advanced BESS in a diesel system

The flow diagram Figure 111 shows the operational modes of a BESS in an advanced diesel power system. The primary functionality of the BESS is to provide:

1. Spinning Reserve – While connected to the diesel generators, the BESS supports the load and provided protection for the diesel generators to maintain step load capacity and avoid the generators from going into underload.
2. Stand Alone – Online and active 24/7 to maintain power security in the event of a diesel power station failure. The BESS will take over the load and become the primary generator for the system.
3. STATCOM – The BESS provides reactive support to the power system which minimised the diesel use.
4. Energy Shifting – BESS charges during excess RE generation and dispatched the energy during low generation periods.
5. Start/Stop of Diesel Generation – In the event that excess energy is provided by the RE and BESS generation, diesel generators are switched off to save fuel. In the event of low state of charge of the BESS, the start signal is sent to generators to come on line.

The typical function of the overall advanced control systems is (over and above all SCADA functions):

1. Calculate the optimal saturation level for the RE generation when the system is approaching underloading. Perform this action dynamically to achieve the best renewable efficiency to the load.
2. Provide Start/Stop signals to the generators (either automatically or manually by sending a message to the operators)
3. Calculate the most optimal diesel generation configuration based on cost of generation. Renewable sources are given priority. This can also be done automatically or manually.
4. Dynamic load dispatch (trip feeders and bring back on line loads during excess RE generation).
5. Provide fail safe functions in events such as loss of communication.

Typical Architecture for Mauritius based on Rodrigues as a sample smaller network is an ideal development strategy to implement island wide controls in Mauritius. Concept could include BESS units integrated into the power system as shown in Figure 112.

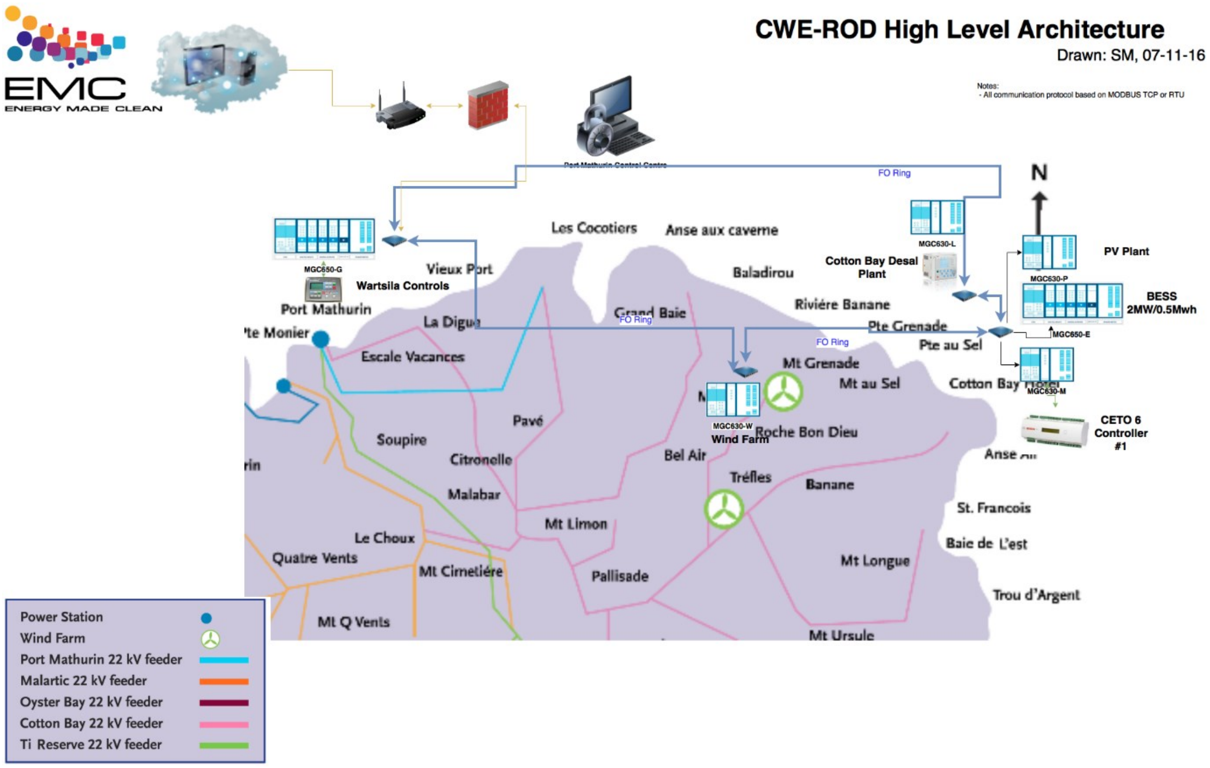


Figure 112: Concept Microgrid Architecture for Rodrigues

The Renewable Roadmap recommends a study for Rodrigues to identify the most optimal way to control the island power system. The study report will carry out such an evaluation, highlight the areas for improvement then ultimately proposes a Microgrid operation and control system that would enable the CEB to automate the operation and control of Port Mathurin PS, Pointe Monnier PS, Solar Farm, Grid Connected BESS, Wind Farms, Desalination Plants, Island main Water pump and the transmission and distribution grid in the most economical (increase renewable) and ergonomic way (best operator outcomes) possible.

Typical functions that can be performed by the above advanced control systems:

1. Charge/Discharge of BESS
2. Desalination Plant Load Control
3. PV Generator Output Control
4. Wind Generator Output Control
5. Wave Generator Output Control
6. Wartsila Generator Output Control

8.5.3.3. Control System Case Study 1 – GESS Ausnet Services

The control system selected for GESS was based on a proven Microgrid Control Platform from ABB that has been deployed in various applications since 2008. The control system was deployed in a utility scale in 2014 in Australia with a Utility Partner, Ausnet Services (ABB 2015).

As large scale battery technology and economies of scale continue to improve, many industrial utilities are investigating the use of battery technology as the basis for Grid Energy Storage Systems (GESS, see Figure 113 and Figure 114). Based in Victoria, Australia, AusNet Services, the state's largest energy delivery service owning and operating approximately $11 billion of electricity and gas distribution assets that connect into more than 1.3 million Victorian homes and businesses, began investigating GESS in 2013.

AusNet Services chose to trial the technology to explore the ability to manage peak demand with the potential to defer investment in network upgrades.

Through a competitive tender process, AusNet Services awarded the contract to design, construct and deliver a GESS to a consortium led by ABB Australia and Samsung SDI, with ABB in Australia providing the integration technology and design and Samsung SDI taking the role of battery supplier.

The GESS consists of a 1 MWh 1C lithium battery system which interfaces to the microgrid through a 1 MVA (an inverter-coupled energy storage system), a 1 MVA diesel generator, a 3 MVA three-winding transformer and a SF6 gas-circuit breaker-based ring main unit with associated power protection systems. The system is fully portable and re-deployable and is installed on an industrial lot in several transportable shipping containers and transportable skids.

Situated in the northern suburbs of Melbourne, the system is located at an end-of-line distribution feeder in an industrial estate. With the design of the system commencing in early 2014 the system was commissioned in December 2014, and a two-year trial is now completed. The GESS is the first Australian system of this type and size, and the trial aims to explore the benefits to peak demand management, power system quality and network investment deferral that large-scale, grid-connected energy systems can provide. Through the installation and commissioning process a full set of site acceptance tests were conducted. These tests demonstrated the capabilities of the GESS with respect to power system supply and stability, islanding and reconnection to the larger grid and management of the various system components (passive and proportional load sharing between the PCS100, battery management and charging etc.).

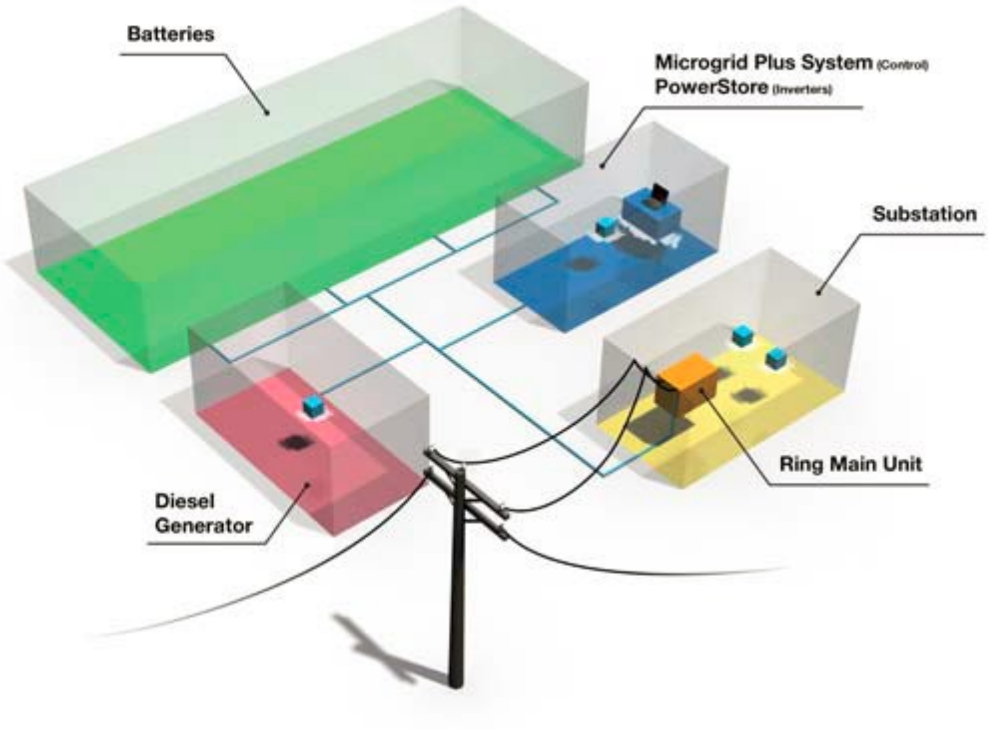
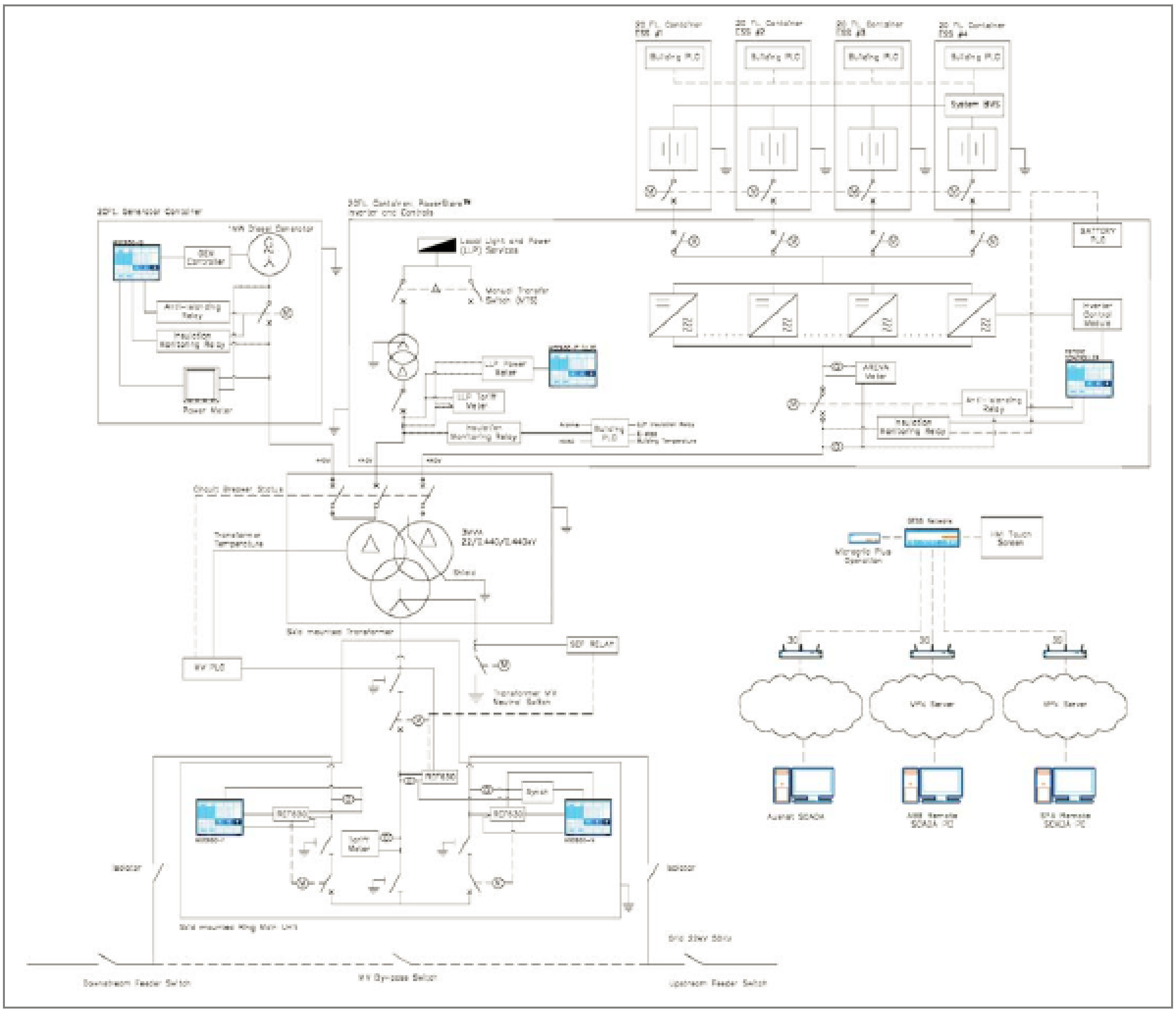


Figure 113: Concept Image of Grid Connected BESS in Australia

Previous ABB Installations included:

1. Coral Bay; a wind/diesel microgrid that achieves 95% wind penetration.
2. Ross Island; 70% wind penetration and frequency conversion between a 60 Hz and 50 Hz grid is achieved through an ABB microgrid solution including a PowerStore.
3. Marble Bar and Nullagine; the world's first high-penetration solar photovoltaic diesel power station achieving 60% penetration.

4. Kalbarri; a PowerStore STATCOM minimizes disturbances in voltage of an end-of-grid network to which 2 x 800kW wind turbines are connected.



5 GESS Single Line Diagram

Figure 114: GESS Single Line Diagram

The heart of the GESS is an ABB PowerStore, an IGBT based PCS100 inverter system which interfaces the Samsung lithium battery energy storage system to the grid. The PowerStore operates in the GESS in Virtual Generator Mode (VGM) as a voltage source inverter. When in VGM the PowerStore inverters supplied by the batteries operate as a synthetic generator, similar to a traditional diesel generator but with exceptional response time and expanded power system supply and stability capabilities as described below.

Using software models of a diesel generator's Governor and AVR in VGM, the PowerStore provides isochronous (droop) frequency and voltage control in the same manner as a diesel generator. Through the commissioning process, the PowerStore control parameters are tuned on site to match the characteristic response of the diesel generator. This allows the PowerStore to passively and proportionately load share both real and reactive power with the generator when both the PowerStore and generator are operating. The PowerStore is also able to use these models to generate in parallel with other generators on the network. The software AVR and governor models utilized by the PowerStore also enable it to act as a grid-forming generation source (a stiff voltage source) that other synchronous generators, such as wind turbines or solar inverters, can use as the network voltage and frequency reference of a microgrid. This includes being able to provide supply to the microgrid by using solely the PowerStore. Additionally, the PowerStore responds to faults in the network in the same way as a synchronous generator, supplying up to 2 p.u. fault current for two seconds. The functionality of the system can be summarized as seen in table below.

Table 139: System functionality for GESS

Functionality	Power Type Supplied	Power Provided by	Control Options
Islanded operation	Active Power Supply, Relay Settings and CB Operation	Battery inverter and/or diesel generator	• Bumpless transition to grid connection • Microgrid shutdown • Microgrid startup • Reactive power supply • Stiff voltage source • Battery charging • Spinning reserve
Grid connected operation	Active Power Supply, Synchronisation, Relay Settings and CB Operation	Grid, battery inverter and/or diesel generator	• Bumpless transition to islanded operation • Reactive power supply • Peak lopping • Battery charging
Reactive power supply	Reactive power (capacitive and inductive)	Battery inverter, when suffi cient, then diesel generator	• Voltage droop • Power factor correction
Stiff voltage source	Active power and reactive power through fast absorption and injection of current	Battery inverter	• None
Peak lopping	Active power supply	Battery inverter and/or diesel generator	• None
Battery charging	Active power consumption	Grid and/or diesel generator	• Timed charging • Charging at minimum feeder load
Spinning reserve	None (generation sources are brought online or offl ine as required)	Microgrid Plus control system	• Schedule of generation sources

8.5.3.4. Control System Case Study 2 – Garden Island Microgrid

Carnegie Wave Limited is developing a test site in Australia to demonstrate the functionalities of a Microgrid Control System. The project is called Garden Island Microgrid (GIMG).

The project includes the following major components:

1. 2MWp of solar system
2. 2MW/0.5MWh Battery Energy Storage System (BESS)
3. CETO 6 Wave Generation System
4. 150kl/d Desalination Plant
5. All balance of System electrical reticulation (415V and 11kV)

The project will interface existing infrastructure on the island that include:

1. Utility grid connection to Western Power
2. 1.5MW diesel generators
3. Existing Department of Defense loads

The GIMG project functionality as shown in Figure 115 and Figure 116 includes:

- Solar Smoothing (provide spinning reserve for the solar systems by monitoring the output from the PV inverter and automatically providing the battery system charge/discharge setpoints)
- GIMG PV Plant power output and ramping control.
- GIMG Wave Plant power output and ramping control.
- Stand Alone (hold the grid frequency in the event WP Loss of Mains CMS1 (Customer Main Switch#1-22kV) trip)
- Load Shedding of Non-Essential Loads on the Island to maintain system integrity during a LOM event.
- Bumpless Transfer in the event of a Loss of Mains (LOM) to the CEPS diesel generators.
- Bumpless Transfer back to the WP grid when the grid returns to healthy state.
- Synchronisation of GIMG to WP grid when the grid health has recovered bumplessly.
- Synchronisation to diesel generators in the event that blackstart being performed by the DG or the BESS is tripped and brought online.

- STATCOM (provide reactive support to the Garden Island Grid on preset PF values or on command). BESS shall share the load using voltage droop control.
- Load control to maximize renewable penetration including control of the desalination plant.
- Local and Remote Operator Control
- Remote Diagnosis

The BESS is intended to transition from ‘P&Q Mode’ to ‘v&f Mode’ automatically in the event of Loss of Mains (LOM) is detected using the CB status of CMS1 or a command is provided via western Power’s Network Operations Control Centre or by an operator locally at the BESS control panel.

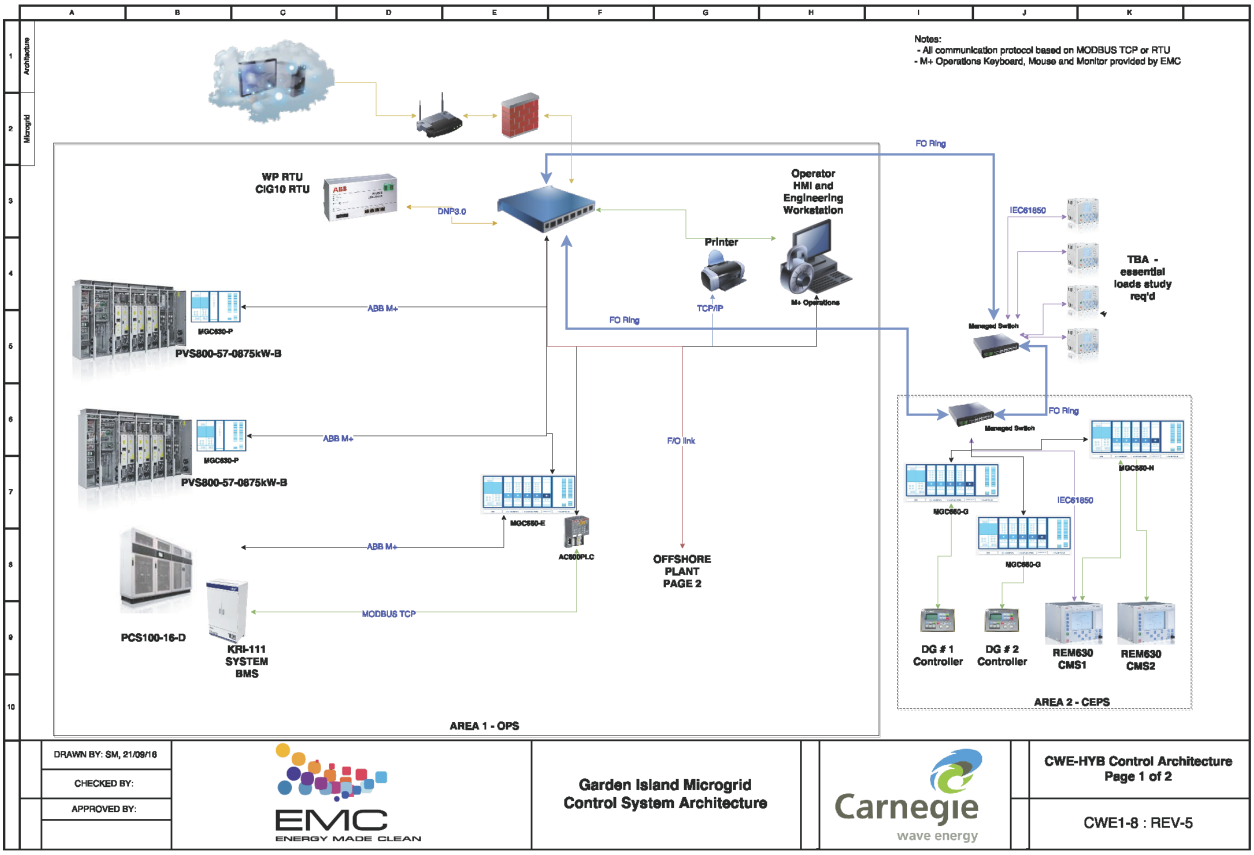


Figure 115: GIMG System Architechture

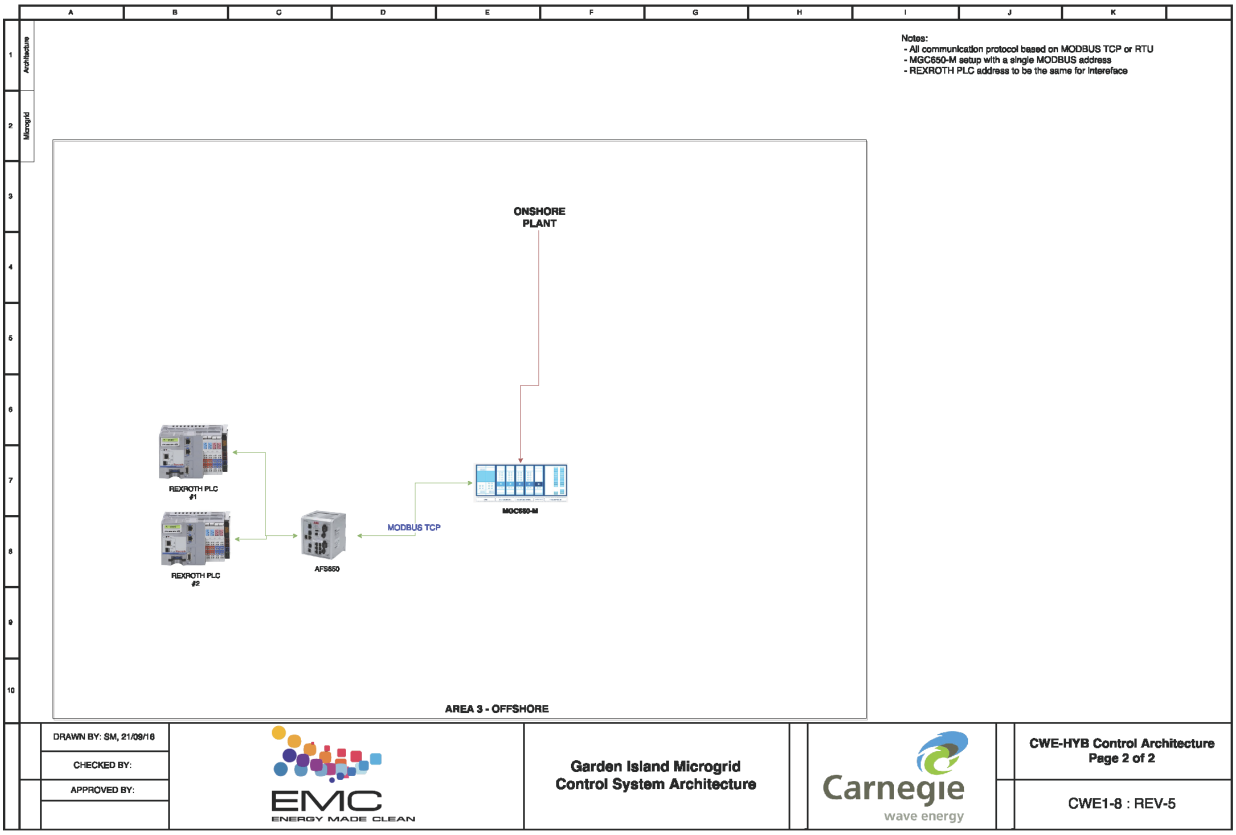


Figure 116: GIMG Wave Interface

This advanced system is being designed currently and to be executed in 2017.

8.5.4. Benefits of Distributed VRE - Case Study: Alice Springs Study.

A recent study was commissioned in Australia on a small islanded grid to determine the impacts of solar generation systems on a small distribution grid. The report is the result of a research project undertaken by CAT Projects and ARENA (Australian Renewable Energy Agency) during 2013 and 2014 (CAT Projects & ARENA for public distribution 2015). The project investigated the impacts of solar radiation variability on PV power output in existing electrical grids. The key aim was to develop an improved estimate for the maximum penetration of grid-connected solar generators achievable without energy storage. The research took into account the solar generators' distribution across the geographical area of the grid based on the hypothesis that the impact of weather variation is mitigated by the distribution of solar generators in the grid – i.e. clouds passing across the area will not affect all generators simultaneously.

The study aimed to quantify the mitigation of geographical distribution on instantaneous weather effects by comparing the data from an array of pyranometers, anemometers and temperature sensors installed across the extent of the Alice Springs electricity grid.

Alice Springs has some unique characteristics that allow it be a viable and useful proxy for the grid in Mauritius:

1. A peak demand of around 55 MW;
2. A grid that spans up to 100 km in each direction;
3. Multiple sources of generation including:
4. Diesel and natural gas reciprocating engines
5. Natural gas turbines
6. Independent Power Producers and Utility generation
7. Utility scale PV supplied via a PPA to Utility Grid
8. 66 kV transmission, with 11 kV and 22 kV distribution

Given all of the above, it can be appreciated that lessons learnt in Alice Springs will be analogous to those that could be expected to be learnt in much larger grids such as Mauritius, as well as many of the islanded grids in regional communities throughout Australia.

Generation and transmission in the Alice Springs network includes:

1. Alice Springs Generation Capacity
   a. Gas/diesel generation stations
   b. Owen Springs: Three x 10.7 MW natural gas reciprocating engines. Pilot fuel is about 1% distillate;
   c. Ron Goodin: 11.7 MW gas turbine. And six lower merit order diesel generators. Many of these smaller units are scheduled for decommissioning;
   d. Brewer Estate: Four x 2 MW spark ignition reciprocating engines;
   e. PV generation (around 4.0 MW, peak penetration around 8%):
   f. 1.2 MW PV systems – Residential;
   g. 1.8 MW PV systems – Commercial;
   h. 1 MW PV Plant (Uterne); and
2. Alice SpringsTransmission/Distribution Network
   a. 66 kV Transmission lines from Primary Generation point (Owen Springs) to main town area
   b. 22 kV and 11 kV local distribution
   c. Several private 11 kV ring main networks e.g. Airport, Desert Knowledge Precinct etc.

The furthest extent of the grid is the community of Santa Teresa, 80 km to the SSE of Alice Springs, as illustrated in below image.

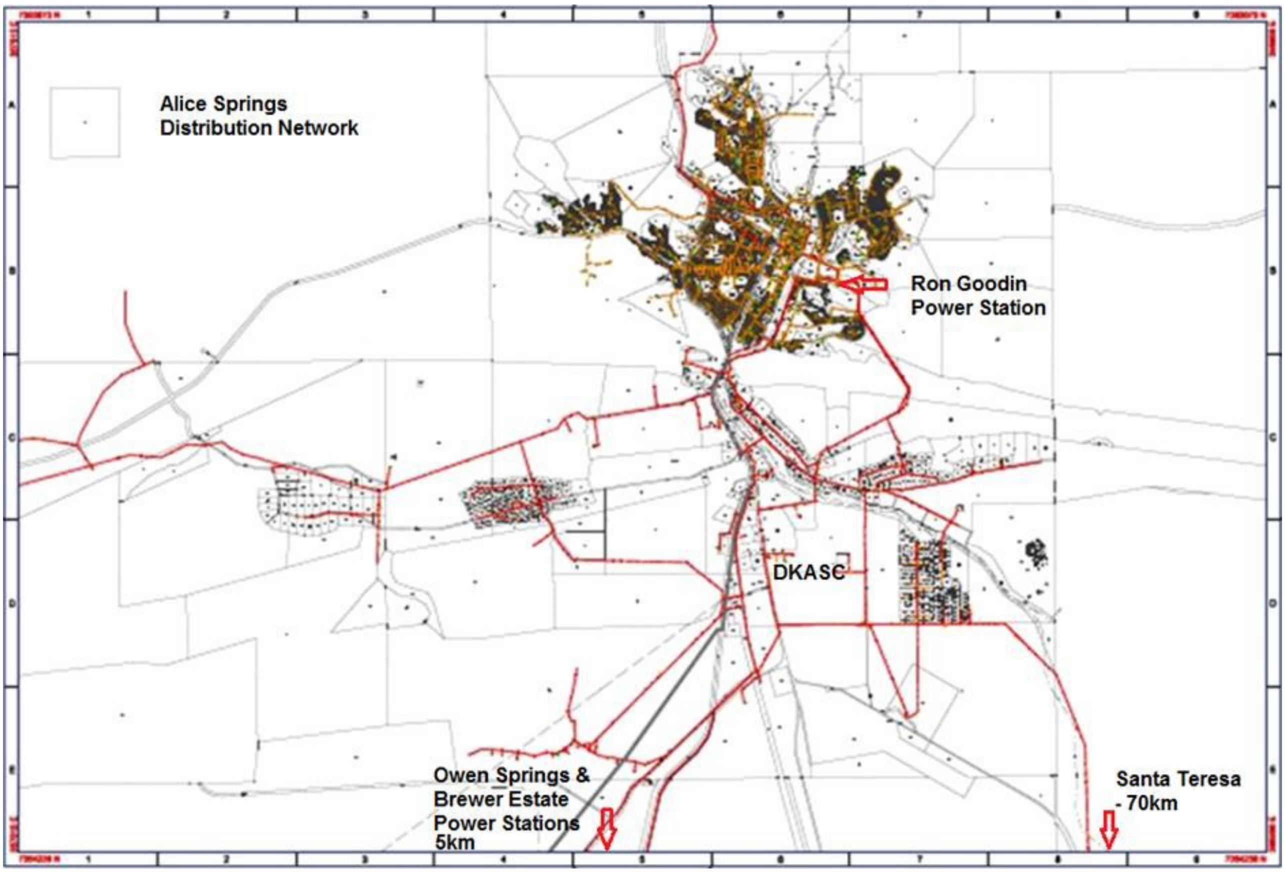


Figure 117: Alice Springs Electricity Network

There were 9 measurement points installed and a comparison was performed on the amplitude variation (Step Load) caused by a random single site (site 3) to a cumulative sum of all 9 distributed sites. The probability variance of the single site to cumulative of 9 sites was determined to be in Figure 118.

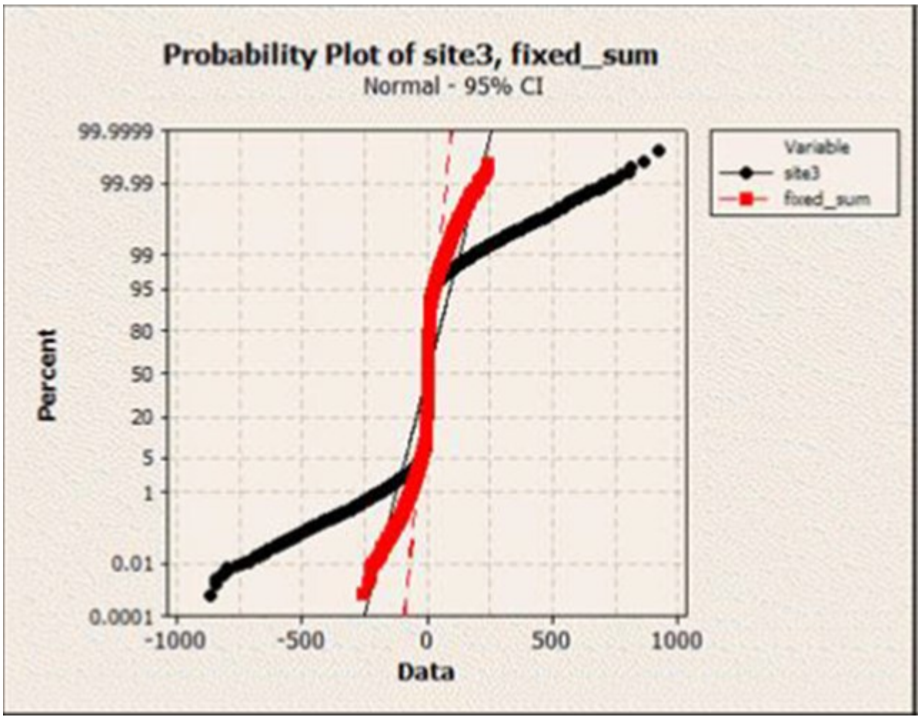


Figure 118: Difference between single to multiple PV location power deviations.

To quantify this effect an examination of the effective step changes in irradiance is required. Figure 119 shows the step changes in the normalized net irradiance for all sites. The normalization allows direct and simple comparison of the net irradiance of all sites with the irradiance for a single site (site 3 in black). What it shows is that the net irradiance is distinctly less variable (comparison between the red curve and black). Where the single site had step changes up to and in excess of 500 W/m2 for any given time interval the normalized irradiance of the combined rarely exceeds the 100 W/m2 level and peaks at 140 W/m2.

To understand the potential impacts of solar intermittency on the overall network during these high and low load demand days three simulations were completed. These simulations model the impact of the installation of an additional 10MW of PV on to the Alice Springs network in concentrated, moderately dispersed and highly dispersed configurations as follows:

1. One 10MWp plant centrally located
2. Three 3.3MWp plants located 5km radially from the solar centre
3. Nine 1.1MWp plants located approximately 15km radially from the solar centre.

It is a commonly held belief that the integration of embedded PV generators will introduce an unacceptable level of variability to the grid, creating difficulties with supply management and scheduling. This belief is based on the assumption that prior to the introduction of PV, that short term demand is inherently stable. Contrary to this assumption, analysis of the Alice Springs load shows that there is already significant variability within the network and that this variability is not directly related to the existing PV on the network.

It is clear from the modelling that the addition of 10MW of PV to the network will have an impact on the variability of the load as seen by the network generators. On a highly variable irradiance day such as the 28th January 2014 the midday demand variability increases and as would be expected, however, this increase is more marked in the 10MW centralized configuration and much less so in the more dispersed configurations. The 9 x 1.1MW dispersion is only marginally more variable than the existing grid variability shown in Figure 120.

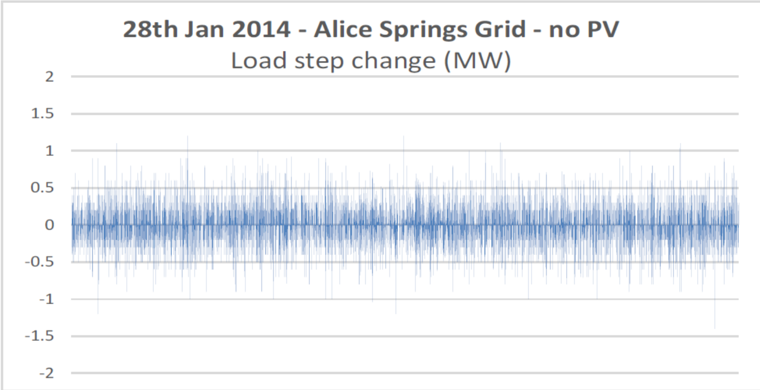


Figure 119: Step load variation at Alice Springs without PV.

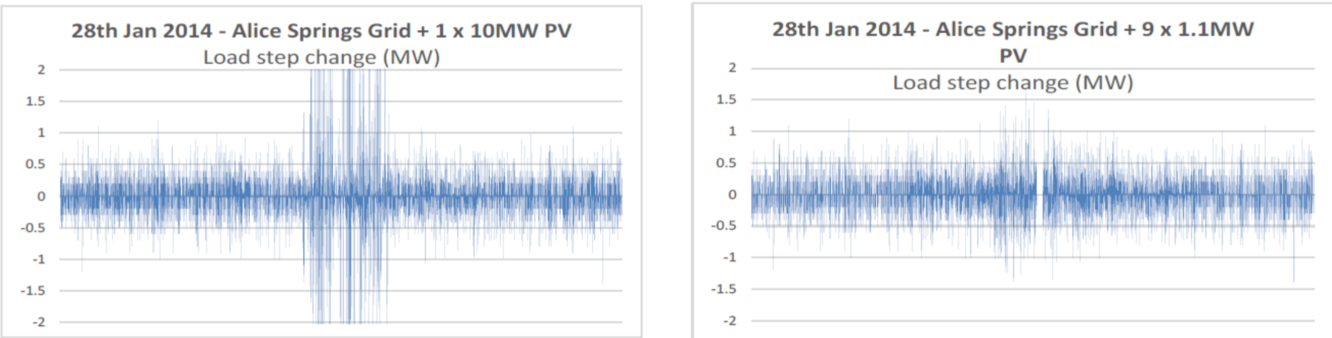


Figure 120: Difference between single to multiple PV location load step deviations.

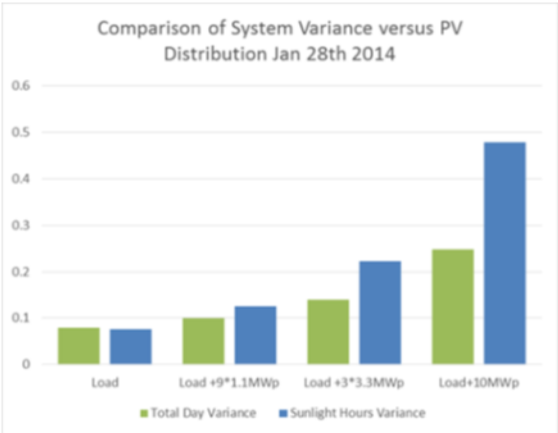


Figure 121 : Comparison of System Variance with and without PV.

This project yielded some important and interesting findings. Firstly, variability in irradiance (and therefore PV generation) can be strongly mitigated against by dispersing PV generation geographically across the electricity network. The most effective way to disperse PV generation is to disperse the PV sites geographically. Sites must be spatially dispersed to achieve the full effect but as long as there is reasonable spatial dispersion then by far the most important determinant in reducing the variability of PV generation is to increase the total number of sites. In this project, the highest levels of solar variability and corresponding aggregate load in the Alice Springs network were selected to demonstrate this point. Namely, a weekday in January after school had returned (highest load) and a weekend in September (lowest load).

In both cases the level of intermittency when a distributed array is put in place comes close to the level of variability extant within the load profile in the first place. This can be further quantified by measuring the variance of the step changes in the load over the course of the day and then comparing that to the variance when the different models are overlaid.

With respect to the impact of dispersed PV, it can be clearly seen that the level of variance for a single 10MWp plant is over four times that for nine 1.1MWp plants separated as per the locations of the pyrometers Figure 122.

The ratios are very similar for both January and September.

Figure 122: Map showing location of monitoring stations around Alice Springs, Northern Territory.

Furthermore, the variance that would be seen by the system generators is higher with the larger presence of PV in the network than if it was not there at all, however it is no greater than the most significant variance that the generation units within the system currently accommodate. The extant variance in the network in sunlight hours for September is 0.11, with the variance in January including nine 1.1MW PV plants is 0.12, thus demonstrating that the existing spinning reserve strategies could accommodate further PV integration without substantive change.

The conclusion of the measurement and the outcomes from the study revealed some very interesting findings that are applicable to Mauritius.

8.5.4.1. Conclusions on Alice Springs Study

Key conclusions include:

1. Pyranometers, by themselves, should not be considered as a useful real time predictive tool in PV output. Given the vagaries of wind effects and the impact of spatial distribution, they are unable to forecast the extent of the variability that exists in a given electricity grid.
2. There is an assumption that large multinodal electricity grids are inherently stable (i.e. they do not experience large short term variances in demand) and that the addition of significant PV input and associated intermittency potential could cause disruptions that would increase the risk of operational problems. However, results from this project indicate that the Alice Springs grid (which is analogous to many other grids in regional and remote areas as well as too many parts of Australia) encounters a significant level of load variance as part of normal operation. In other words, the network already accommodates a high degree of variability without compromising on operational outcomes.
3. Furthermore, results show that for Alice Springs the variance created by the installation of a further 10 MW of Dispersed PV inputs into electricity grids can end up being very similar to the step-change ‘noise’ variance which currently occurs in the network. The results demonstrate empirically that it is possible to install large amounts of PV, potentially exceeding 60% of demand, into existing networks without disrupting the underlying variance that normally exists in grids, as long as there is adequate spatial distribution of the PV input.

It is important to note, however, that the conclusions reached above are in the context of the entire network, and there may be local areas of the networks where such installations are not appropriate due to other gird constraints, voltage rise and frequency instability etc.

One area of further research the study required to be reviewed is the cost impact of installing a single 10 MW PV plant in comparison to 9 x 1.1 MW PV plants. The cost factors would include:

1. Cost of project development to allocate 9 sites in comparison to a single site.
2. Mobilization and demobilization in constructing 9 plants instead of one.

9. Preparing for a 60% Renewable Energy Target

The previous sections have clearly indicated that it is technically feasible to achieve a renewable energy target of 60% by around 2030. However, to achieve this will require both government, private sector and public support. The rapid change to a high level of renewable energy does not come cost free and will need the right incentives to ensure adequate levels of investment. This section details how Mauritius should lay the ground work for a 60% target to be achieve in this timeframe.

Support polices have been a significant driver of the rapid worldwide expansion of renewable energy in recent years. Typically, these aim to address market failures (also known as Institutional barriers) to promote the uptake of renewable energy while realising several other objectives, including diversification of energy generation, independence from imported energy and job creation.

Mauritius faces challenges in the energy sector due to:

- An overreliance on imported energy and therefore is exposed to world energy market price fluctuations;
    - The grid emissions factor of Mauritius is extremely high at 1.01 tonnes CO_2/MWh due to the prevalence of imported coal (approx. 43%) and fuel oil (approx. 37%) in the energy generation mix (Green Climate Fund 2015).
- The absence of true competition in the energy business sector and the natural monopoly the government has over the delivery of electricity to the people of Mauritius;
- The effective and efficient establishment of public-private energy sector partnerships for the generation of renewable energy;
- Electricity load growth;
    - Difficult to predict future energy demand due to the reliance on future energy efficiency programs and potential for transfer of energy from other sectors such as transport (i.e. transport moving from fossil fuels to electric vehicles)
- Increases in the load mean that greater amounts of renewable energy are required to meet renewable energy targets; and
- Land constraints;
    - Will affect the ability of the nation to exploit renewable energy resources.
        - For example, the country's current major source of renewable energy – bagasse, which accounts for 16% of Mauritian electricity generation and 80% of renewable electricity generation – is intrinsically unscaleable (due to land constraints and its seasonal availability) (Green Climate Fund 2015).

In most countries, innovation policy for renewable energy technologies is the subject of multiple government departments, creating significant coordination and continuity challenges. Crucially, innovation policy which encourages the development of renewable energy technologies requires capital intensive funding for many years – often decades. Policy makers can struggle to provide market driven policies that provide such long-term confidence (IEA-RETD 2014).

9.1. Institutional Barriers

There are legal, regulatory and cultural barriers that may hamper the progress of renewable energy projects in Mauritius. These barriers can be described as "Institutional" barriers. An in-depth look at Market Barriers and the theory behind them is beyond the scope of this study, however, this section uses an adapted version of Dunstan's simplified classification system to provide a basis from which to discuss the institutional barriers facing renewable energy projects in Mauritius (Dunstan and Daly 2009). An adapted version of Dunstan's proposed simplified classification system for institutional barriers comprising seven types is shown in Table 3. Although originally developed for distributed energy and energy efficiency, these barriers can be equally applied to renewable energy projects.

Table 140: List of Institutional barriers adapted from Dunstan & Daly (Dunstan and Daly 2009)

Barrier Type	Description
Information	Lack of available and accurate information
Split Incentives	The challenge of capturing the benefits spread across numerous stakeholders
Payback Gap	The gap in acceptable payback periods for renewable energy
Inefficient Pricing	Failure to reflect costs (including environmental costs) properly in energy prices
Regulatory	The biasing of regulation against distributed generation (DG)
Cultural Values	Low priority and/or opposition to energy issues (BAU)
Confusion	The additional barriers created by the interaction between the six types of barriers listed above.

9.1.1. Information Barriers

An Information Barrier refers to a lack of available and accurate information that would have been freely available in an ideal market. The ideal market can be described as truly efficient when information is both perfect and freely available (Brown 2001). However, the reality is that markets are far from being truly efficient and thus information is usually expensive and often difficult to obtain. In a study of the Market failures inhibiting energy efficiency measures in the US, Brown refers to this type of barrier occurring because of 'insufficient and inaccurate information' (2001) and notes that it is not only the energy sector that is prone to this type of barrier. Clearly a lack of information in any endeavour is going to be a barrier and although no information can be perfect, there should be sufficient and accurate information available to make good decisions (Garnaut 2008).

Information available regarding solar and wind technology are abundantly available now. Wind mast data is essential to evaluate a potential site for the installation of wind turbines and this requires additional investment by developers. Solar data is freely available through international agencies and economic information can be easily developed. Other technologies such as offshore wind and wave have further complexities due to the terrain and the sophistication of equipment required to gather resource data.

9.1.2. Information asymmetry

Garnaut notes that information asymmetry "occurs when two parties to a transaction do not have equal access to relevant information" (2008). An example of this would be the agreement that both the RE developer and CEB enter to connect the RE project to the distribution network.

In a study conducted by Snow into the market operation in the city of Melbourne, Australia, the study found that the operation of the market can be influenced by the network operator because the information required to facilitate a sound design for connection approval of distributed generation is under the network operators control and is often treated as confidential (2009).

Further complicating this barrier is that fact that even when the distribution network information is provided there may be a challenge for the RE developer to successfully interpret the data as they may lack the expertise to do so (Dunstan and Daly 2009). This often requires the RE developer to contract third parties to interpret the data for them which can be time consuming and expensive and requires the RE developer to have additional skills in managing third party contracts.

9.1.3. Split Incentives

There exist circumstances where a course of action is obstructed between two parties because one of the parties concludes that it is not in their best interest (Dunstan and Daly 2009). A commonly cited example of such a barrier is the circumstances which exist between a landlord and tenant while the course of action involves upgrading the energy efficiency of the rental property. There will typically be no incentive for a landlord to make the upgrade if there is little ability for the landlord to charge a higher rent while all the benefits are obtained by the tenant through lower energy bills.

A similar situation can occur between a network operator and a distributed generator. A network operator will need to allocate resources for both accessing an application to connect a RE project, and if approved, provide further resources to establish the physical network connection. Although the network operator will be able to incorporate charges into the connection fee to cover this work there is no incentive for the network operator to provide the resources when there is no advantage for them to do so. Furthermore, as most companies run lean businesses these resources can be considered “scarce resources” which could be more efficiently allocated to network augmentation issues, for example, as these can have a direct impact on the network operator’s income.

9.1.4. Principle-agent problem

A variation of the split incentive is called the principle-agent problem. This occurs when an agent, acting on behalf of a client, does not take into consideration the client’s best interest (Dunstan and Daly 2009). An example would be the financial investment industry where agents have been found to be selling products to clients that gave the agent better commissions while not necessary giving the client the best return on investment. This may occur between the RE developer, the client, and third party contractors, the agents. The selection of RE technology, switch gear, voltage compensation equipment, line upgrades are examples where complex decisions are usually made, at least in part, on behalf of the RE developer as the agent is considered the expert.

9.1.5. Payback Gaps

The payback gap refers to the acceptable payback and/or rate of return for RE projects verses commercial fossil fuel projects and the associated impact on any debt financing that may be required. There are two issues of concern regarding payback gaps for RE Projects. They are:

1. Establishment of a viable income stream to support debt financing,
2. Rate of return to investors of the RE project

9.1.5.1. Establishment of a viable income stream

The establishment of a viable income stream begins with building a business case for the RE resource itself and concludes with a decision on a method for the sale of the generated electricity. For a RE project to obtain loans and investor financing the business case needs to address, site evaluation and feasibility studies, address the high capital costs associated with RE projects and identify the rate of return on investment.

9.1.5.2. Site Evaluation and Feasibility Study

Substantial RE resource evaluation is needed for any RE project to establish a viable business case. This normally includes hiring a third party, someone with proven knowledge in RE resource evaluation, to carry out site measurements over a minimum period. This will prove the first of many barriers for the RE developer to overcome as it requires a significant upfront cost, in the tens of thousands, and will provide the key data as to whether the project is viable or not.

9.1.5.3. High Capital Costs

As is typical for many renewable energy generation projects, the projects will have higher capital costs but lower ongoing or operating costs as no fuel purchases are required (Dunstan and Daly 2009). Hence a potential barrier for RE projects and distributed generation in general, is a potential inability for these projects to access finance to cover the higher up-front capital costs.

9.1.5.4. Rate of Return

Due to several issues, such as economies of scale, remote location and connection costs, the rate of return will potentially be lower than what may be demanded in some business sectors. For example, many industries look for relatively short payback periods of only a few years to recover their initial investment. The Stern Review noted that this can imply an average discount rate of 30% or more (2006, cited in Dunstan and Daly 2009, p. 26). This is clearly an unrealistic situation for many RE projects being proposed for a developing island nation such as Mauritius as the initial capital costs would make such a return impossible. Further impacting the rate of return is the amount of debt financing sort by the RE developer. If the debt is too high the RE project could run at a loss or be forced to pay very low rates of return during the early years of operation. Getting this balance right will require extensive work by the RE developer and the financial bodies it engages.

9.1.6. Inefficient Pricing (mispricing)

Inefficient pricing is concerned with the failure to properly reflect the full cost of energy production in the electricity price structure. This is primarily concerned with the unpriced external costs often associated with social and environmental impacts of energy production, known as externalities.

9.1.6.1. Externalities

Unpriced external costs are the result of producing a good or service but are not included in the final price of that good or service (Dunstan and Daly 2009). For example, electricity is produced and priced based on the cost of production and transmission but does not include any price for the pollution that is released as a result. The most obvious external cost results from both the health and climate impacts of this pollution. The grid emission factor of Mauritius is extremely high at 1.01 tonnes CO_2/MWh due to the prevalence of imported coal (approx. 43%) and fuel oil (approx. 37%) (Green Climate Fund 2015). The burning of coal has been cited as one of the leading causes of smog, acid rain, global warming, and other airborne toxic substances (Union of Concerned Scientists 2016). A carbon tax is a method to include the external costs associated with GHG pollution into the cost of producing a good or service, thus reducing the inefficient pricing barrier facing renewable energy generators.

9.1.7. Regulatory Barriers

Regulatory barriers refer to the biasing of regulation against distributed energy resources such as wind farms.

9.1.7.1 Lack of policy to promote RE technologies

In some markets, there may not be guidelines available for the RE project developers to follow to make an application to the network operator to connect. Mauritius has been proactive in developing grid codes for both RE projects less than 50 kW capacity and projects greater than 50 kW and less than 200 kW in capacity with the support of the UNDP and MID fund. However, to promote the installation of larger projects it would be ideal for the CEB to develop guidelines for larger projects.

9.1.8. Cultural Values

Cultural values refer to the barriers that exist due to society's expectations and norms. These values have resulted in both a low priority for and opposition to wind technology in some nations.

9.1.8.1. Opposition and Scepticism of Wind Technology

When working with a geographically local community, there are essentially two key groups that are likely to oppose a wind development. First, the citizens who have a long-term relationship with the area, this type of relationship is often described as "place identity" (Pearce 2008). The second group are the lifestyle -changers or "blow-ins" as described by Pearce. Involving these groups in the planning and sitting can help to reduce opposition, however the people that oppose such a development because they are ingrained sceptics of wind technology (typically believe that the technology is flawed) will not be swayed by involvement with the local community.

9.1.8.2. Business Culture

It may be assumed that a responsible network operator would operate their business to account for future changes in the market and embrace distributed generation, especially considering the Mauritian government's announcement of a 35% renewable energy target by 2025 and the benefits that can be obtained from some distributed generation in terms of demand management. However, a business's main priority is to maximise profits within the bounds of the current market regulations. Therefore, any risk imposed on that business will influence the business culture and can result in poor responses and low priority given to renewable generation wishing to connect to the network.

9.1.9. Confusion

Obviously, the above-mentioned barriers don't exist in isolation, there can be many interactions between each barrier with some interactions being quite complex in nature. A few examples will be presented of the types of interactions that can take place between barriers resulting in further confusion.

9.1.9.1. Interaction between split incentives and information asymmetry

One of the split incentives previously noted was that of the landlord and tenant problem, meaning there was little incentive for the network operator to cooperate with RE generators. A further complication of this problem may occur due to the interaction with information asymmetry. This may result in the RE generators being lumped with the costs associated with distribution network upgrades regardless of whether the upgrade was required due to the addition of generation or not. As noted in section 9.1.1.1, the network operator often considers network information confidential, hence it may be difficult to prove whether the distributed generator is paying an excessive amount or not to connect their generation assets.

9.4.9.2. Connection Approval Process

There is little incentive for the network operator to cooperate with RE generators in a timely fashion beyond the specified regulatory requirements regarding the connection process. This is due to a combination of barriers including information asymmetry, split incentives, and business culture. This may result in the RE developer being forced to endure unnecessarily long delays between the initial application for connection of generator assets and the offer to connect being made by the network operator. A similar situation has been reported for the connection of cogeneration plants within the city of Melbourne, Australia, with the approval process taking over 18 months (Snow 2009).

9.2. Recommendations to overcome Institutional Barriers

Having examined both the Technical and Institutional barriers faced by RE projects, the following section will detail proposed recommendations to reduce or eliminate the impact of these barriers. The recommendations are summarised in Table 141.

Table 141: Summary of recommendations

Barrier Type	Description	Options to overcome barriers
Information	Lack of available and accurate information	• Update the Electricity Act 1939 as a priority and ensure that it covers future smart grid applications • MID fund/MARENA to allocate funding to identify potential onshore wind and offshore wind sites and fund the data gathering, such as wind monitoring, to allow potential IPPs to prepare business cases. • Make all resource data gathered public domain • Opportunity to work with the Mauritius University and other not-for-profits on the data gathering projects • Provide services to support potential IPPs with connection applications
Split Incentives	The challenge of capturing the benefits spread across numerous stakeholders	• Currently there are multiple organisations within government providing planning for renewable energy, this is confusing • Investigate incentives for landlords to invest in solar PV for rental properties • Investigate the feasibility of selling electricity behind the meter, thereby eliminating the need for consumers to provide capital upfront for small and medium-scale solar PV projects • Provide incentives for the CEB to perform detailed power systems studies to allow for more distributed solar in the SSDG scheme.
Payback Gap	The gap in acceptable payback periods for renewable energy	• Implement Feed-in-tariffs (FiT) for renewable energy • Ensure that the period of the FiT is sufficient to create profitable projects • Implement reverse auctions for the procurement of renewable energy at least cost • Provide a fund that can be used to help finance prospective community energy projects.

Barrier Type	Description	Options to overcome barriers
Inefficient Pricing	Failure to reflect costs (including environmental costs) properly in energy prices	• Carbon Tax – Implement a price on carbon to level the playing field between polluting industries and renewable energy.
Regulatory	The biasing of regulation against distributed generation (DG)	• Update the Electricity Act 1939 as a priority and ensure that it covers future smart grid applications
Cultural Values	Low priority and/or opposition to renewable energy issues (BAU)	• Engauge the public in all decisions, as is the case with the MID • Promote the use of electric vehicles to reduce diesel use • Prioritise renewable generation within the MEPU and the CEB • All new generation to be RE were possible
Confusion	The additional barriers created by the interaction between the six types of barriers listed above.	• Further networks studies to establish the best locations for future renewable energy projects • Network upgrade plan to meet a 60% RE target outlining the locations where RE can be connected for lowest cost • Establish time limits for the network operator to both respond to a connection application and provide the final connection approval – Fast track applications that propose connection in areas designated high priority

9.3. Policy

Many developed and developing nations are planning the mass deployment of renewable energy technologies, whether as a path to a low-carbon future, to avoid dependence on imported fossil fuels, or as a business opportunity. Regardless of the rationale, nations have tried a range of policies for promoting the deployment of renewables. Policies include, but are not limited to: production subsidies, feed-in tariffs and preferential pricing, command and control measures such as quota/portfolio standard approaches, land grants, and tax incentives (Cozzi 2012). This section details several of the most common and successful schemes in use today.

9.3.1. Feed-in Tariffs (FiTs)

A feed-in tariff (FiT) is a price paid to generators of renewable energy for a guaranteed period for electricity fed into the grid (Couture and Gagnon 2010). FiTs have become increasingly popular in the previous couple of decades by encouraging investment, stimulating rapid development, and creating a more diverse range of clean electricity options. It achieves this by offering long-term contracts to renewable energy producers, typically based on the cost of generation of each technology. There are now more than 75 jurisdictions worldwide with FiT or renewable energy credit schemes in 2014 (Burtt and Dargusch 2015).

In addition, feed-in tariffs often include a "tariff digression", a mechanism by which the price (or tariff) ratchets down over time. This is done to track and encourage technological cost reductions. Fixed prices created by FITs for renewable energy sources can also help stabilise electricity rates which can entice new business and attract new investment.

Advocates for FiTs as a regulatory signal argue that experience, particularly in other countries including community owned generation in Denmark and Germany, has shown that they are a better way of stimulating growth in the renewable energy sector than other methods such as quota systems (Walker, What are the barriers and incentives for community-owned means of energy production and use? 2008). The Mauritian government has had some limited success in stimulating small-scale distributed generation from renewables through FiTs.

9.3.1.1. FiT Models

In a survey of FiTs schemes used worldwide, Couture & Gagnon (2010) discovered that there are many differing types employed, however, these where able to be grouped based on whether they were market-dependent or independent. This means that the scheme is based on whether the FiT offers remuneration that is dependent or independent from the actual market electricity price. It is important to note that the design aspects of these FiT models can overlap (i.e. are not mutually exclusive) and can be tailored to the specific needs or context of the jurisdiction where it is to be implemented.

Market-independent FiT policies based on a fixed-price option are the most commonly employed model and are generally accompanied by a purchase guarantee. Market-dependent models are also known as feed-in premiums as they are usually designed to pay a premium above the market rate of electricity to the generator (Couture and Gagnon 2010).

Table 142: Summary of Market-dependent FiT Models (Couture and Gagnon 2010)

Model	Description
Premium Price Model	Offers a constant premium or bonus over and above the average retail price.
Variable Premium Price Model	Like the premium price model but adds both caps and floors effectively allowing the premium to vary as a function of the market price. The premium amount declines in a graduated way until the retail price reaches a certain level, at which point the premium declines to zero and the generators receives the spot market price.
Percentage of Retail Price Model	Establishes a fixed percentage of the market retail price to be paid to the generator.

Table 143: Summary of Market-independent FiT Models (Couture and Gagnon 2010)

Model	Description
Fixed Price Model	Establishes a fixed minimum price at which the electricity generated will be bought for a fixed period, irrespective of the retail price of electricity.
Fixed Price Model with full or partial inflation adjustment	Like the Fixed price model but adds inflation adjustment to guard against a decline in the real value of project revenues by tracking changes with the broader economy.
Front-end loaded model	Like the Fixed Price model but pays a higher remuneration in the earlier years than the later years of the project, effectively skewing the cash flows in favour of the earlier years of the project's life.
Spot Market gap model	The actual FiT payment is comprised of the gap between the spot market and the required FiT price. Thus, the total remuneration is the fixed price consisting of the sum of the spot market price and the variable FiT premium, which when combined make up the total FiT payment.

Because the retail price of electricity cannot be predicted reliably over a 15 to 20-year period, market-dependent models create greater uncertainty for investors and developers because the future payment levels are not known. This presents significant problems for renewable energy projects as they require a stable and predictable revenue stream to obtain financing and attract investors. Market-dependent FiT models can also suffer from both over and under compensation if the premium offered remains fixed.

Lesser and Su, cited in (Couture and Gagnon 2010), have argued that fixed price FiTs in which the FiT payment remains completely independent from the electricity market prices can distort the wider electricity price. The distortion arises from the fixed-price FiT remaining the same over time regardless of the electricity market price trends such as a development that leads to overall lower costs to deploy renewable energy and may lead to lower electricity prices. However, because the FiT is fixed the consumer will continue to pay a higher cost than what the market would pay otherwise. This could be possible for a FiT that is applied to a large sector of the Renewable Energy market, however, when applied only to small and medium scale generation, these sectors should not be large enough or expected to be large enough to cause such a distortion.

9.3.2. Carbon Pricing

Carbon pricing is an efficient method for placing a price on those who emit carbon dioxide (CO_2) and hence is often favoured by economists for overcoming the price externalities of generating energy and burning fossil fuel. For example, electricity is produced and priced based on the cost of production and transmission but does not include any price for the pollution that is released, meaning there is no market response to the costs of that pollution. This type of institutional barrier is known as Inefficient Pricing.

The charge placed on carbon dioxide emissions usually takes the form of either a carbon tax or a requirement for emitters to purchase permits to emit, known as cap-and-trade schemes. The price charged in either form is based on the amount of CO_2 emitted in tonnes.

Both forms of carbon pricing have similar economic outcomes, both are considered efficient, have similar social costs and the same effect of profits provided permits are auctioned. However, some say that the form, whether tax or cap-and-trade, can have negative effects, arguing that:

- Caps can prevent non-price polices, such as RE subsidies from reducing emissions, while taxes do not
- A tax will not prevent those who can afford to do so from continuing to generate emissions, an enforced cap will guarantee emissions reduce

The choice of pricing approach, therefore, must consider other renewable energy and carbon emissions reduction policy already in place. Cap-and-trade schemes are generally favoured by those that prefer market based approaches while the carbon tax is favoured on economic grounds for its simplicity and stability. Both schemes can be used to raise funds that can be used to further deploy renewable energy generation and fund other schemes to reduce emission while also providing funds to help those in society most effected by the increases in electricity and other carbon intensive goods and services.

Both forms of pricing can be applied to specific industries such as electricity generation or can be applied broadly to cover as many industries that have emissions as possible. Industries potentially covered by a carbon pricing scheme include:

- electricity generation,
- coal or other mining,
- natural gas retailing,
- industrial processing (cement, chemical and metal processing),
- transport via fuel retailing,
- other fossil fuel intensive industries, and
- the waste disposal sector

Due to the small market in Mauritius and the ease of implementation, this report would recommend the carbon tax approach for pricing CO_2 emissions. It may be sufficient for a Mauritius based carbon tax to apply only to the electricity generation and transport sectors.

9.3.2.1. How is a carbon tax implement?

A carbon tax typically applies at the point where the fossil fuels or fossil fuelled energy is supplied to the market for sale. These fuel and energy suppliers and processors would pass along the cost of the tax to the consumer to the extent that the market will allow. For example, electricity generated by a coal plant would have an additional cost to cover the portion of carbon emitted while a consumer purchasing electricity from a renewable energy source would not pay any extra. An example of how a carbon price mechanism can operate is show in Figure 123.

If these companies can work more efficiently, then they can reduce the amount they pay each year. This places a financial incentive on these companies to reduce their emissions and move to cleaner technologies.

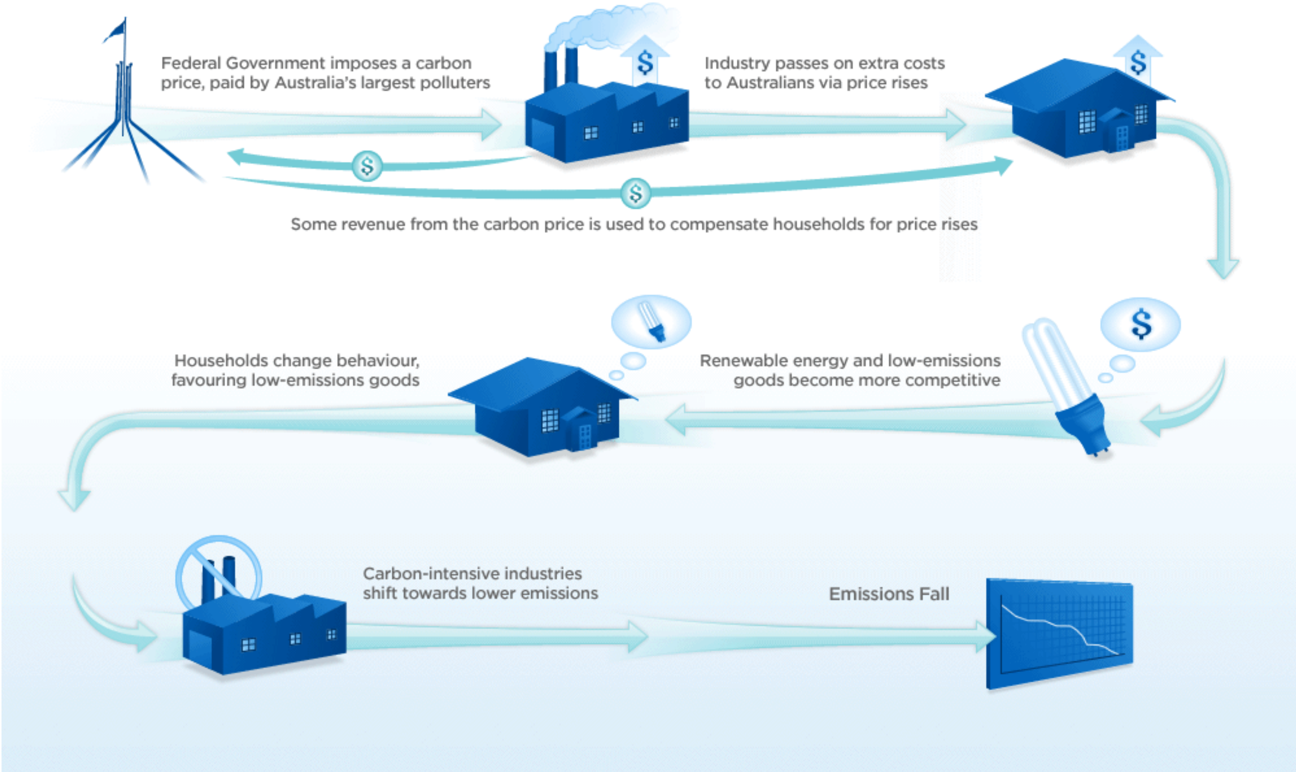


Figure 123: How the Carbon Pricing Mechanism (CPM) worked in Australia (ABC 2014)

9.3.3. Reverse Auctions

In recent years' reverse auctions have become a favoured tool for policy makers looking to deploy renewable energy technologies quickly and at the lowest possible cost. While the concept of a reverse auction mechanism is not new, it is a new approach for procuring renewables. The number of countries using reverse auctions increased from 9 in 2009 to at least 44 in 2013 of which 30 were developing countries (Lucas, Ferroukhi and Hawila 2013). Well-designed reverse auctions have driven increased interest by policy makers due to their potential to be able to achieve deployment of renewable energy technologies in a cost-efficient and regulated manner. Where auctions have been deployed, it has been used to let the competitive market determine the price paid for renewables, but also provide the government with protection against "overpayment".

Reverse auctions may also be known as "large-scale feed-in tariff (FiT) reverse auctions" or "demand auctions" or "procurement auctions", whereby the government issues a request for tenders to install a set electricity generating capacity from a renewable energy technology such as solar PV or wind generation.

Renewable energy project developers that wish to participate in the auction process must submit a bid with a price per unit of electricity for which they can successfully implement the project. The bid submissions are then evaluated by the government based on the price and key criteria established prior to the auction which reflect each country's priorities in terms of local content, employment and social benefits etc. Once the preferred bidders have been evaluated the government signs a power purchasing agreement with the successful bidder(s).

Although an increasingly popular policy, auctions do have risk associated with developer implementation as there is no guarantee that the bid will be successfully contracted. The auctions also tend to favour large renewable energy developers that can afford the associated administration costs of submitting a detailed bid.

Reverse auctions can be designed either to be technology specific or technology neutral. Technology specific auctions tend to promote diversification of electricity generation and certain renewable energy technologies whereas technology neutral auctions promote the most cost effective renewable energy technology that meets the nations natural advantages in terms of renewable resources. Not only can auctions be technology specific, they can also be site-specific. This has some key advantages for reducing investor risk if the auction identifies sites with ideal resources and secured grid connection. Renewable energy auctions can deliver benefits for workers and the environment by adopting measures that encourage local jobs and manufacturing.

The findings of the *Renewable Energy Auctions in Developing Countries* study conducted by IRENA indicate that in designing and implementing auction schemes, policy makers may want to consider the following (70):

- Type of auction: the sealed-bid auction is simple, easy to implement, fosters competition and avoids collusion. Descending clock auctions are more difficult to implement, but they allow for a fast price discovery as well as greater transparency.
- Ceiling prices should not be disclosed to the bidders to ensure greater competition.
- Auction volumes must be determined in relation to the capacity of the market to deliver, particularly in markets with a limited number of local renewable energy developers and suppliers. Determining the optimal number of rounds and the volumes that would create greater competition is a challenge that requires learning by doing.
- Streamlined administrative procedures, with communication and transparency provided equally to all bidders, are essential to the success of an auction scheme.
- Strong guarantees and penalties are essential to the success of auction schemes, preventing potential underbidding and minimising the risk of project delays and completion failure.

Instrumental to the design of auctions are stringent bidding requirements (financial, environmental, grid connection, etc.) and strong compliance rules (penalties, bid bonds, project completion guarantees, etc.) that reduce the risk of underbidding, project delays and project failure.

9.3.4. Community Energy

The community at all levels is becoming more familiar with climate change and its consequences and thus is looking for actions that they can take to have a positive effect on their greenhouse gas emissions. Consequently, community owned renewable energy (CORE) projects can fill part of this need. Research in the UK has indicated that renewable energy projects that allow for significant community input and recognition, and which focus on the positive values of the project can facilitate support for the promotion of renewable energy or open the door to these ideas (Walker and Devine-Wright 2008).

CORE projects with few exceptions (possibly farmer based models) involve the local community from the inception of the project. This direct involvement in the project helps raise public awareness and increases the number of local individuals with a stake in the success of the project. By doing this the local community can become involved in such things as the siting and the orientation of turbines and can control the scale of the development. This has been shown to increase local acceptance and contribute to fewer planning issues (Walker, What are the barriers and incentives for community-owned means of energy production and use? 2008).

One thing we can all relate to is the sense of ownership we have with relation to a project in which we can express control and influence. More concisely a 'sense of ownership' in a community project or development is described as "*a concept through which to assess whose voice is heard, who has influence over decisions, and who is affected by the process and outcome*" (Lachapelle 2008). Lachapelle goes on to make a case for a relationship between capacity for and quality of trust and the potential for ownership. Although a sense of ownership can be quite subjective as compared to legal ownership (Warren and Mc Fadyen 2008), this needs to be considered in the early stages of a project to ensure that trust and a sense of ownership are developed otherwise this could strengthen the voice of local objectors.

This sense of ownership clearly cannot be ignored as demonstrated by research in the UK that suggests it is possible that projects that are owned or part-owned by local communities generally ha ve fewer problems with obtaining planning permission (Walker, What are the barriers and incentives for community-owned means of energy production and use? 2008). Interestingly in a study of wind farms in Scotland, support for wind power was relatively strong and it was found that it did not impact on the ability of the region to attract tourists (Warren and Mc Fadyen 2008). The authors of this study go on to argue that the key finding of their study in Scotland and the UK more broadly was the positive impact that the community -based model had on local acceptance and increased support for wind farm development.

9.3.4.1. Benefits for Rural communities

The most obvious benefit from community owned renewable energy (CORE) projects is the financial return on investment and sale of generated electricity (Walker, What are the barriers and incentives for community-owned means of energy production and use? 2008). This could be significant for rural communities that are in decline and want to become more financially resilient in the face of climate change and peak oil. Furthermore, rural communities are typically very reliant on fossil fuels which could see significant increases in the price in the medium term. From an investigation of wind farms in 2 districts in Scotland (Warren and Mc Fadyen 2008), it was shown that the community-owned project returned over ₤28,000 per turbine whereas the utility-owned project returned only ₤369 per turbine to the community. In addition, it showed that the community-owned project also created new local jobs, net immigration and growing numbers in the local school. This is a significant indicator of how strong a financial case exists for such projects at a community level.

Another similar project in Germany, the Galmsbull GE co-operative wind farm (which produces enough electricity for 3600 homes) returns 33% of its profits to the local community (Wijngaart, Pemberton and Herring 2009). A community wind farm can provide a significant additional revenue for a local community, for example if 2 million shares are locally owned out of a possible 9.5 million (1 share = $1) then at a very conservative 6% return per annum would result in over $120,000 returned to the local community each year. There is also the benefit of lease agreements with local land owners, many of whom are farmers looking for more stable incomes to supplement their agricultural returns.

9.3.4.2. Ownership models

David Toke (Elliott 2007) suggests 3 typical community ownership models have developed globally:

- Local co-operatives
    - The local co-operative model is typically formed with the local residents owning the entire wind farm assets. The best example of this form of wind farm comes from Denmark, in which the entire funding comes from equity capital, thus negating the need for bank credit resulting in increased income security.
- Non-local & non-commercial co-operatives
    - Under the non-local & non-commercial co-operative model the shareholders are not confined to the local area of the wind farm itself and may include ethical investors.
- Farmer ownership
    - Farmer ownership is a commonly used in both Denmark and Germany. Financing can be more difficult as the farmer(s) usually finance via a bank loan for most the capital to set up the wind farm. Because the farmer requires the motivation to acquire additional knowledge to establish a wind farm, this is the key barrier to this form of ownership

In the UK, other models that have been used for renewable energy projects include community charities and development trusts (Walker, What are the barriers and incentives for community-owned means of energy production and use? 2008). These typically are of a smaller scale than a community owned wind farm in terms of capital costs. Another model of relevance was gifting of shares or a wind turbine to a local community organization such as at the Earlsburn Wind farm in Scotland (Walker, What are the barriers and incentives for community-owned means of energy production and use? 2008). A similar model has been used by an Australian commercial wind farm development, the Challium Wind farm near Ararat in Victoria, where $30,000 is given to the local council annually to be used specifically for community projects (Wijngaart, Pemberton and Herring 2009).

9.4. Government Support

The Mauritius government has been very supportive of the transition to a less fossil fuel dependant society through the MID.

In most countries innovation policy for renewable energy technologies is the subject of multiple government departments, creating significant coordination and continuity challenges.

9.4.1. Financing Mechanisms

This section of the Renewables roadmap provides an outline of the numerous types of financing support systems that governments have put in place across the globe. These subsidy systems and government supported entities have allowed for the rapid expansion of the renewable energy sector by providing access to the finance required. An understanding of the variety of financing mechanisms being implemented around the world can be useful in developing effective renewable energy policy and support mechanisms in the Republic of Mauritius.

9.4.1.1. Market constraints

In any developing market, industries face challenges to development and expansion. Two of the key aspects that prevent financial investment in a developing industry are policy stability and term of contracts. These are expanded on below:

9.4.1.2. Policy stability

It is key for a developing market to establish stable policies and subsidy systems to support industry growth. Financial investors heavily rely on secure governments that have targets or policies aimed at increasing renewable energy generation. Policy stability minimises risk of fluctuating future cash flows and therefore provides financiers with confidence in future returns in renewable infrastructure development.

For example, in Australia, market participants remain cautious about the stability of the government's policy position, which affects the way risk is allocated in contractual arrangements. They also question the longevity of the renewable energy target (RET) and what this implies for their return requirements. Policy uncertainty leads to future price uncertainty and in turn a lack of private financial investment which is key for a developing industry.

9.4.1.3. Term

The length of a secure offtake commitment is key to ensuring confidence in the market as the bilateral contract provides revenue certainty and minimises refinancing risk for infrastructure projects. Many renewable energy projects require a secure offtake agreement to reach financial close. The standard length of a solar long term offtake contract ranges from 15-20 years depending on the country, investor, and availability of the plant.

Developing markets are often wary of shorter term offtake contracts as it raises concerns about whether project sponsors will be able to recontract to secure the long-term financial viability of the project for sponsors and equity and debt providers.

There are projects that have shorter offtake agreements, for example the DeGrussa Mine Solar project in WA which has a 7-year term Power Purchase Agreement (PPA). However, this Project required innovative funding support from the Australian government (through ARENA and CEFC) to make the Project feasible with this short term PPA.

Markets struggle to match up the term of offtake with what is required from risk adverse financial investors who have internal financing hurdles. Subsidy systems are able to give long term cash flow guarantees which enables the development of renewable energy projects (as demonstrated in section 9.4.3).

9.4.2. Government Funding and Financing Bodies

To attract new capital to the immature renewable energy industry, many countries including Australia and the UK have sought to provide government investment into infrastructure through grants or on commercial terms. These countries understand that attracting new capital and creating a liquid market for operating assets is crucial to the continued growth of the energy sector and will also help to reduce the long-term cost of finance.

Accordingly, several governments around the world have established independent agencies with remits to provide funding and financing support to the renewable energy sector. Below are three different examples from Australia and the UK.

9.4.2.1. Australia: Australian Renewable Energy Agency

The Australian Renewable Energy Agency (ARENA) is an independent agency of the Australian federal government, established in 2012 to manage the government's renewable energy programs. The aim of ARENA is to provide investment into energy projects to improve the competitiveness of renewable energy technologies and increase the supply of renewable energy in Australia. To do this, ARENA has approximately \$2.5 billion in funding until 2022 to invest in renewable energy projects and initiatives.

ARENA is overseen by a skills-based Board and includes the Secretary of the Department of the Environment to ensure an ongoing commitment to the strategic aims. Additionally, ARENA produces a General Funding Strategy and Investment Plan each year. This establishes the strategic framework for program development and determines ARENA's investment priorities.

There are currently three primary ARENA programs in place that supply funding to renewable projects. See Table 144.

Table 144: Currently funded ARENA projects

Programs	Key facts
Research and Development Program	Supports world-class research and development in priority renewable energy technologies. Up to \$300m has been provided through grants to develop the R&D across Australia. Interested entities applied to the program for grants through specified competitive rounds. There have been two rounds to date: • Round 1: Solar Excellence. The round provided \$21.5m funding for cutting edge solar R&D projects • Round 2: Industry – researcher collaboration. This round promoted the commercialisation of renewable energy technologies
Advancing Renewables Program	Supports activities that reduce the cost or increase the value delivered of renewable energy, advance renewable energy technologies towards commercial readiness, reduce or remove barriers to uptake, or increase relevant skills, capacity and knowledge. Interested entities are able to apply for all activities identified in the ARENA Investment Plan on a rolling basis (or in some cases under specific competitive calls for funding) on the condition that they must demonstrate how the project will meet the aims of the program. For competitive areas of the Investment Plan, funding is provided through specific competitive rounds. The most recent competitive round was: Large-scale solar photovoltaics: ARENA allocated \$100 million to support large-scale solar PV projects. The round announced 12 successful projects which are in total expected to triple Australia's large-scale solar capacity from 240 MW to 720 MW.
Renewable Energy Venture Capital Fund	This program was created to provide venture capital and active investment management to encourage the development of Australian companies that are commercialising renewable energy technologies. The Fund has committed capital of up to \$120 million and is managed by private sector fund manager, Southern Cross Venture Partners Pty Ltd. The fund is a co-investment between ARENA and Softbank China Venture Capital, with each providing half of the committed capital to the Fund. Potential investments made by this fund are governed independently through private investment criteria.

ARENA now supports a portfolio of energy investments which align with the strategic aims and programs outlined above. The figure 124 highlights the total investment made by ARENA in each state across Australia (to June 2016).

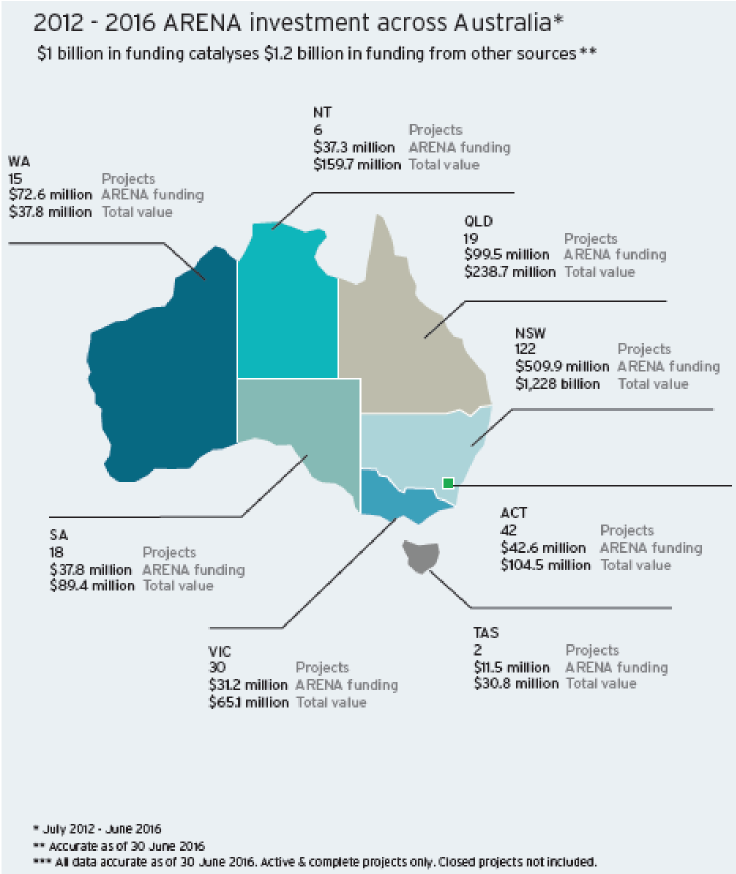


Figure 124: Total investment made by ARENA

9.4.2.2. Australia: Clean Energy Finance Corporation

The Clean Energy Finance Corporation (CEFC) is a statutory authority established by the Australian Government in 2012 to invest in clean energy technologies. The CEFC operates with the mission "to accelerate Australia's transformation towards a more competitive economy in a carbon constrained world, by acting as a catalyst to increase investment in emissions reduction."

The aim of the CEFC is to mobilise private capital investment into the renewables industry. There are currently three investment programs run by the CEFC.

Table 145: Current Clean Energy Finance Corporation investment programs

Fund	Key facts
Sustainable cities	The Sustainable Cities Investment Program will seek to invest $1 billion over 10 years in clean energy and energy efficient technology solutions in cities and the built environment. The finance will be for investments in renewable energy and low emissions technologies, as well as energy efficiency, in cities and the built environment. To date, the programs within this specifically relating to renewable energy are: 100 million cornerstone commitment to the new Australian Bioenergy Fund, to accelerate investment in bioenergy solutions such as energy from waste, and landfill waste solutions. Finance through partners to install Solar PV and batteries on business rooftops
Reef funding	The Reef Funding Program will invest $1 billion over 10 years to help address the two biggest threats to the health of the Great Barrier Reef - climate change and poor quality water runoff.
Innovation fund	The Clean Energy Innovation Fund is a unique $200 million program supporting the growth of innovative clean energy technologies and businesses which are critical to Australia's clean energy transformation. The fund provides debt and/or equity finance for innovative clean energy projects but no grants. Operates in conjunction with ARENA The latest investment was in January 2017 whereby $5 million was committed to GreenSync, a company aiming to bring smart technology solutions to the energy grid of the future, as part of an $11.5 million Series B capital raising.

9.4.2.3. UK: The Green Investment Bank

The UK Green Investment Bank (GIB) was commissioned by the Government to provide investment into renewable or “green” energy projects in the UK. The capital for investment is exclusively provided by the UK Government with a focus on energy infrastructure. The aim of the GIB is to invest in projects on commercial terms and mobilise additional private sector capital.

To promote the energy industry, GIB can provide investment into a range of projects. GIB is limited to matching commercial terms offered by the market in an official tender process to ensure that the investment is made in line with the current market appetite. Potential projects requiring investment submit a formal application either directly to GIB or to one of the specific funds managed by GIB. Originally, the GIB was to support UK investment only but as the industry has expanded additional funds have been set up to meet the market’s needs. Two of the current funds are detailed below:

Table 146: UK Green Investment Bank current funds

Fund	Key facts
UK Climate Investments LLP (UKCI)	Targeting developing countries including: India, South Africa and Kenya. Minority investments of c. £10-30m Fund of £200m provided by the UK Government
Offshore Wind Fund	World’s first dedicated offshore wind fund Europe’s largest dedicated renewable energy fund Current assets c £1.12 billion. Collectively these projects have a capacity of 1.45GW producing over 4,500 GWh renewable electricity each year

To date, GIB have backed approximately 98 green infrastructure projects investing over $2.8m. Recently, GIB has committed 35 million pounds of senior debt to fund the construction of the Wheelabrator Parc Adfer, a new £180m energy-from-waste (EfW) plant at Deeside Industrial Park in Flintshire, North Wales. The new facility is being built and operated under a public private partnership (PPP). Additionally, GIB have fully financed the Lincs offshore wind farm, provided an investment of c. £281m in 2016.

9.4.3. Government Subsidy systems

Governments around the world have also implemented a variety of subsidy systems to stimulate growth in renewable energy and provide the long-term stability required to develop renewable energy projects. Some examples of these types of subsidies are provided below and include: Large Scale generation certificates, Contract for Difference, Feed in Tariffs, Green Bonds and Export Credit Agencies.

9.4.3.1. Australia: Large and small generation certificates

In Australia, the Large-scale generation certificates (LGCs) is the government initiative to promote large renewable energy projects. In addition, small-scale technology certificates (STCs) promote installations that fall under a designated threshold (see below). The system is administered by the Commonwealth Government in Australia as part of the Large-Scale Renewable Energy Target (LRET).

Table 147: Large and small generation certificates in Australia
*** STCs are restricted to Solar PV, Solar Water Heating and Wind**

Fund	Technologies
Large Scale Generation (LGCs)	Solar PV: Installations over 100kW Wind: Installations over 10kW Hydro: Installations over 6.4kW
Small Scale Generation (STCs)*	Solar PV: Less than and including 100kW Wind: Less than and including 10kW Hydro: Less than and including 6.4kW

Accredited renewable energy power stations are entitled to create large-scale generation certificates based on the amount of eligible renewable electricity they produce above their baseline. As a guide, one large-scale generation certificate is equal to one megawatt hour of eligible renewable electricity.

Once created and validated, these certificates act as a form of currency and can be sold and transferred to other individuals and businesses at a negotiated price. Large-scale generation certificates are usually sold to liable entities (electricity retailers), who are required to surrender a set number of certificates to the Clean Energy Regulator each year. The set amount of certificates each liable entity must surrender is based on their energy consumption and sales.

Large-scale generation certificates are sold through the open large-scale generation certificate market (LGC market), where the price varies depending on supply and demand along with other market factors. Payment for sold large-scale generation certificates is completed outside of the LGC market.

9.4.3.2. UK: Contract for Difference

Contracts for Difference (CfDs) is a UK subsidy scheme to incentivise investment in new low-carbon electricity generation. A CfD is a long-term contract between a generator and the Low Carbon Contracts Company (LCCC). The LCCC acts as the retailer and is wholly owned by the UK Government.

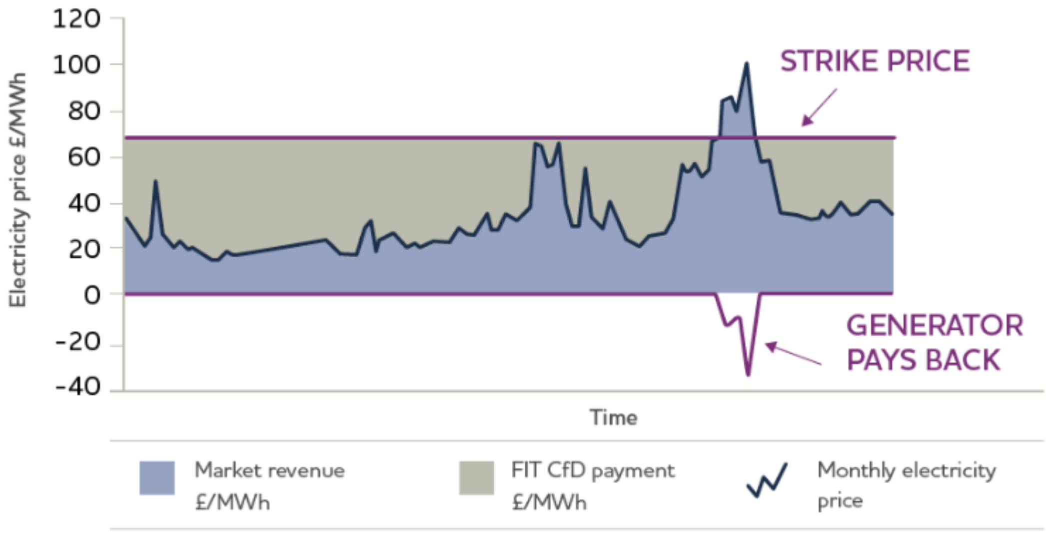
To achieve a CfD, the generator will bid in a price to stabilise its revenues at a pre-agreed level. The price will be bid in amongst a pool of potential prices dependent on the technology. From this a strike price is set which is for the duration of the contract. The strike price is the electricity price per MWh for the term of the contract.

The strike price is set for each “pot” of the CfD scheme. The pots, funding and technologies are detailed below.

Table 148: Current UK Contract for Difference pots

Pot	Funding	Technologies	Admin Strike Prices (£/MWh, 2012 prices)
Pot 1	£65 million from 2016/17 onwards; For established technologies	Onshore wind (>5MW)	90-95
		Solar PV (>5MW)	100-120
		Energy from Waste with CHP	80
		Hydro (>5 and <50MW)	100
		Landfill Gas	55
		Sewage Gas	75
Pot 2	Pot 2 (less established technologies): £155m for projects commissioning in 2016/17, rising to £260 million from 2017/18 onwards	Offshore wind	140-155
		Wave	305
		Tidal Stream	305
		Advanced Conversion Technologies	140-155
		Anaerobic Digestion	140-150
		Dedicated biomass with combined heat and power	125
		Geothermal	140-145
		Scottish Island onshore wind projects	115
Pot 3	Biomass conversion No budget released in this allocation round but this does not preclude budget being allocated to this pot in future rounds.	n/a	n/a

Under the CFDs, when the market price for electricity generated by a CFD Generator (the reference price) is below the Strike Price set out in the contract, payments are made by LCCC (see below) to the CFD Generator to make up the difference. However, when the reference price is above the Strike Price, the CFD Generator pays LCCC the difference. This is shown in the Figure 125 below.



Source: UK Government White Paper, July 2011, licensed under the Open Government License v1.0

Figure 125: Contract for Difference pricing

Since the introduction of CfDs in the UK, many other countries including Australia have used the mechanism to support renewable investment. Notably, Queensland introduced the Solar 60 incentive scheme which supported a total of 60MW of solar generation capacity.

9.4.3.3. Feed in Tariffs

Currently, Feed in Tariffs (FiTs) exist in over 40 countries around the world and they are widely considered one of the most effective ways to increase solar energy uptake. FiTs can be used in two forms:

- A net feed in tariff, also known as export metering, pays the PV system owner only for surplus energy they produce;
- A gross feed in tariff pays for each kilowatt hour produced by a grid connected system.

FiTs are a tried and tested subsidy system that expand the solar market. Germany enhanced their FiT subsidy in 2000 and in the following years the quantity of electricity fed into the grid from eligible sources had more than doubled, with a seven-fold increase in installed solar photovoltaic (PV) capacity to over 1,500 MW by the end of 2005.

In Australia, individual States run independent schemes to incentivise investment in the market. Current market rates range from $0.06/kWh to $0.12/kWh.

9.4.3.4. Green bonds

A Green bond is a type of long term financing that can be secured for a low cost of capital as they do not rely on banks or large scale financiers. These are particularly good for small scale energy developers as their projects are normally capital intensive but cannot guarantee sufficient levels of return to provide comfort to the banks.

Green bonds come in two types with substantially different risk profiles for potential investors:

- Corporate backed bonds – supported by the credit worthiness of the issuer.
- Asset backed bonds – supported only from the revenues generated by the underlying project.

Asset backed bonds are often only given to operational assets because investors typically require a few years of operational history from the underlying assets. These bonds are therefore often used as a refinancing option. These bonds are the only type that have been used in Australia to date.

A notable project financed by a project bond was the Topaz solar farm in the US. It was financed by a US$850m project bond priced at 5.75% issued by MidAmerican Energy. The project, which was constructed in March 2015, is one of the largest solar PV projects in the world. Pacific Gas & Electric are the contracted off taker for 25 years.

9.4.3.5. Export credit agency

An export credit agency (ECA) with a renewable energy focus is typically a government authority with the mandate to provide debt guarantees. This allows for projects to access more financing at a lower cost. Prominent ECAs in the renewable energy sector include EKF, the Danish export credit agency that has underwritten significant volumes of debt associated with the export and use of Danish products such as wind turbines produced by Vestas or Siemens.

In Australia, the export credit agency EFIC partners with banks to provide financing to small and medium enterprises on commercial terms.

9.4.3.6. Export grants

In Australia, there is an Export Market Development Grants (EMDG) scheme which is a system designed to supports a wide range of industry sectors and products, including inbound tourism and the export of intellectual property and know-how outside Australia. For renewable technologies, it promotes the sharing of knowledge on a global scale.

The EMDG scheme:

- encourages small and medium sized Australian businesses to develop export markets
- reimburses up to 50% of eligible export promotion expenses above $5,000 provided that the total expenses are at least $15,000
- provides up to eight (8) grants to each eligible applicant.

9.4.4. Mature markets

The aim for the renewables industry worldwide is for it to act as a mature market where projects can be financed independently without government support. Subsidy systems are catalysts to drive an industry forwards and are not intended to become active in the long-term market.

Markets such as the US and UK are now deemed mature markets for renewable energy – particularly solar PV generation which is reaching grid parity in the UK. Mature markets are often driven by large corporates who have looked to access the market to decrease their costs, improve energy price predictability and enhance their reputations. This is due to renewables being proven to be economic and profitable.

9.4.5. Merchant models

Large scale corporates can invest directly into infrastructure (be it construction financing or for an operational asset). Due to the scale of these investors, they are more comfortable in taking merchant risk whereby they do not have a contracted offtake to secure the long-term revenues.

In Chile, which has one of the largest solar photovoltaic (PV) markets in Latin America, solar projects are being financed on a purely merchant basis. Banks and other providers of finance are willing to take the risk of the secure cash flows on the basis that the demand for power in the country will be sufficiently high to keep the spot price high enough for official return.

In 2013, most of the PV projects financed in Chile, were partially or fully contracted, with only one merchant project, Saferay and Seltec's 29.1 MW La Huayca II, reaching financial close. By contrast, in 2014, most projects financed were relatively large merchant facilities. This suggests that, in Chile, commercial lenders have gained a high degree of confidence in the trajectory of underlying electricity prices.

Table 149: Case Studies of Merchant Models

Case Study	Description of Merchant Model
Ararat Wind Farm, Austral-ia	The Ararat Wind Farm (240 MW), which is co-owned by a consortium of Renewable Energy Sys-tems (RES), GE, Partners Group and OPTrust, was awarded a 20-year feed-in tariff (FiT) by the ACT Government for 80.5 MW of capacity. The Project sponsors could raise sufficient equity and debt finance to fund the construction of the entire project despite the FiT only covering roughly a third of the project's output.
Moree Solar Project and White Rock Wind farm, Australia	Both the Moree Solar Project (56 MW) and the White Rock Wind Farm (175MW) in Australia were developed as merchant models but subsequently signed long term PPA agreements.

9.4.6. Conclusion

As evidenced above, there are a variety of support mechanisms being put into place to support the development of the renewable energy industry around the world. There is no single right way to support growth of renewable energy; each country's unique set of resources and social, political and economic factors have led to various innovative solutions.

However, it is of critical importance to implement stable policies, targets, government support bodies and/or subsidies which allow for the long-term pricing certainty that is required to develop renewable energy projects. Some of the most successful financing schemes which have helped renewables become a more mature market are the ongoing subsidy schemes that allow investors to secure long term cash flows and therefore provide construction financing. This, combined with secure government structure and independent bodies that govern investment procedures, have led to ever increasing investment in the renewable energy sector.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10. SUMMARY AND RECOMMENDATIONS

The purpose of this study is to provide a high penetration renewable energy roadmap for the Republic of Mauritius to increase the share of renewables in the energy generation mix to a target of 60% or more.

Despite the Republic of Mauritius having very good renewable energy resources, the proportion of the nation's energy requirements that are currently met from renewable energy resources is low, currently at 22.7%. This places the country's uptake of renewables behind the target of 24% set in the Long-Term Energy Strategy (LTES) for 2015. However, modelling conducted as part of this study demonstrates that Mauritius is on track to reach the 35% target assuming that all currently planned works are completed.

Further recommendations will be made that, if adopted, would increase the development of renewable energy resources beyond the 2025 target of 35% to a total of greater than 60%. This has been determined by examining the availability of renewable energy resources, the costs of converting to renewable energy, the policies and programs that are in place to support investment in renewable energy and by the sizes of the energy loads, as well as various factors that serve to constrain investment in renewable energy.

2015 ENERGY GENERATION MIX

The total renewable energy generation for the Republic of Mauritius is calculated by summing the total electricity generation from both Mauritius and Rodrigues, see Table 150. For the baseline year, the percentage is 22.7% of total electricity generation. The energy generation mix of Mauritius represents approximately 99% of all electricity generation for the Republic of Mauritius.

Table 150: Total electricity generated and renewable energy split for the Republic of Mauritius

Electricity Source		Units Generated (GWh)	%
Renewable	Mauritius	676	22.6%
	Rodrigues	2.7	0.1%
Non-renewables	Mauritius	2,280	76.1%
	Rodrigues	37	1.2%
Total Electricity Generation		**2,956**	**100.0%**
Total Renewable Generation		**679**	**22.7%**
Total Non-renewable Generation		**2,317**	**77.3%**
Renewable	Mauritius	2,956	98.7%
	Rodrigues	40	1.3%

ENERGY GENERATION MIX TO 2025

Based on the Long-term Energy Strategy and information from the CEB, the likely energy generation mix as determine by this study for 2025 is presented in Table 151.

Table 151: Total likely installed generation capacity by type for in 2025

Fuel Type		Effective Capacity – Crop Season (MW)	Effective Capacity – Off -crop Season (MW)
Renewable	IPP Thermal - Bagasse	142.5	0
	CEB Hydro	56.3	56.3
	WtE	33.0	33.0
	Onshore Wind	98.8	98.8
	Solar PV	140	140
Sub Total (Renewable)		471	328
Non-Renewables	CEB Thermal - Fuel Oil	510	510
	IPP Thermal - Coal	30	193
Total Electricity Generation Capacity		1,011	1,031

As can be seen in Table 151 the total installed capacity of onshore wind needs to increase from the 38.8 MW expected to be commissioned by the end of 2016 to a total of 98.8MW in 2025. As discussed in section 4.2.5 solar PV projects planned to 2025 are sufficient to meet the 2025 goal. The study has determined that the total electricity generation by each generation source based on the likely installed generation capacity for Mauritius in 2025.

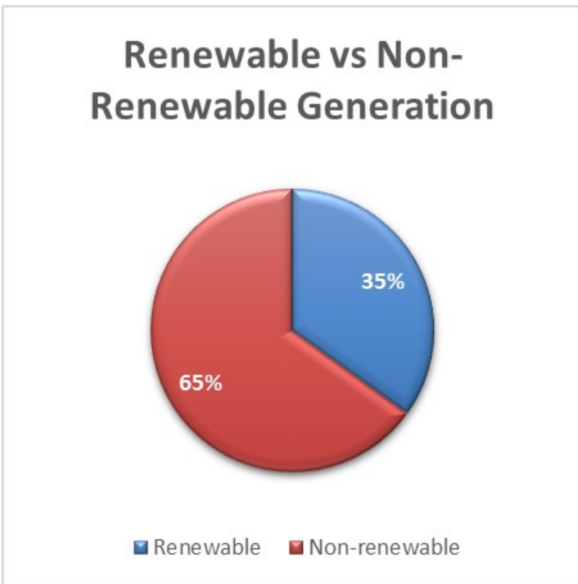
The total electricity generated, including the self-consumption total, was used to determine the total renewable energy generation for Mauritius, for 2025. The modelling results indicate that renewable energy will account for approximately 35.0% of total electricity generation on the Island, see Table 152 and Table 153.

Table 152: Total electricity generated and exported to the grid by type as modelled for 2025

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse	356	11.0%
	Hydro	92	2.8%
	WtE	157	4.8%
	Onshore Wind	262	8.1%
	Solar PV	234	7.2%
Sub Total (Renewable)		1,101	33.9%
Non-renewables	Fuel Oil	1,415	43.6%
	Coal	729	22.5%
Total Electricity Exported to CEB Grid		3,245	100.0%

Table 153: Electricity exported to the grid and self-consumed by IPP generators as modelled for 2025

Fuel Type		Units Generated (GWh)	%
Renewable	Bagasse (crop season)	356	10.2%
	Hydro	92	2.6%
	WtE	157	4.5%
	Onshore Wind	262	7.5%
	Solar PV	234	6.7%
Sub Total (Renewable)		**1,101**	**31.4%**
Non-Renewables	Fuel Oil	1,415	40.4%
	Coal(non-crop season)	729	20.8%
Total Electricity Exported to CEB Grid		**3,245**	**92.6%**
IPP Self-consumption	Renewable—Bagasse (crop season)	124	3.5%
	Non-renewables—Coal (non-crop season)	136	3.9%
Total Electricity Generation		**3,505**	**100.0%**
Total Excess Electricity Generation		**0**	**0.0%**
Total Grid Load/Demand Serves		**3,505**	**100.0%**
Total Renewable Generation		**1,225**	**35.0%**
Total Non-renewable Generation		**2,280**	**65.0%**



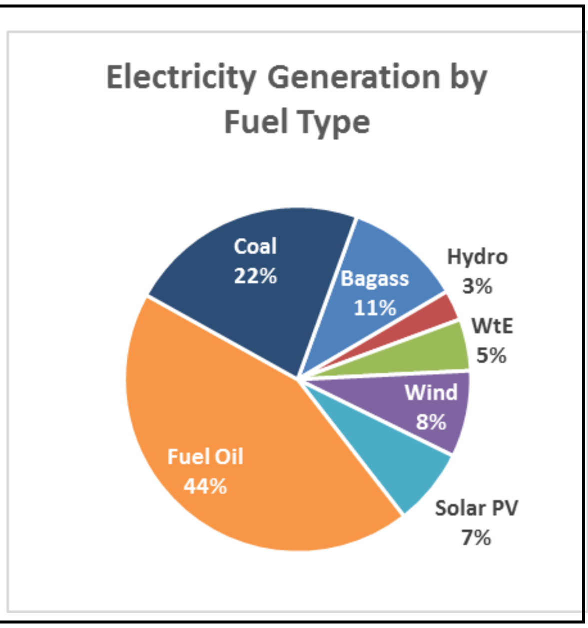


Figure 126: Electricity sources for Mauritius as modelled for 2025

DEMAND AND SUPPLY BEYOND 2025

This report has predicted the growth of annual average electricity consumption for Mauritius, concluding that the total electricity consumption will grow by 552 GWh from the 2015 level by 2025. This assumption has not considered the current disruptive trend in the transport sector with the introduction of electric cars.

Demand beyond 2025 with be dependent on population growth and the impact of any energy efficiency schemes/programs. Energy efficiency has seen demand in some western countries level off and even reduce. The 60% or greater renewable energy target would be expected to be set around 2030, although it is assumed for this study that demand growth will stabilise around 2035 due to the implementation of energy efficiency measures. The predicted annual electricity generation around 2030 is expected to be 3,745 GWh an increase of more than 1,000 GWh from 2015, refer to Chapter 3 - Demand and Supply Beyond 2025 for more details.

Energy generation mix for a 60% RE Target

Although Mauritius is on target to deliver 35% of its energy generation mix from renewable energy by 2025, significant planning and development will be required to increase the penetration of renewable energy to 60%. This study has considered several commercialised and developing renewable energy technologies and modelled potential scenarios for a future energy generation mix to meet a 60% renewable energy target. Each scenario was modelled to determine the likely contribution from each renewable energy source and likelihood of producing 60% or more energy from the most suitable renewable energy sources for Mauritius.

The opportunities for utilising renewable energy sources on Mauritius are a function of the nature of the resources that are available and the stage of commercial development of the associated conversion technologies, and the costs. Note that any expansion in biomass generation from bagasse has been excluded as any increase in production will come about via incremental improvements and not through expansion of the industry. This industry is affected by climate change and coupled to the import of coal. Coal generation accounts for 40% of total electricity generation for the island and will need to be reduced to meet a higher renewable energy target and the goals of the MID initiative.

Section 7.1.2 details the assumptions made in modelling the different scenarios. Of the four scenarios considered, scenario 4, as detailed in 7.1.6, has been determined as the most appropriate for Mauritius, see Table 154 and 155. The scenario meets the target renewable energy penetration with low excess energy production while offering a diverse mix of renewable energy generation sources. This scenario comprises an increase in both solar PV and onshore wind over the 2025 target of 160 MW and 101.2 MW respectively plus the addition of 220 MW of offshore wind and 220 MW of wave energy. It is apparent that to increase the renewable penetration beyond 45%, Mauritius would need to consider off-shore renewable technologies.

This scenario is reliant on the ability of the CEB to expand the solar PV schemes and increase the total solar PV from an estimated 140 MW in 2025 to 420 MW around 2030. Similar, onshore wind energy needs to expand from an estimated 100 MW in 2025 to 200 MW around 2030. With the right incentives in place along with falling prices for both solar PV and onshore wind, these targets should be easily achievable within a 10-year timeframe out to 2030.

The most significant generation change will require the installation of 220 MW of both offshore wind and wave energy. As the installation is due to occur sometime after 2025, there is sufficient time for the technology to mature and for Mauritius to play a part in the development of these technologies by participating in research and development. This could involve the deployment of offshore wind and/or wave energy technology as demonstration projects over the next 5-year period prior to the roll-out of 220 MW of both offshore wind and wave energy to meet the 60% renewable energy target.

Table 154: Scenario 4 - explanation of electricity generation technology mix

Technology	Changes to capacity	Capacity	Comments
Onshore Wind energy	Increase	200 MW (up from 98 MW in 2025)	New onshore wind farms, will be limited by amenity and need to consider tourism industry. May help some farmers with additional income stream.
Solar PV	Increase	300 MW (up from 140 MW in 2025) Utility scale – 110 MW SSDG – 130 MW MSDG – 60 MW	Significant increase in SSDG solar PV with additional capacity from utility scale and MSDG, solar PV has good potential for local job development
Offshore Wind energy	Installation of wind turbines in shallow depth areas	220 MW	Under this scenario, offshore wind becomes cost competitive with fossil fuel generation
Wave energy	Installation of CETO 6 or equivalent	220 MW (equivalent to 220 x 1 MW_e units)	Under this scenario, wave energy conversion technologies become cost competitive with fossil fuel generation

Table 155: Total likely installed generation capacity by type for Mauritius in scenario 4

Fuel Type		Effective Capacity – Crop Season (MW)	Effective Capacity – Off -crop Season (MW)
Renewable	IPP Thermal - Bagasse	142.5	0
	CEB Hydro	56.3	56.3
	WtE	33.0	33.0
	Onshore Wind	200	200
	Solar PV	300	300
	Offshore Wind	220	220
	Wave Energy	220	220
Sub Total (Renewable)		**1,172**	**1,030**
Non-Renewables	CEB Thermal - Fuel Oil	510	510
	IPP Thermal - Coal	30	193
Total Electricity Generation Capacity		**1,712**	**1,733**

Managing Power System with high RE penetration

It is anticipated that the following renewable generation is brought online to achieve the 60% renewable target:

1. Solar = 300kW
2. Onshore Wind = 200kW
3. Offshore Wind = 220kW
4. Wave Energy = 220kW

Based on the generation mix from Table 155, firm generation capacity of the island is expected be 771.8MW (crop season) and 792.3.3MW (off-crop season). From a network stability point of view, worst case scenario could be seen during crop season. The percentage of variable to firm generation capacity in crop season is 54.9%.

Detailed Power factor modelling is required to determine the impact on the stability of the system to maintain such high percentages of variable generation. This study is not part of this report and this report recommends further detailed studies would need to be perform to determine the ultimate solution to achieve stable renewable contribution.

There is a good potential for the solar generation in Mauritius to be implemented on rooftops of residential and commercial housing. This has the valuable effect of geographically spreading the solar energy that mitigates the variable effects of the solar production.

It is likely that all slow responding generators will need to be kept on line at the lowest load point. This information is currently not available. Another important factor to achieving stable usage of VRE is the ability to bring online fast acting spinning reserve. This can be achieved from existing generating sources such as the kerosene generators and hydro generators. New spinning reserve capacity of 18MW of battery storage is planned for construction on the island to manage the VRE for the 35% renewable energy target. This would need to be expanded further to achieve higher levels of VRE contribution to load. It would be likely that additional high speed diesel generators be also installed to be utilised as secondary control units that can be dispatched within 30 seconds of demand requirement.

One point to note is that the wave generation data supports the operation and utilisation of the wave output to be close to firm capacity. Therefore, the required spinning reserve and step response typically needed for wind and solar is likely to be reduced.

10.1 Recommendations

Mauritius has good solar and wind resources. Onshore technologies such as solar PV and wind are the cheapest forms of renewable energy and at utility scale are lower in cost than new build fossil fuel generation. The number of buildings on Mauritius would indicate that there is significant potential for roof mounted solar PV beyond what has already been installed through the CEB SSDG scheme. Therefore, solar PV along with onshore wind should be considered the best renewable energy sources for the short term. However, as mentioned above, without energy storage to shift energy generated by these sources to times when they are not generating, there remains a limit to the amount these sources can contribute. Our analysis indicates that the limit of this contribution from solar and onshore wind to be approximately 45% depending on the generation mix employed.

Recommendation 1:

Develop and implement a plan to significantly expand the SSDG and MSDG solar PV scheme beginning early 2020’s with a target to increase the total install base to 130 MW and 60 MW respectively by 2030.

- Investigate incentives for landlords to invest in solar PV for rental properties.
- Investigate the feasibility of selling electricity behind the meter, thereby eliminating the need for consumers to provide capital upfront for small and medium-scale solar PV projects.

Recommendation 2:

Commission a detailed study to evaluate the roof top potential for solar and the impact of this distributed solar on the overall power systems in Mauritius and Rodrigues.

- Investigate the feasibility of home energy storage systems to lessen the impact of distributed solar generation

Recommendation 3:

Develop and implement a plan to significantly expand the utility scale solar PV scheme beginning early 2020's with a target to increase the total install base to at least 110 MW of firm capacity using energy storage by 2030.

- Provide incentives for the CEB to perform detailed power systems studies to allow for more distributed solar across the entire electricity network and to identify locations for utility scale solar PV farms.

Recommendation 4:

Develop and implement a plan to significantly expand the onshore wind farms beginning around 2020 with a target to increase the total installed base to 200 MW of firm capacity using energy storage by 2030.

To achieve higher levels of renewable contribution, offshore technologies need to be considered. Mauritius has very good offshore wind and wave resources with the potential to provide a greater portion of generation over a full 24-hour period. Several offshore technologies where considered in this report being close to commercialization with offshore wind and wave energy being the most promising. These technologies could provide a path toward a 60% target over the medium to long term meaning any future planning should consider the integration of these technologies.

Recommendation 5:

Commission a study to develop an offshore wind farm industry beginning around 2025 with a target to install 220 MW by 2030.

- Study to consider potential electricity network connection points for future offshore development.

Recommendation 6:

Develop and implement a plan to create a wave energy industry beginning around 2025 with a target to install 220 MW by 2030 including Rodrigues island being used as a trial site to test wave units in Mauritius.

Given the good to very good solar, wind and wave resources in Mauritius region, a program to release resource mapping for Mauritius should be undertaken. Where necessary resource mapping could be carried out in conjunction with local university and research organisations. Governing bodies around the world have found that this can provide a boost for local research programs while at the same time reducing the risk for potential investors in renewable energy infrastructure without providing direct subsidies. In addition, Governing bodies around the world are finding that releasing specific non-private data sets for free can enable innovative problem solving.

Recommendation 7:

Allocate MID fund/MARENA funding for research to identify and map potential onshore and offshore wind sites and offshore wave energy sites including:

- Resources for both onshore and offshore wind monitoring
- Bathymetry data generation for offshore wind and wave energy sites (this can be integrated with mapping for other marine research activities)
- Make all resource data gathered public domain

The costs of generation management solutions are high and those investing in renewable energy generation (centralised or distributed) in CEB's supply areas should not be required to invest in high cost solutions unless it is absolutely necessary for them to do so. It should also be important to develop the lowest cost possible renewable energy generation management solutions. This will include for example, understanding the appropriate energy storage capacities required to be incorporated into renewable energy generation management systems.

Recommendation 8:

Prioritise renewable generation within the Ministry of Energy and Public Utilities (MEPU) and the Central Electricity Board (CEB) - all new generation to be RE were possible.

- Commission studies to perform detailed assessments of grid infrastructure including the ability to accept greater renewable generation and to establish preferred locations for energy storage and renewable generation.
- Expand the CEB Integrated Electricity Plan (IEP) 2013-2022 to target 60% RE contribution integrating the outcomes of the proposed study above including the locations where renewable energy can be connected for lowest levelised cost.
- Commission a study to assess the benefits of residential solar systems and distributed utility scale projects as geographic spread has been shown in other locations to reduce generation variability by up to 90% compared to a central utility scale project.
- Fast track RE connection applications that propose connection in areas designated high priority.

Recommendation 9:

Set up a dedicated research organisation funded by government to review the technologies and methods of achieving higher levels of renewable generation. Research mandate to include a mechanism to trial advanced technology projects to achieve the higher contribution of renewables in Mauritius and Rodrigues.

- The organisation should facilitate research and demonstration projects with research partners (such as CEB, university research groups, and industry) to develop and trial low cost renewable energy generation management solutions.
- Policy for renewable energy is the subject of multiple government departments, creating significant coordination and continuity challenges. The Mauritius government should aim to reduce the number of departments involved in renewable energy policy.

There are legal, regulatory and cultural barriers that may hamper the progress of renewable energy projects in Mauritius. These barriers can be described as “Institutional” barriers. The following recommendation should be considered to ensure the successful transition to a higher renewable energy target. As previously noted in recommendation 7, making all resource data gathered public domain, particularil for offshore wind and wave renewable energy resources, is an import step in reducing “information” barriers.

Recommendation 10:

Update the Electricity Act 1939 as a priority and ensure that it covers future smart grid applications.

- Investigate the impact from the deployment of smart meters, additional distributed generation and small behind the meter battery storage systems.

Recommendation 11:

To achieve acceptable payback periods for renewable energy and encourage investment in the industry, consider implementing reverse auctions for the procurement of utility scale renewable energy at least cost.

Recommendation 12:

To overcome inefficient pricing barriers for renewable energy and to level the playing field between polluting generators and renewable energy, organise an independent review with the objective to determine the best method of implementing a price on carbon for Mauritius.

- Methods such as a carbon tax are efficient to implement, have a low to moderate impact on consumers and can provide additional revenue to fund the transition to a higher renewable energy target (i.e. funds can be used to help low income consumers, fund improvements in the electricity network, and fund research and development).
- The review could be conducted by a dedicated research organisation, see recommendation 9.

Recommendation 13:

To overcome opposition to renewable energy, consider the implementation of and/or priority for community renewable energy projects. This provides local community members with some ownership in the transition to a higher renewable energy target. These projects can take many forms, for example:

- a community owned generator (co-operative model);
- private utility scale projects gifting a small part of the project to the local community; and
- private utility scale projects providing funds directly to local communities for the installation of solar PV on the local hall, school or church.

Renewable energy employment in Mauritius could be a great driver for jobs creation and these jobs can be exported to neighbouring countries (e.g. Madagascar) to support the development of renewable energy projects in the region.

Recommendation 14:

Commission a study to evaluate the potential job and economic benefits of a more aspirational renewable energy target, such as the 60% target proposed.

The 2011 Mauritius census logged 1,700 households that did not have electricity. There are several options available to provide standalone power systems to homes without access to electricity, however, the circumstances behind why these households do not have an electricity connection needs to be investigated before a comprehensive solution can be proposed.

Recommendation 15:

Commission a study to evaluate why these households do not have an electricity connection and the costs for connecting them to the grid versus utilising standalone power systems where applicable.

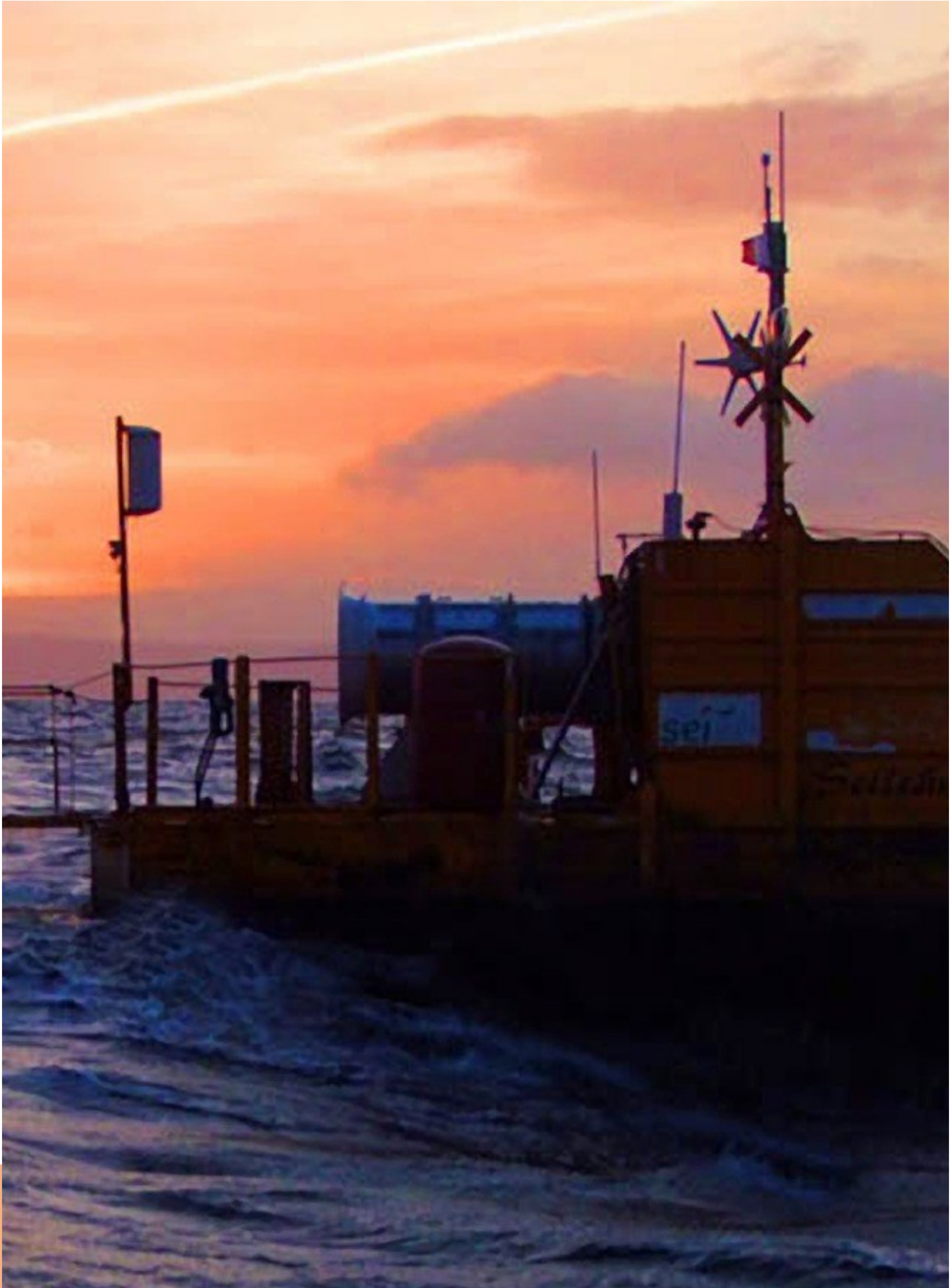
- This is an ideal project to be conducted by universities and/or other not-for-profits organisations as part of humanitarian efforts in Mauritius.

As countries look to meet future energy mix requirements in a rapidly growing and changing world, trying to achieve sustainable transportation is emerging as a key mission. Electric vehicles (EVs) are one of the most beneficial ways to improve energy security and at the same time reduce greenhouse gases and other pollutants. For a geographically small country like Mauritius, EV technology is well suited as the driving ranges are short.

Recommendation 16:

Commission a study to evaluate the full impact of an expansion and deployment of EVs across Mauritius and Rodrigues, particularly the impacts on future energy demand growth (electricity production).

- This is an ideal project to be conducted by local universities and/or other research organisations.



Tables

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Appendix A: Tropical Cyclone Classifications

Table 156 lists tropical cyclones classifications by region, the Republic of Mauritius is considered in the 'SW Indian Ocean' region.

Table 156: Tropical cyclone classifications

<table>
<tr><th colspan="10">Tropical cyclone classifications</th></tr>
<tr><th>Beaufort scale</th><th>1-minute sustained winds</th><th>10-minute sustained winds</th><th>NE Pacific & N Atlantic</th><th>NW Pacific</th><th>NW Pacific</th><th>N Indian Ocean</th><th>SW Indian Ocean</th><th>Australia & S Pacific</th></tr>
<tr><td>0–7</td><td><32 knots (59 km/h)</td><td><28 knots (52 km/h)</td><td rowspan="2">Tropical Depression</td><td rowspan="2">Tropical Depression</td><td rowspan="3">Tropical Depression</td><td>Depression</td><td>Zone of Disturbed Weather</td><td rowspan="3">Tropical Disturbance
Tropical Depression
Tropical Low</td></tr>
<tr><td>7</td><td>33 knots (61 km/h)</td><td>28–29 knots (52–54 km/h)</td><td rowspan="2">Deep Depression</td><td>Tropical Disturbance</td></tr>
<tr><td>8</td><td>34–37 knots (63–69 km/h)</td><td>30–33 knots (56–61 km/h)</td><td rowspan="3">Tropical Storm</td><td rowspan="3">Tropical Storm</td><td>Tropical Depression</td></tr>
<tr><td>9–10</td><td>38–54 knots (70–100 km/h)</td><td>34–47 knots (63–87 km/h)</td><td>Tropical Storm</td><td>Cyclonic Storm</td><td>Moderate Tropical Storm</td><td>Category 1 tropical cyclone</td></tr>
<tr><td>11</td><td>55–63 knots (102–117 km/h)</td><td>48–55 knots (89–102 km/h)</td><td rowspan="2">Severe Tropical Storm</td><td rowspan="2">Severe Cyclonic Storm</td><td rowspan="2">Severe Tropical Storm</td><td rowspan="2">Category 2 tropical cyclone</td></tr>
<tr><td rowspan="9">12+</td><td>64–71 knots (119–131 km/h)</td><td>56–63 knots (104–117 km/h)</td><td rowspan="2">Category 1 hurricane</td><td rowspan="7">Typhoon</td></tr>
<tr><td>72–82 knots (133–152 km/h)</td><td>64–72 knots (119–133 km/h)</td><td rowspan="8">Typhoon</td><td rowspan="3">Very Severe Cyclonic Storm</td><td rowspan="3">Tropical Cyclone</td><td rowspan="3">Category 3 severe tropical cyclone</td></tr>
<tr><td>83–95 knots (154–176 km/h)</td><td>73–83 knots (135–154 km/h)</td><td>Category 2 hurricane</td></tr>
<tr><td>96–97 knots (78–180 km/h)</td><td>84–85 knots (156–157 km/h)</td><td rowspan="2">Category 3 major hurricane</td></tr>
<tr><td>98–112 knots (181–207 km/h)</td><td>86–98 knots (159–181 km/h)</td><td rowspan="3">Extremely Severe Cyclonic Storm</td><td rowspan="3">Intense Tropical Cyclone</td><td rowspan="2">Category 4 severe tropical cyclone</td></tr>
<tr><td>113–122 knots (209–226 km/h)</td><td>99–107 knots (183–198 km/h)</td><td rowspan="3">Category 4 major hurricane</td></tr>
<tr><td>123–129 knots (228–239 km/h)</td><td>108–113 knots (200–209 km/h)</td><td rowspan="3">Category 5 severe tropical cyclone</td></tr>
<tr><td>130–136 knots (241–252 km/h)</td><td>114–119 knots (211–220 km/h)</td><td rowspan="2">Super Typhoon</td><td rowspan="2">Super Cyclonic Storm</td><td rowspan="2">Very Intense Tropical Cyclone</td></tr>
<tr><td>>137 knots (254 km/h)</td><td>>120 knots (220 km/h)</td><td>Category 5 major hurricane</td></tr>
</table>

Appendix B. Technology descriptions

B.1. Solar

B.1.1. Photovoltaic (PV)

Solar photovoltaic (PV) cells convert solar radiation to electricity via semiconductor materials, which exhibit the photovoltaic effect. These cells are arranged into panels, and when a number of these panels are mounted together on a roof or other appropriate structure it is known as a Solar PV array.

Due to economies of scale, the price of solar PV modules has recently dropped, falling dramatically since around 2008. In the near term it is expected that module prices will stabilise, but prices may reduce further in the mid to longer term.

The sunlight received by the array (multiple solar PV modules) is affected by a combination of tilt, type of tracking and shading. The most cost effective installation is to install the panels directly on a north facing tilted roof space. Using a frame to tilt the panels on a flat roof or for orientating the panels to face north increases yield, but adds cost and the array would need to be rated for prevailing wind conditions. Tracking also increases the yield, but also increases both the installation and the maintenance cost significantly. A dual axis tracker can increase the yield, but the additional install and maintenance costs increase the payback period significantly. Furthermore, such a system would typically not be rated for strong wind conditions.

In order to understand the amount of energy that can be generated by a Solar PV array we must first determine the area of the solar PV array. This requires the amount of area and dimensions of available roof space available to be known, which is then used to calculate the number of panels that could be installed on the available roof area.

The output of a solar PV array is a product of the area, the efficiency, and the solar irradiation. The capacity factor of solar PV panels is relatively low, typically from 10% to 30%, as solar irradiation ranges from about 2.5 to 7.5 sun hours per day depending on latitude and prevailing weather.

Panels are rated under standard conditions by their output power. The DC output is a product of the rated output multiplied by the number of panels multiplied by the solar irradiation multiplied by the number of days. Temperature effects can reduce efficiency by up to 10%. The AC output is lower than the DC output due to various losses, including the efficiency of the inverter. As the prevailing weather strongly affects the output, monthly and annual energy production varies substantially from year to year, by as much as 40% monthly and 10% annually. Published solar irradiation values are normally 10-year averages, and long-term output estimates tend to be accurate to within 10 to 12% (NREL 2014).

B.1.2. Concentrating solar thermal (CST)

Concentrating solar thermal (CST) technologies use mirrors to reflect and concentrate sunlight onto receivers that collect solar energy and convert it to heat. The thermal energy can then be used to produce electricity via a heat engine or steam driven turbine or be stored as molten salts for later use.

There are three primary types of CST technologies currently in various stages of development. Most of the development is centred in Europe and North America. Of these, there are approximately X number of plants completed, connected to the grid and operating. No CST technologies are currently planned for Australia although a few studies have been carried out and a coal power station was converted to hybrid with CST used to preheat the water entering the boiler.

The four primary CST technologies being develop are (NREL 2014):

1. Parabolic Trough
2. Linear Fresnel Reflector
3. Power Tower
4. Dish Engine

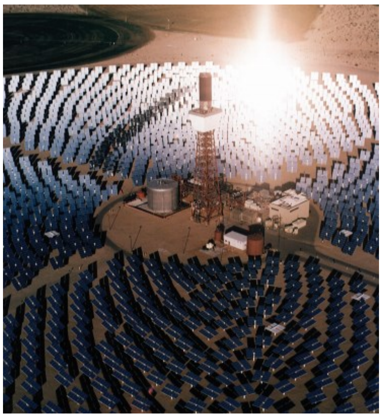
 Parabolic Trough	 Linear Fresnel Reflector
 Power Tower	 Dish Engine

Figure 127: The four key types of CST technology being developed (NREL 2014)

This type of solar technology is likely to be of too large a scale for Mauritius with facilities in the tens of MW or greater needing to be built to obtain economies of scale. Due to the size and tracking nature of these technologies they would all suffer from cyclonic wind conditions meaning they would need to be built inland away from coastal communities and in doing so require a new grid infrastructure to connect centres to that location. Furthermore, CSP plants require a land area of approximately 5 acres per MW of installed capacity (NREL 2014).

B.1.3. Concentrating photovoltaics (CPV)

Concentrating photovoltaics (CPV) technologies work by concentrating solar radiation onto a high-efficiency semiconductor PV cell which converts the energy into electricity. These technologies make use of mirrors or lenses constructed using inexpensive materials such as glass, steel and plastics which concentrate the sunlight 2 to 1,200 times. This means that a smaller area of PV cell semiconductor material can be used to produce a given amount of electricity. Given that the semiconductor material is the most expensive and complex component of many PV modules, particularly for high efficiency multijunction (MJ) cells, this can aid in reducing the overall manufacturing costs.

For this technology to operate at its peak efficiency and maintain the concentration of sunlight on the cell, these systems must use tracking to follow the sun across the sky and in some cases liquid cooling to maintain the PV cell efficiency and prevent damage from overheating. Tracking and cooling results in greater system complexity and increased maintenance costs making for a more expensive installation.

The two most promising technologies being developed are flat plate and parabolic dish concentrators. Flat plate concentrator utilises many lenses to concentrate the sun light onto many small solar cells whereas the parabolic dish concentrators use mirrors to concentrate the sunlight onto a single cell module. Because the parabolic dish concentrators concentrate the sunlight from 500 to 1000 times the cell module requires active cooling. Due to the high concentration levels this type of technology is often referred to as High-Concentrating Photovoltaic (HC-PV).

The flat plate concentrators don't concentrate the sunlight to the same level and typically do not require cooling making the system less complex but also less efficient for the same surface area of the concentrator. Some research organisations predict that CPV could be up to 30% cheaper than PV by 2016 (Willis 2012) although many CPV systems are still in the commercialisation phase.

Solar Systems based in Victoria are currently in the Economic Feasibility phase of commercialising their CPV technology. They have built several CPV demonstration plants, the largest in Australia being the 1.5 MW plant in Mildura which opened in July 2013 using the CS-500 dish product, see Figure 119. There are plans to expand the facility to 100 MW with construction to begin in late 2014. Solar Systems have also supplied remote communities with CPV solar power stations at Windorah, Queensland, and at Hermannsburg, Yuendumu and Lajamanu in the Northern Territory (Solar Systems 2014). Although the technology is rated for 41 m/s (148 km/h) wind speeds it would not withstand cyclonic wind conditions.

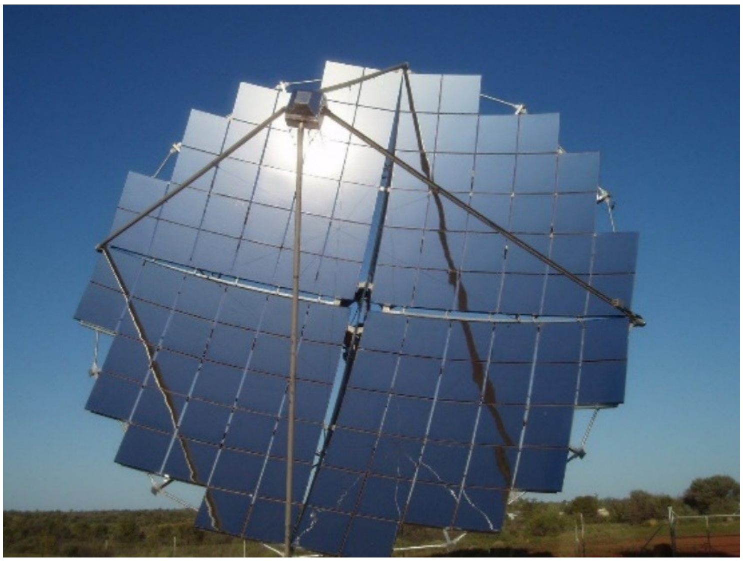


Figure 128: Solar Systems 35 kW CS-500 dish product (Solar Systems 2014)

Figure 129: Example of flat plate solar concentrators (Lozanova 2009)

CPV may have application on Rodrigues as it can be built on a smaller scale than CST and the current loads on Rodrigues are not massive. However, engineering a CPV system for installation in cyclone risk areas may be a significant challenge. Therefore, this technology may not be suited the Mauritius region where the possibility of wind damage from cyclones is great.

B.2. Wave energy

The large number of concepts and designs makes classification of WEC technologies somewhat difficult. Various classification systems exist but they are not always consistent or in agreement, and terms used such as nearshore, offshore, deep and shallow, are ill-defined. The World Energy Congress classification system is based on distance from the shore or depth (onshore, nearshore and offshore), and on whether the device or structure is fixed, floating or submerged, see Figure 121.

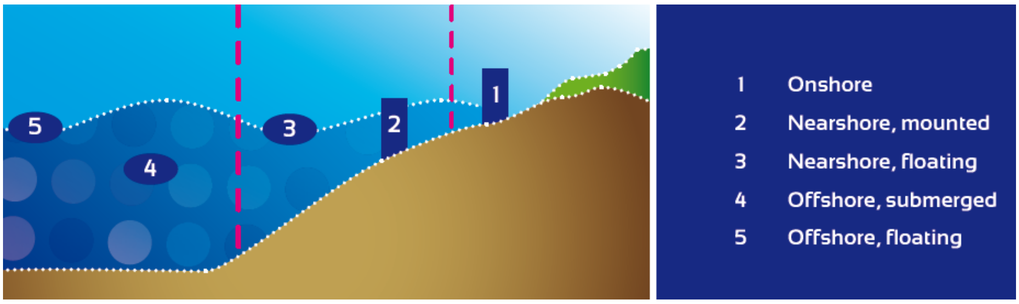


Figure 130: World Energy Congress classification of wave power systems according to position (onshore, nearshore, offshore) and anchoring (mounted, floating or submerged).

(Falcao 2010) on the other hand, groups ocean energy conversion technologies into three broad groups: oscillating water columns, oscillating bodies and overtopping systems, see Figure 122.

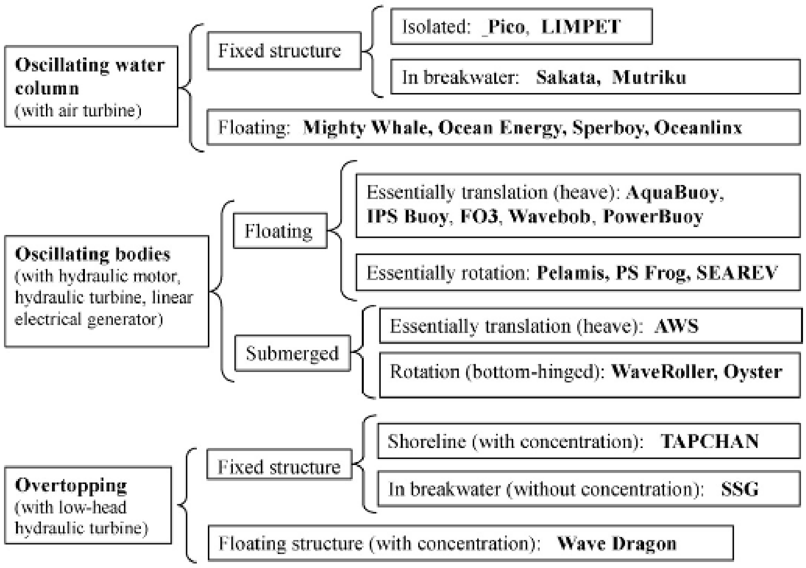


Figure 131: Classification of wave energy conversion technologies used by (Falcao 2010)

Yet another classification system is based on the operating principle of the device (Drew, Plummer and Sahinkaya 2009). For example, group WECs in four broad types: (A) attenuators (linear absorbers), (B) point absorbers, terminators (C), and overtopping terminators (D). This classification system appears to have been recently adopted by the CSIRO.

B.2.1. Attenuators or linear absorbers (Type A)

Attenuators or linear absorbers (A) are oriented parallel to the direction of wave propagation and 'ride' the waves. They are composed of multiple sections that rotate in pitch and yaw relative to each other. The energy generating capacity of a single attenuator device can be up to 1 MW. An example of an attenuator WEC is the Pelamis, see Figure 123, that is being developed by Ocean Power Delivery Ltd, and which is considered to be the most commercially advanced of the WEC technologies currently under development.

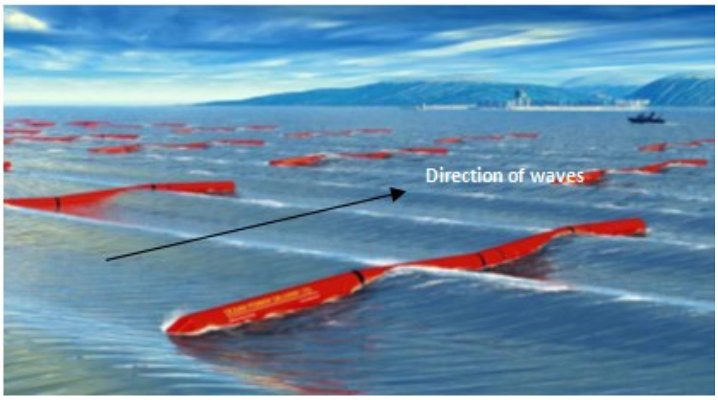


Figure 132: Artists impression of an array of Pelamis wave energy converters

B.2.2. Point absorbers (Type B)

Point absorbers (B) capture energy from the oscillating ("up and down") motion of the waves and they may be fully or partially submerged. They are small relative to a typical ocean wave wavelength and are able to absorb wave energy from all directions. An individual point absorber device may produce up to 11 MW of electricity, although most current designs produce much less. An example of a point absorber is Carnegie Wave Energies CETO 5 array that was connected into the grid of the department of defence in Australia. The CETO project successfully supplied power and desalinated for the duration of the project. Carnegie is currently working on CETO 6 which again will be connected into the department of defence as part of a wave integrated micro grid.

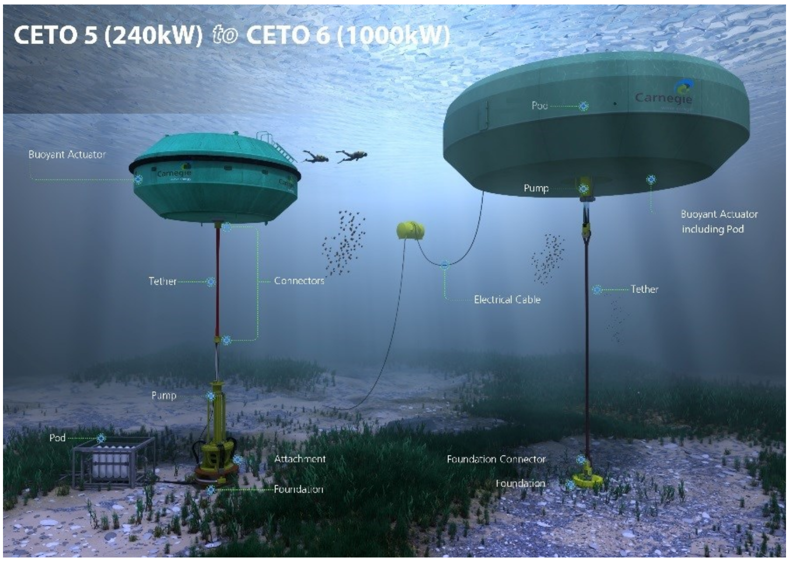


Figure 133: Point absorber generators

Submerged point absorbers use the pressure difference above the device between wave crests and troughs. They comprise two main parts: a sea bed fixed air-filled cylindrical chamber and a moveable upper cylinder. As a crest passes over the device, the water pressure above the device compresses the air within the cylinder, moving the upper cylinder down. As a trough passes over, the water pressure on the device reduces and the upper cylinder rises. An advantage of this device is that since it is fully submerged, it is not exposed to the dangerous slamming forces experienced by floating devices. The visual impact is also reduced. However, maintenance of the device is a possible issue. As a part of the device is attached to the sea bed, these devices are typically located near shore.

B.2.3. Terminators (Type C)

Terminators (C) are oriented perpendicular to the direction of the wave travel and physically intercept waves. Water is forced through a turbine by the power of the wave. They are often designed to be located either onshore or near shore. One type of terminator is the oscillating water column. These devices contain a chamber where the water level changes as waves go in and out. Changes in the water level increase or decrease the pressure, which causes air to flow through a turbine. The energy generating capacity of a single terminator device can be up to 1.5 MW. An example of an oscillating, onshore terminator WEC device is the Limpet being developed by Wavegen in Scotland, see Figure 125.

Figure 134: Turbo machinery of the Limpet prior to construction of the main building

B.2.4. Overtopping devices (Type D)

Overtopping devices (D) are generally anchored in open water and consist of reservoirs that are filled by wave action to levels above the surrounding sea level. Ocean waves are elevated by the device to a reservoir above sea level where water is let out through a number of turbines to produce electricity in the same way that a hydroelectric plant does. Overtopping devices have been designed and tested for both onshore and floating offshore. The electrical energy is fed down a single umbilical cable to a junction on the seabed and is then linked to shore through a single underwater transmission cable. The energy generating capacity of a single overtopping device can be up to 11 MW. An example of an overtopping WEC device is the Wave Dragon, see Figure 126, which is being developed by Wave Dragon ApS in Denmark. This device uses a pair of large curved reflectors to gather waves into the central receiving part, where they flow up a ramp and over the top into a raised reservoir, from which the water is allowed to return to the sea via a number of low-head turbines.

Figure 135: The Wave Dragon

Within these four groups mentioned above (A, B, C and D) are subgroups (such as oscillating water column, oscillating wave surge converter, surface attenuators, submerged attenuators, multipoint absorber and buoys) and the turbine type (air, hydro, pump to shore, direct drive, direct drive generator, linear generator and hydraulic). Others group WEC devises into Oscillating water column devices, Attenuators, Point absorbers, Pressure differential, Oscillating surge converters and Overtopping devices (Holmberg, et al. 2011).

B.3. Biomass and Waste to energy (WtE)

B.3.1. Thermal processes

There are three primary ways in which to recover energy from thermally treated waste. These processes include pyrolysis, gasification and combustion. Each process is distinguished by the ratio of oxygen (or air) required for complete combustion, defined as ‘lambda’ (l), and whether external heat is applied, see Table 132.

Table 157: Waste to energy thermal processes

Process	Lambda (l)	Thermal treatment	Produces
Pyrolysis	l=0, no air	By external heat source without combustion	Syngas, biooil, and bio-char
Gasification	l=0.5	Partial use of external heat without combustion	Syngas
Combustion	l=1.5+	No external heat with combustion (external heat may be applied to maintain temperatures to ensure complete combustion and conversion of organic compounds as exhaust treatment)	N/A

B.3.3. Non-thermal processes

The most applicable non-thermal WtE technology that could be employed on Mauritius is Anaerobic Digestion (AD). AD is a biochemical process whereby complex organic materials are broken down into simpler compounds by microbes (Khanal and EWRI. 2010). The process utilises the natural decomposition process of organic material in the absence of oxygen. It is the principle process that occurs in landfills and results in the creation of landfill gas (Demirbas 2009).

The microbes that make this process possible are mostly anaerobic bacteria. The process consists of several stages of decomposition which is driven by particular microbes present and cultivated during the process. A review of the literature indicates that the AD process is usually demonstrated using a simplified process model as shown in Figure 127. The process consists of 4 phases as outlined in

Table 133. These are indicated by the large arrows in the process diagram shown in Figure 127.

The AD process results in both a biogas and a biogenic solid waste (also known as the process residue). The biogas consists of approximately 60-75% Methane (CH_4) and 25-40% Carbon Dioxide ($C0_2$) with other impurities such as hydrogen sulphide (H_2S), moisture, and particulate matter (Demirbas 2009, Khanal and EWRI. 2010). The biogenic solid waste is a stable, humus-like product that can be used as compost if the input materials are low in toxic compounds. The compost is nutrient-rich and is ideal for use as a soil conditioner or fertilizer (Khanal and EWRI. 2010).

Table 158: The four stages of the anaerobic digestion process

Phase	Description
Hydrolysis	The first stage of AD when the complex organic matter is broken down into its components units; proteins to amino acids, carbohydrates to sugars, and lipids to long chain fatty acids and glycerin.
Acidogenesis	During the second phase, another group of bacteria ferments the products produced in phase 1 to acetic acid, hydrogen, carbon dioxide, and other intermediary products.
Acetogenesis	During this phase of the AD process further acetic acid, hydrogen, and carbon dioxide are formed from the intermediary products and between the acetic acid and hydrogen/carbon dioxide gases.
Methanogenesis	The final stage can be characterised by the formation of methane, produced by a unique group of microorganisms called methanogens (Khanal and EWRI. 2010). Only a limited number of substrates are available for methanogenesis, usually acetate and H_2/CO_2 for AD. The two most important transformations during this stage are the acetoclastic reaction and the reduction of carbon dioxide.

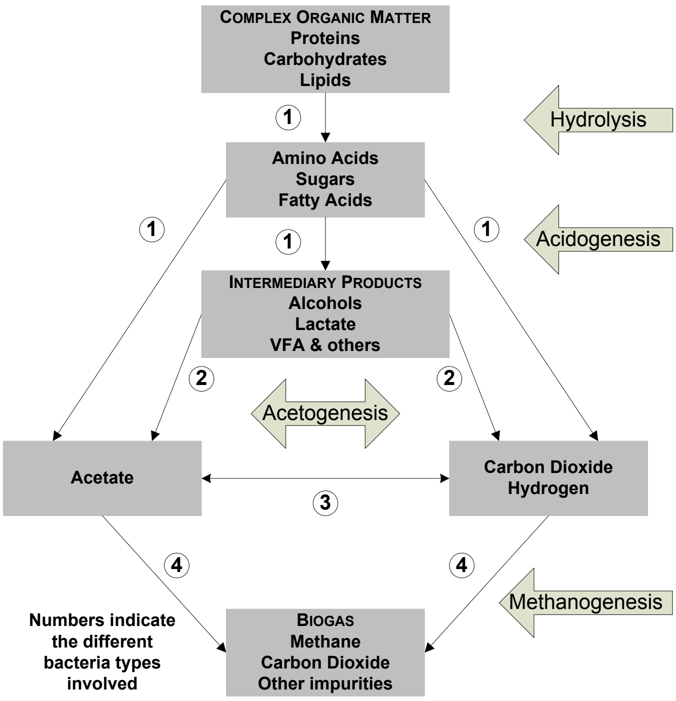


Figure 136: A simplified anaerobic digestion process adapted from Khanal and Demirbas (2009, 2009)

B.3.2.1. Plant Configurations

An Anaerobic Digestion (AD) plant can utilise a number of different process configurations. This section will discuss the key process configurations commonly used in AD plants around the world today.

B.3.2.2. Wet or Dry Process

Anaerobic digestion can be classified as either wet or dry based on the moisture content or Total Solids (TS) concentration of the feedstock. The total solids (TS) levels for a dry process vary from 25 to 40% while a wet process has TS levels which are typically less than 15%, see Table 159 (Khanal and EWRI. 2010). A wet process typically requires a more complicated system including additional mixing, pulping and pumping systems (Khanal 2009). Depending on the process being used the feedstock may need to have water added or removed to ensure that the correct Total Solids (TS) content is maintained.

Table 159: Definitions for Wet and Dry processes (Khanal & EWRI. 2010

Process Type	TS content of feedstock
Wet	10-22%
Dry	25-40%

B.3.2.3. Batch or Continuous Processing

Batch processing takes place by filling a bioreactor with feedstock and then sealing the reactor until the anaerobic digestion process has completed (Khanal and EWRI. 2010). The reactor is then emptied and a new batch of feedstock added. As an individual batch can take more than 30 days to complete, either the feedstock must be stored in preparation for the next batch or multiple reactors have to be used. Therefore the additional storage space for feedstock or space and capital expenditure required for the additional reactors are key disadvantages of this method.

For a continuous process an amount of fresh feedstock is mixed with digested material and added to the bioreactor (Khanal and EWRI. 2010). This typically occurs daily but is dependent on the bioreactor employed. An equivalent amount of digested material is removed at the same time that the fresh feedstock is added.

Table 160: Definitions for Batch and Continuous processes (Khanal & EWRI. 2010)

Process Type	Description
Batch	Reactor is filled with feedstock and sealed until the anaerobic digestion process completes.
Continuous	Fresh feedstock is added daily and an equivalent amount of the digested material removed.

A schematic is presented in Figure 128 of a typical Anaerobic Digestion (AD) plant. The AD plant comprises three distinct phases of operation, pre-treatment, anaerobic treatment, and post-treatment of residues. These phases are discussed in the following sections.

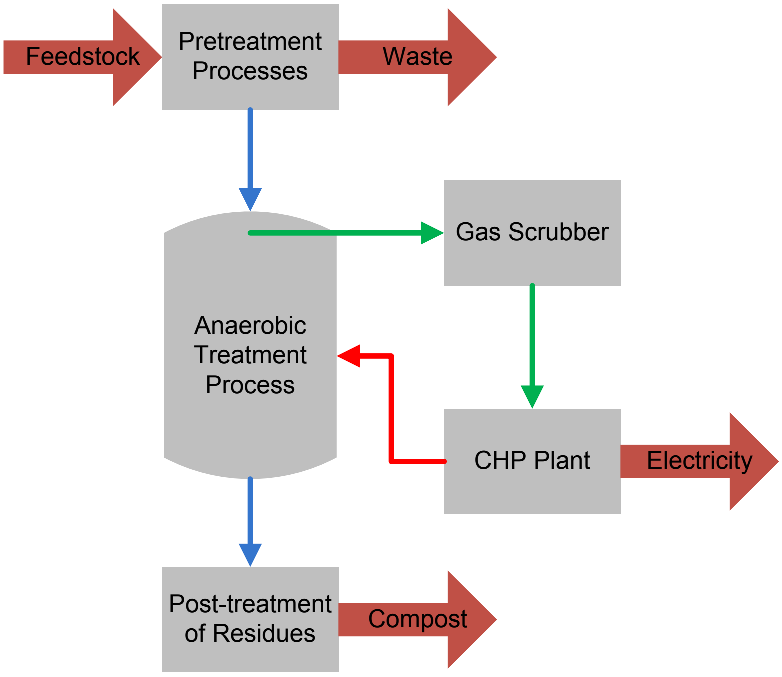


Figure 137: Schematic for a typical Anaerobic Digestion (AD) plant

B.3.2.4. Pre-treatment Phase

The pre-treatment phase is important for increasing both biodegradability and improving performance (Khanal and EWRI. 2010). The most common pre-treatment method is source separation in which undesirable components are removed from the feedstock creating a clean waste stream input for the Anaerobic Digestion process. Source separation usually involves sorting and screening the waste input stream for components such as plastics, metals, and glass.

Once the waste stream has been sorted it must be tested for the Total Solids (TS) content. If a dry process is being used then the TS content must be between 25-40% and if a wet process the TS content must be between 10-22%, see Table 159. If the waste stream TS content is too low, meaning there is too much moisture, then the waste will have to be de-watered. If the waste stream TS content is too high, meaning to little moisture, then water will need to be added.

Mechanically shredding, pulping or liquefaction of the waste stream reduces the particle size and solids content of the feedstock (Khanal and EWRI. 2010). This in turn produces a greater surface area for bacteria to access resulting in reduced retention times (the time the feedstock must spend in the bioreactor).

B.3.2.5. Anaerobic Treatment Phase

Once the input waste has been pre-treated, it is pumped into the bioreactor. The bioreactor can take many different configurations, however, it is primarily an insulated holding tank in which the anaerobic reactions take place (Khanal 2009). This stage requires mixing of the bioreactor contents to enhance the digestion process. If a wet process the contents of the bioreactor are mixed using a mechanical stirrer inside the reactor vessel. For a dry process the contents are mixed by recirculating the reactor contents where a portion of new feedstock material is added while some of the reactor contents are removed for post-treatment.

The key requirement of this phase is the removal of biogas from the bioreactor. Too much biogas in the reactor can inhibit the metabolism of methanogen bacteria (Deublein and Steinhauser 2008). The gas is then treated using gas scrubber equipment to remove impurities such as hydrogen sulphide, carbon dioxide and moisture. Once the gas is treated it is stored ready for use in the Combined Heat and Power (CHP) plant.

The CHP plant usually consists of either a gas or diesel internal combustion engine or gas turbine (Deublein and Steinhauser 2008). The engine or turbine will be used to generate electricity while excess heat is used to produce steam that is fed back to the bioreactor where it is used to heat the feedstock that is being added. Wet processes typically use more electricity than dry processes as they need constant stirring. However, very little electricity is used by both processes so electricity can be exported to the grid or used in pre- and post-treatment phases of operation.

B.3.2.6. Post-treatment of Residues

The residue from the anaerobic digester requires post-treatment to ensure that the production of methane is stopped. This is usually done by simple aerobic composting for a few days to stabilise the residue (Khanal and EWRI. 2010). If the residue has a high moisture content upon leaving the bioreactor it may need to be dewatered until it has at least a 50% Total Solids (TS) content before being composted (Khanal and EWRI. 2010).

B.3.2.7. *Small scale plant*

Small-scale gasification plants that are currently in developed include:

- Minimum feed rate as low as 3-10 t/day
- 600-800 kWh per ton of MSW
- Installed cost = US$6000+ per kW
- LCOE $0.15 to $0.20 per kWh (dependent on tip fee)

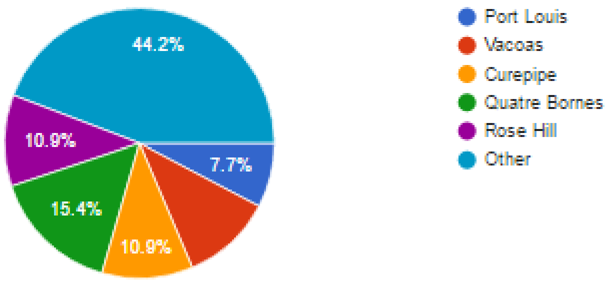
Table 161: Small scale WtE plants (Ellyin 2012)

Company	Country	Number of plants	Minimum feed rate	Comments
Energos	Norway	Currently in operation at six plants in Norway, one in Germany, and one in the UK	30 tons/day or 2.2 t/hour	Grate gasification and combustion technology
Novo Energy	Colorado, USA	Various small scale thermal processes in Japan (e.g., Ebara). Smallest is Babcock and Wilcox air cooled grate that have an average of 16 ton/ day.	16 tons/day	Inclined fixed grate combustion technology and air cooled grate
KI Energy	Turkey/ Portugal	Electricity production = 50 kW	1100 t/y	Fixed bed gasifier, fluid bed gasifier, fluid bed combustor
IST Energy GEM	Massachusetts, USA	Unknown	3 tons/day	Mobile microscale downdraft gasification system about the size of a 40’ container
Compact Power	Bristol, UK	Unknown	6,000 t/year	

Appendix C. Mauritius Solar PV Survey Results

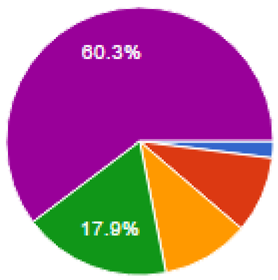
Carnegie Wave Energy (CWE) collaborated with the Mauritius Research Council (MRC) to conduct a survey of Mauritius citizens to identify attitudes towards solar PV and potential for the further deployment of solar PV. There was a total of 156 responses to the survey which ran from 17th August to 9th November 2016.

In which town or city is your residence located? (156 responses)

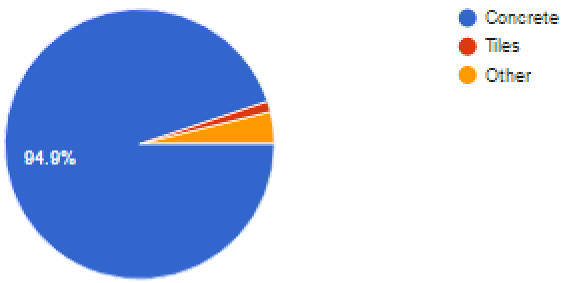


C.2. Energy Usage

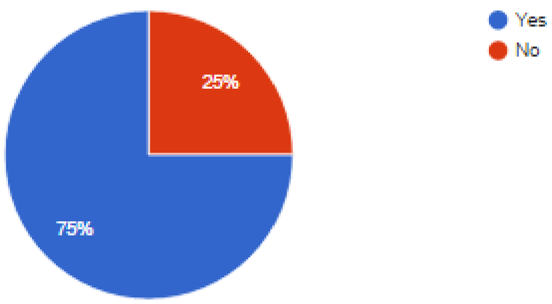
How much do you pay per month for electricity? (152 responses)



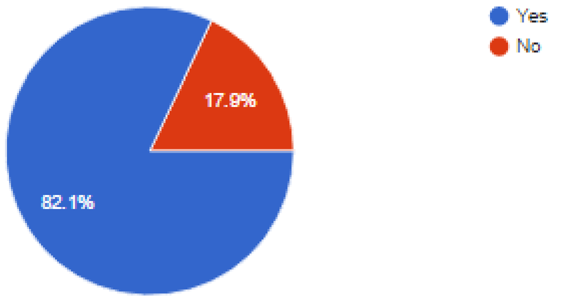
What material is your roof constructed of? (156 responses)



Are you the owner of the Residence? (156 responses)

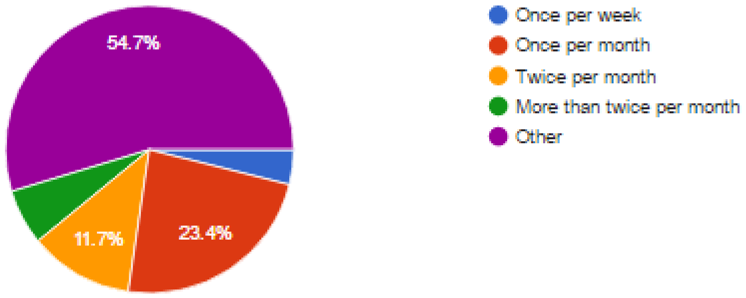


Have you experienced any power cuts in the last calendar year? (156 responses)

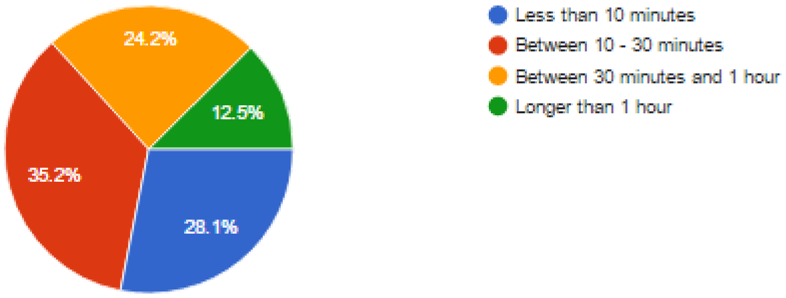


C.3. Power Outages

How often do these power outages occur? (128 responses)

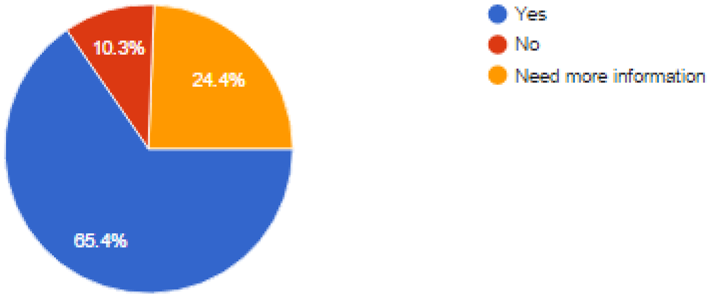


How long would a power outage usually last? (128 responses)

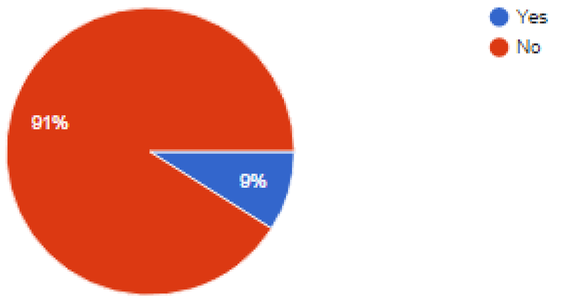


C.4. Solar PV

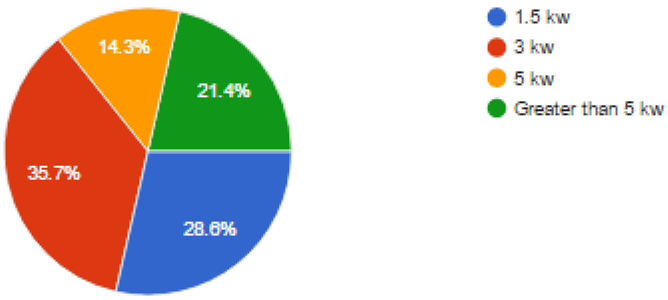
Would you consider a Solar Photovoltaic (PV) installation on your roof? (156 responses)



Have you applied to have a Solar PV System Installed? (156 responses)

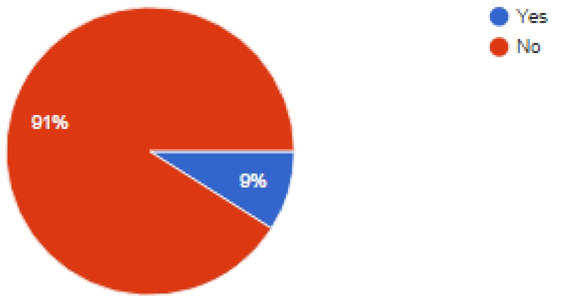


What size have you placed in your application? (14 responses)

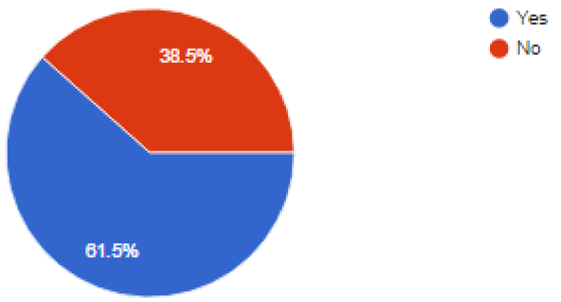


C.5. Power Dynamics

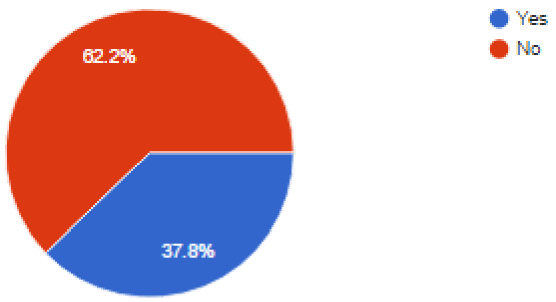
Is a roof top Solar PV system installed on your residence? (156 responses)



Is there a solar hot water system currently installed on your roof? (156 responses)

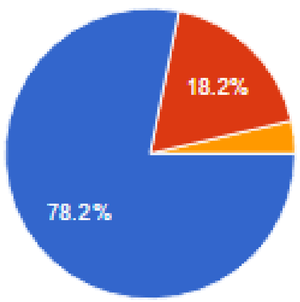


Is there an air-conditioner installed at your residence? (156 responses)

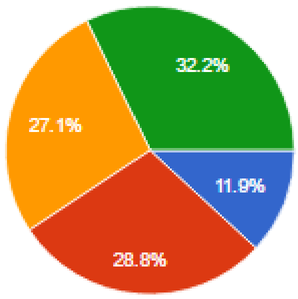


C.6. Air-conditioning

What is the size of the air-conditioner? (55 responses)



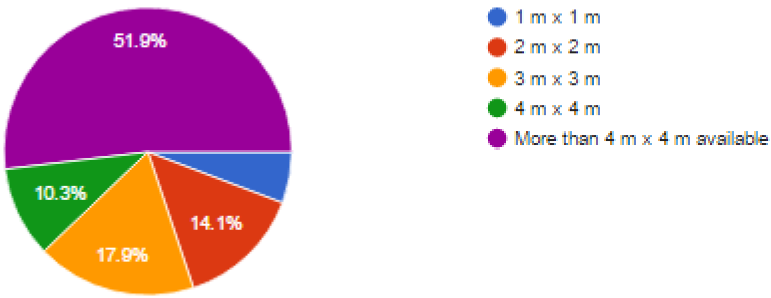
How often is the air-conditioning used? (59 responses)



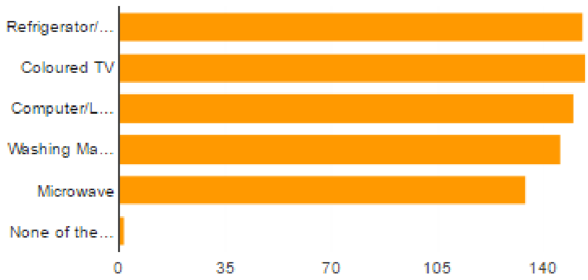
Which season(s) do you use your air-conditioner? (58 responses)

Summer (Nov-Feb)	55	93.2%
Winter (Apr-Oct)	3	5.1%

How much space would you estimate you have on your roof for a rooftop solar PV system? (156 responses)

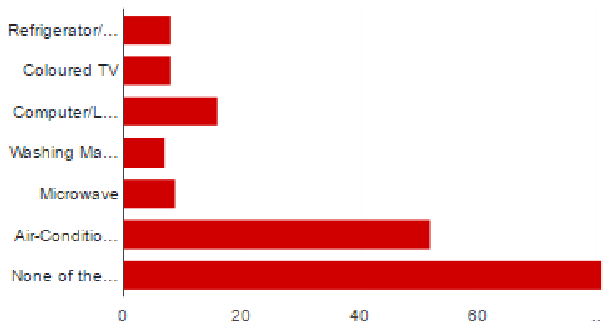


Please check any of the following appliances you have in your residence (156 responses)



Refrigerator/Freezer	**153**	98.1%
Coloured TV	**154**	98.7%
Computer/Laptop	**150**	96.2%
Washing Machine	**146**	93.6%
Microwave	**134**	85.9%
None of the above	**2**	1.3%

Please check any of the following electrical appliances you are planning on buying in the next calendar year (156 responses)



Refrigerator/Freezer	**8**	5.1%
Coloured TV	**8**	5.1%
Computer/Laptop	**16**	10.3%
Washing Machine	**7**	4.5%
Microwave	**9**	5.8%
Air-Conditioner	**52**	33.3%
None of the above	**81**	51.9%

Appendix D. Technology Overview – Deep Seawater Air Conditioning

Seawater Air Conditioning (SWAC), eliminates the need for heat pumps/chillers by using only a heat exchanger between the cold seawater loop and the district chilled water distribution loop. Requires good access to deep cold water which is in close proximity to the shore and a small distribution network. The primary cost driver for this type of configuration is the cold water inlet pipe. Significantly higher fixed costs versus a conventional system.

- Predominate cooling load of equal to or greater than 3,500 kW.
- The typical temperature profile in the tropics for the world's deep oceans:
  - 7°C or colder can be reached at 700 m depth,
  - 5°C or colder at 1000m.
- Systems have been installed in:
  - Toronto, Canada – 58,000 tons (1,580 kW)
  - Kona, Hawaii, 2001 – 50 tons (1,580 kW)
  - Cornell University, New York – 20,000 tons (1,580 kW)
  - Bora Bora, French Polynesia, 2006 – 450 tons (1,580 kW)
  - The Alderney 5 Energy Project was a successful demonstration of an integrated community energy solution that used an innovative combination of traditional and new technologies to develop a seawater-based cooling system for a Halifax municipal building complex. The new technology utilizes the cooling effect of the seawater both directly, when seawater temperatures allow, and indirectly through a borehole field that would essentially, store "cold energy".

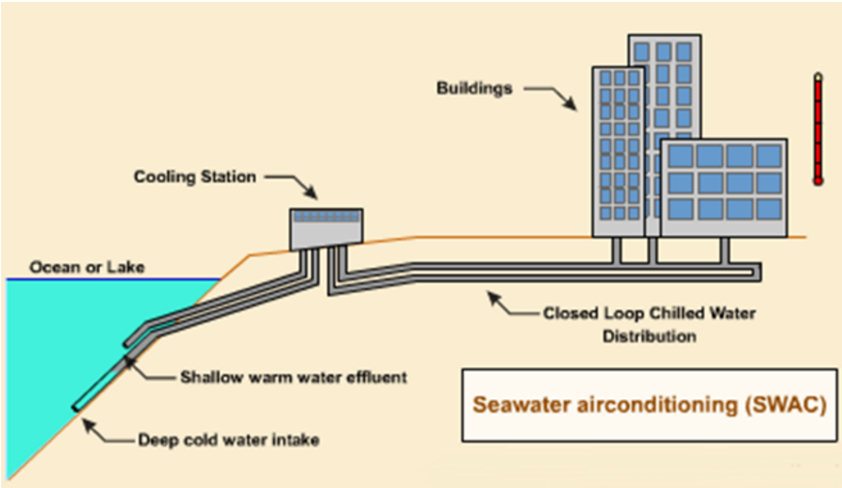


Figure 127 : Schematic for sea water air conditioning (SWAC)

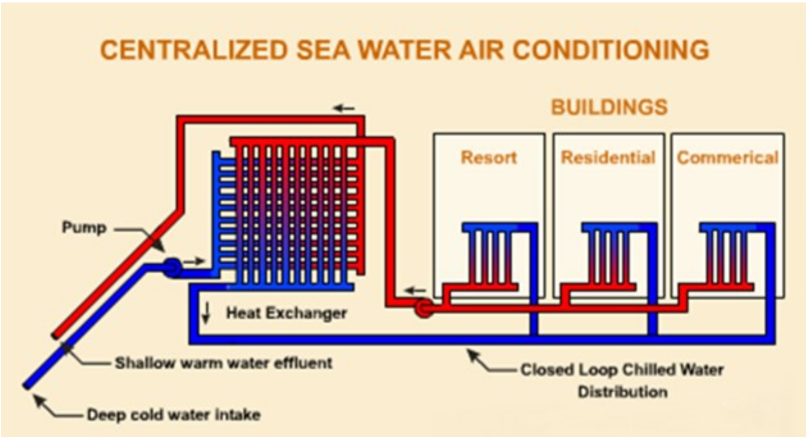


Figure 128 : Heat exchange system for a district cooling system using deep sea water

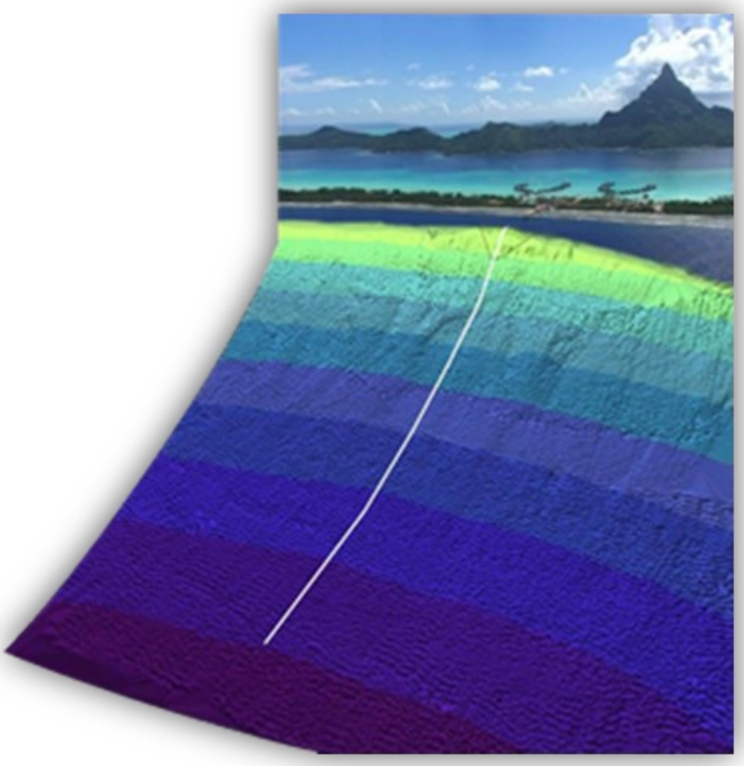


Figure 129: Bora Bora, French Polynesia 2006 – Cold water

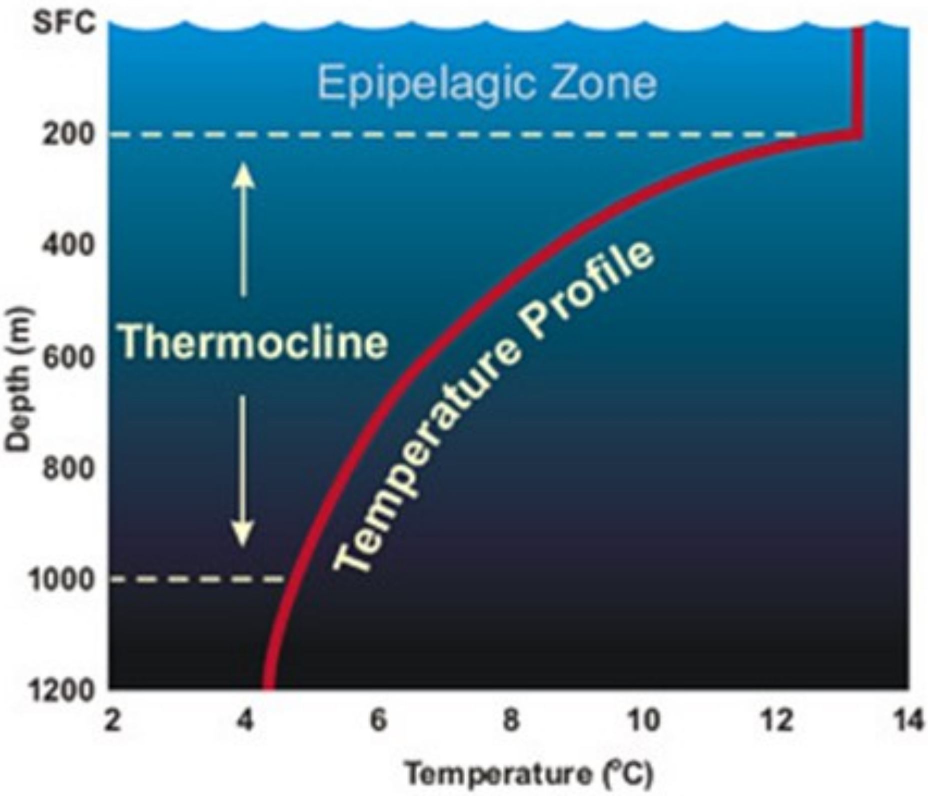


Figure 130 : Typical ocean thermocline (depth vs temperature). (http://www.srh.noaa.gov/jetstream/ocean/layers_ocean.htm)

Appendix E. District Cooling System Case Studies

E.1. James Cook University, Townsville – Conventional District Cooling with Storage

James Cook University consists of a distributed campus of 28 buildings spread across a 255-hectare site. The University had a total air conditioned floor area of 69,000 m^2 prior to the installation of the district cooling system in 2007. The majority of the existing buildings were built before 1990 and the University has a building expansion plan to add an addition 50,200 m^2 of air conditioned floor space by 2015. The electrical infrastructure to the site has a maximum demand upper limit of 9 MW with a site maximum demand of 7.3 MW recorded in 2007. On a pro-rata basis future demand up to 2015 due to the building expansion plans could total approximately 12 MW.

Key drivers of the district cooling system design included:

- The building expansion plan would result in the site exceeding both the maximum electricity demand (9 MW) and the maximum electricity feeder capacity. This would prompt an expensive electricity infrastructure upgrade.
- Additional 50,200 m^2 of air conditioned floor space by 2015.
- High utility bills in the order of $2.7M pa.
- Maintenance associated with servicing 28 different chillers, pump groups, cooling towers and the like, many of which are near end-of-life. Replacement cost of chillers over the next five years (from 2007) was estimated at $9M.

The district cooling system design comprises a Central Energy Plant (CEP) with integrated Thermal Energy Storage (TES) and chilled water distribution network to each campus building with allowances for future connections as buildings are added.

The CEP is the centralised plant for the district cooling and comprises the chillers, cooling towers, pumps and TES. It was essential that the design utilised thermal storage in order to reduce site electricity demand and eliminate the need for expensive electricity infrastructure upgrades. The TES makes use of off-peak electricity to produce and store chilled water at night when electricity demand is at its lowest. The system utilises a 12 mega litre thermal storage tank which is specially engineered with top and bottom water diffuses to prevent turbulence which allows the warm water to stratify and site above the cooler chilled water at the bottom. During times when the site demand exceeds the average demand, usually in the afternoon, chilled water can be drawn from the storage tank instead of utilising the chillers, see Figure 133. The plant has a design Coefficient Of Performance (COP is a measure of efficiency) of 6 at summer conditions of 33°C dry bulb and 27°C wet bulb.

District cooling system design outcomes:

- Reduction of the instantaneous maximum electrical demand for the site by approximately 40 per cent from 9.9MW to 5.4MW (2010 scenario) avoiding any high voltage feeder upgrades. It will also provide a relatively ‘flat’ or consistent electrical demand, which frees up capacity on site, allowing capacity for future expansion.
- Economies of scale provide greater opportunities for efficiency of the larger plant, and therefore reduced running cost, CO_2 emissions, maintenance costs, and simpler upgrades as technology improves.
  - Reduced electricity operating costs by approximately 30 per cent from $3,200,000 to $2,260,000, saving of $940,000 pa (based on 2007 utility tariffs) by 2010.
  - Reduced greenhouse gas emissions attributable to the University from 43,000 tonnes to 31,000 tonnes, saving approximately 12,000 tonnes CO_2 per year by 2010.
  - Reduced maintenance costs and transport costs associated with servicing 28 different chillers, pump groups, cooling towers and the like. The combined benefit is anticipated to be more than half the current maintenance costs.

- The plant room is air-conditioned to prolong plant life and prevent condensation (corrosion) issues.

- New refrigeration plant with a projected economic life of 30 years and improved system reliability (redundancy).
- Reduction in noise pollution generated by multiple air conditioning plant compared with the central plant and acoustic treatment.
- A building services master plan that includes a central spine of underground service trenches throughout the campus, which streamlines existing services, and allows for future development programs.

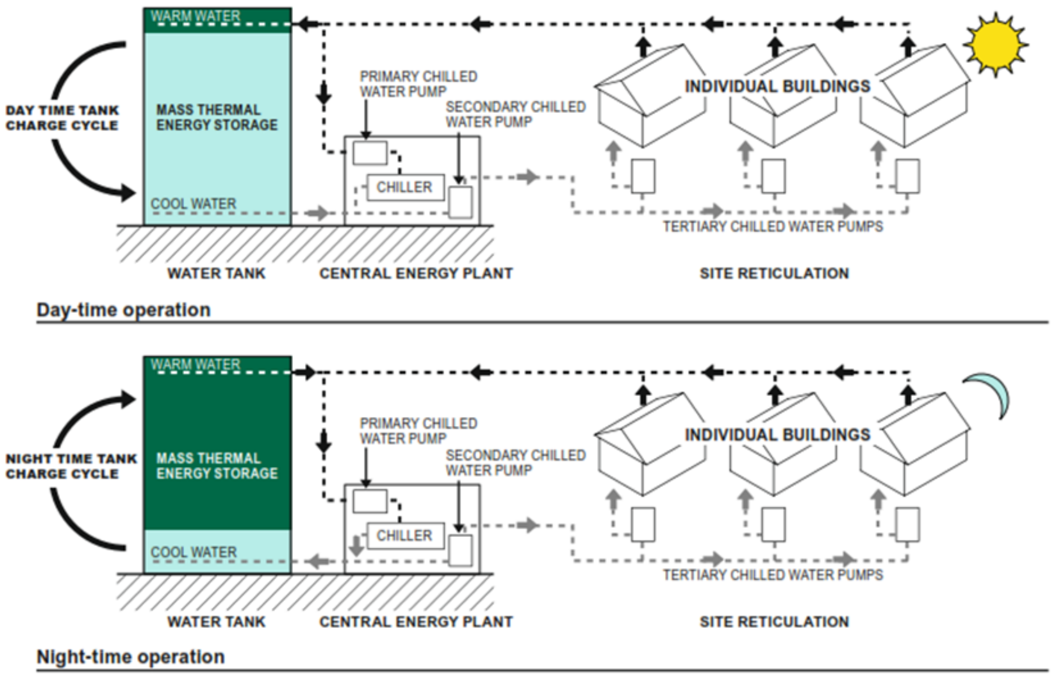


Figure 131 : James Cook University, district cooling system with thermal storage process flow chart

Central to the success of this project was the control strategy of the central plant. The plant operation is governed by an algorithm which is based on seasonal ambient conditions, ambient temperature and humidity sensors, time-of-use and demand tariffs, along with input on site consumption and demand. This ensures that the plant uses the least energy when operating during on-peak periods when the cost of electricity and electricity demand charges are highest while providing a reliable cooling system across the campus.

Additional cost savings where made through:

- Utilisation of high voltage, high efficiency chiller compressor motors that run from 11kV meaning there was no requirement to install special equipment to reduce the voltage to 415V
- Reduced the plant room roof structure. Normally pipe work is hung from the roof structure meaning the roof has to be specially reinforced. By using a special pipe manifold structure, the pipes were able to be stacked five high on the floor. This meant the weight of the pipes was carried directly by the floor slab and not the roof frame.
- By using Medium Density Polyethylene (MDPE) pipework to reticulate the chilled water throughout the campus, insulation was avoided, and the longer 12M pipe lengths available reduced the number of joints thus providing savings. The wall thickness of the 500mm diameter MDPE is 29.6mm which is directly buried in a compact sand fill, offering high thermal performance, and inherent vapour barrier and mechanical protection with the MDPE outer surface of the pipe.

- Higher than normal chilled water differential was used. The central plant produces chilled water at 6° C with a return water temperature of 15°C providing a 9°C temperature differential. Using the greater differential allows for a 25 per cent lower chilled water flow rate which has the following effects on the design:
    - Reduces pumping energy requirements.
    - Smaller pipe can be used (160 to 560 mm diameter).
    - The air handling units with the buildings have to be calibrated for the less common temperature differential.
    - Chillers have to work harder at night during the cooling cycle to reduce the chilled water to 6° C.

By combining existing services into a central spine of underground service trenches throughout the campus; allowed for the streamlining of existing services; and allows for future development programs. Although not a direct cost saving, the benefits of central service trenches includes significantly reducing the chances of services being disrupted in the future and costly upgrades for future expansion.

E.2. Case Study: Sydney Harbour Heat Exchange Systems

Sydney has been one of the few locations in Australia to take advantage of sea water cooling for building air-conditioning systems. One of the first systems being an open loop sea water cooled chiller system installed at the Sydney Opera House. One of the biggest challenges faced in Sydney has been the high maintenance costs due to marine growth in the temperate sea water. The existing Sydney Opera House system was upgraded and now employs a series of fine screens, filters and strainers to protect and filter out marine life and small organisms in an effort to minimise the effects of marine fouling. This will mean that only clean sea water will pass through the chiller system heat exchangers. The proposed district cooling system being built at Barangaroo will also incorporate a similarly complex water cleaning system.

The centralised cooling system at Barangaroo will be the largest harbour water system operating in Sydney. It is designed to support the cooling systems of all of the buildings proposed in the precinct and could save the equivalent to 40 Olympic swimming pools worth of fresh water each year that would normally be lost via evaporation from water cooling towers.

Table 162: Sydney sea water cooling systems listed by type

Open loop sea water cooling systems	Closed loop sea water cooling systems
Sydney Opera House, Circular Quay	Balmain Water Police (200 kW)
AMP Building, Circular Quay	Wharf 11 Woolloomooloo (500 kW)
Park Hyatt Hotel, Circular Quay	Proposed Rocks Heat Exchange (7 MW) – heat exchanger testing failed in 2013
Sydney Convention and Exhibition Centre, Darling Harbour	
Power House Museum, Darling Harbour	
King Street Wharf, Darling Harbour	
Star Casino, Pyrmont Bay	
Workplace 6, Pyrmont Bay	
Macquarie Bank Building, King Street Wharf	
Barangaroo, Darling Harbour (under construction) – 62 MW district cooling system	

- Sea water system challenges encountered by the Sydney systems:
    - High maintenance costs due to the continual marine growth which effects both open loop and closed loop systems:

- Closed loops systems can become fouled (on the outside of pipes) with marine life and debris resulting in reduced energy savings, see Figure 134.
- Open loop systems require a more complex set of screens and filters to reduce the costs associated with cleaning and maintenance routines.
- Corrosion from contact with salt water, which can be overcome with titanium heat exchangers.
- Complex and difficult maintenance routine:
    - Divers to inspect and clean the underwater pipework and associated infrastructure.
    - Requirement by the Environmental Protection Authority (EPA) to capture all dislodged matter when cleaning underwater pipework and associated infrastructure.
- Increasing compliance requirements such as those imposed via the EPA:
    - Recent systems have been designed to add no more than 2°C to the harbour inlet water temperature to provide compliance and not affect the local marine ecosystems.
    - Concerns have been raised regarding the impact on marine ecology from chemicals used in open-loop systems to prevent fouling.
- A changing marine ecology.
- Heat exchanger cost and efficiency for closed loop systems:
    - Sufficient heat exchange area

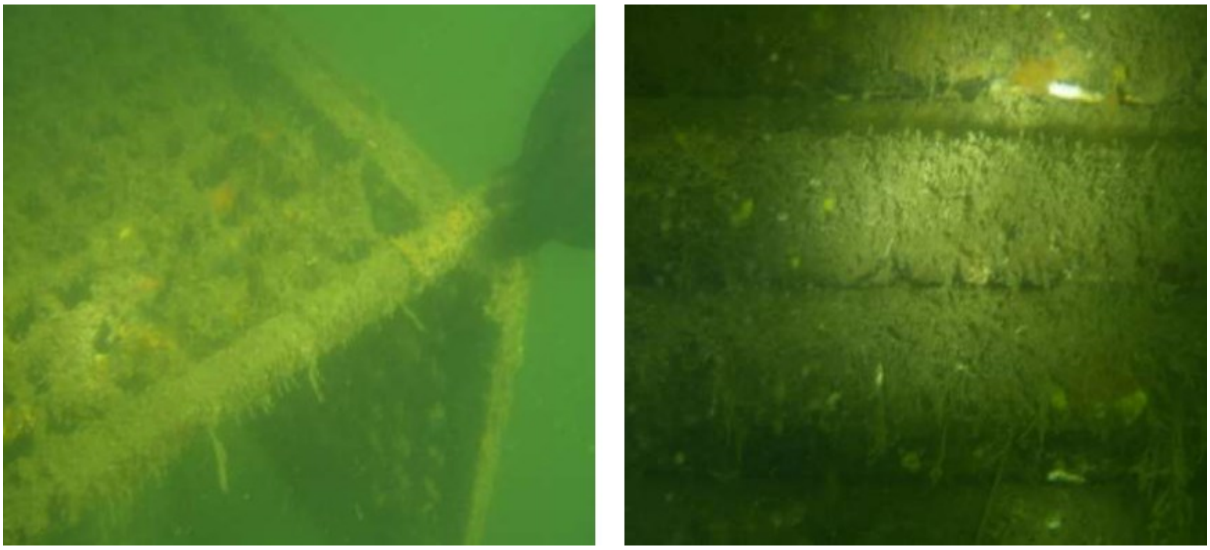


Figure 143: Balmain Water Police closed loop cooling system – marine fouling

A key advantage of the Sydney systems is the elimination of cooling towers which provides the following benefits:

- Dramatically reduced water consumption;
- Rooftop or external plant footprint reduction; and
- Legionella risk and control management.

While the capital costs and on-going maintenance can be higher for a sea water cooling system, these costs can be offset in a properly designed system by the annual savings from reduced or eliminated water consumption for cooling towers and reduced chiller system energy use. Important factors for consideration for sea water systems include depth, temperatures, flows, tides, salinity, water cleanliness and biology in terms of likely fouling, filtering and cleaning. Appropriate system materials are then selected to suit.

E.3. Lessons Learned from International District Cooling Systems

This section is based on experience from many district cooling systems with a particular focus on sea water cooling systems. Many district cooling systems in Europe and North America have now been in operation for around 20 years. From these systems a lot of useful information has been collected which can provide valuable insight for cities and councils in Australia that are considering their own district cooling system utilising sea water or aquifer water.

E.3.1. Lessons – Sea Water Systems:

- Permitting activities can be extensive and potentially expensive:
  - Project may require an Environmental Impact Statement
  - Complex data collection required to meet permit requirements such as collecting volumes of water, annual water temperature variations, marine life survey, etc.
  - The sea life must be evaluated due to the warm reject water into the shallow sea
- Local marine life needs to be understood in order to select the most appropriate materials for the location
- Higher build network costs for the whole district system
- Closed loop systems must be installed such that the pipework surface area exposed to the sea water is maximized (i.e. underwater structure to support pipework instead of installing on sea floor)
- Consistent fouling of closed loop systems occurs due to marine life build up on the pipework surface and fouling of open loop systems can occur due to marine life build up on the heat exchanger internal surface without appropriate filtration
- Cleaning processes can be dictated by environment and water authorities, which may require that the dislodged matter be captured as part of the underwater cleaning process
- Possible to lay the return chilled water pipe directly in the water body if sufficiently cold

E.3.2. Lessons – District Systems:

- Over estimation of cooling load which can have serious impacts on project economics
- Considering thermal load diversity across the connected sites can reduce equipment and pipework sizing, which in turn reduces the associated project cost
  - Too low a temperature differential between entering and leaving chilled water:
  - Leads to lack of capacity in the system (i.e. for expansion or if under sized); and
  - High pumping energy costs.
- Traditional hot water pipe surveillance systems (leak detection) not appropriate for cooling systems due to high number of false alarms:
  - These types of systems sometimes often use wires embedded into the pipe which may not be needed for cooling systems
- Ensure that the technology is optimal for the local conditions
- Reduced maintenance costs for a central energy plant versus current distributed systems
- Central plant can provide several advantages over distributed systems including:
  - Economies of scale;
  - High efficiency;
  - Reduced maintenance;
  - Ease of expansion;
  - Technological upgrades as technology advances;
  - Save building space that can be used for more valuable purposes; and

- Allows for 'redundancy' or back-up systems to be included in the system architecture.

- Storage systems can provide reduction in daytime demand and overall site electricity demand if the storage is charged using overnight or 'off-peak' electricity.
- A key advantage of district cooling systems using a water body is the elimination of cooling towers which provides the following benefits:
  - Dramatically reduced water consumption;
  - Rooftop or external plant footprint reduction; and
  - Legionella risk and control management.
- Eliminate noise and vibration caused by distributed cooling equipment
- Provide a reduction in GHG emissions in order to meet sustainability goals
- Pipework reticulation on brownfields sites can be a high cost component due to trenching and rein-stating the ground surface
- Site expansion should be allowed for in the initial design:
  - This should not substantially increase costs if properly planned;
  - Allow for plant expansion via future connection points and ability to increase capacity with additional chillers; and
- This should be planned for at the beginning as DCS projects typically have a 30+ year life.

E.3.3. Trends

- Scaling and corrosion remain important issues
- There is the need to develop more efficient production pumps
- Geothermal district cooling systems are increasing in size
- No longer a northern hemisphere technology – growth occurring in hot and tropical areas such as the Middle East and South East Asia
- District cooling used to reduce GHG emissions

E.3.4. Risks

- Underground congestion:
  - Higher than anticipated costs due to unforeseen congestion in underground services;
  - Consider underground obstacles early in planning process;
  - Add budget margin where data is lacking; and
  - No master plan for site services with poor 'as-built' drawing records, thus making it difficult to locate or plan alterations to existing underground services – James Cook, Townsville.
- Barnacles, mussels and other sea life can grow inside the inlet and outlet pipework for open loop sea water systems and on the outside of the underwater pipework for closed loop systems, which in both cases can foul the system
- In the sea water loop corrosion may occur due to the concentration of salt
- During stormy periods the sand can erode the facilities located under the sea
- Lack of respect for timing plan:
  - Issues with permitting in particular can delay projects; and
  - Projects are complex and should be broken down into manageable milestones so that should delays in one stage occur other stages can continue in parallel.
- Lack of qualified specialists in the sector
- Complexity of the permitting and development process:
  - Environmental impact assessment cost for EPA approvals

Appendix F. Carnegie Wave Energy

F.1. Introduction

Carnegie Wave Energy Limited is an Australian, ASX listed (ASX:CWE) wave energy technology developer, best known as the inventor, developer and 100% owner of the CETO wave energy technology. CETO is designed to extract energy from the ocean waves to generate clean, renewable and emission-free electricity. Carnegie also owns 35% of leading Australian battery/solar microgrid EPC, Energy Made Clean, with whom Carnegie has a Strategic Alliance agreement focused on delivering mixed renewable microgrid projects to islands and remote and fringe of grid communities.

CETO offers the potential to revolutionise power and water production globally through the conversion of ocean wave energy into zero-emission electricity and desalinated water. Carnegie has invested over $140 million on CETO technology over six prototype cycles. This has meant that we have been able to develop a system that is environmentally friendly, has minimal visual impact and attracts marine life. Our design has also seen us become the only wave power station to operate anywhere in the world.

The CETO system is different from other wave energy devices as it operates under water where it is safer from larger storms and invisible from the shore. CETO possesses many unique characteristics including; converts ocean wave energy into zero-emission electricity and desalinated water, environmentally friendly-has minimal visual impact and attracts marine life and finally, it is fully submerged in deep water away from breaking waves and beachgoers.

F.2. The Perth Wave Energy Project (PWEP)

The Perth Wave Energy Project consisted of three submerged CETO Units (Units) in an array, hydraulic conditioning equipment, subsea pipelines to shore and an onshore power generation facility (Onshore Plant). The PWEP site off Garden Island (Figure 135) provided an ideal pre-production test site due to its exposure to open, medium intensity, wave conditions, its immediate proximity to marine support infrastructure and expertise, and security provided by its proximity to Australia's largest navy base, HMAS Stirling. Carnegie has a formal relationship with the Department of Defence (DoD) for site access and power/water purchase.

Figure 144: PWEP Location

At this scale, the Project was never intended as a stand-alone economic investment rather its aim was the successful engineering, operation and grid compliant power sales demonstration. The Project was therefore designed and operated as a demonstration Project, not a commercial project. As such, Carnegie operated the Project in order to maximise system and technology learning not to optimise energy extraction or electrical generation. The Project was operational for 13 months; it began operating when the first unit was installed in November 2014 and ceased operations when the final unit was retrieved in December

2015. The project completed a total of over 14,000 cumulative operating hours which remains a world record.

The Project was designed to centralise and automate Plant operating functions and to minimise Plant operators. Therefore, operation of the Plant largely consisted of operating the Process Control System (PCS) which is the main interface for operating and monitoring the plant other than the physical controls on the equipment. A Plant Operator monitor the system. at all times, working in shifts.

During the operational phase of the Project, Carnegie conducted operational testing to find the optimum differential pressure value that would maximise the power produced in each wave state. This optimisation process was an important part of Carnegie's technology development and learning and one that will be repeated for the CETO 6 Project; however, it means that for most times the system was intentionally operated in a sub-optimal control state – either under or over damped – and only rarely at the optimal differential pressure setting. This is the opposite of what would have been the situation should the objective of the project been to maximise power extraction and output.

In addition to better understanding and validating the performance of the CETO 5 technology, one of the other goals of the PWEP was to validate the accuracy of the model developed to estimate the power produced and the loads applied to the system. Carnegie's analysis to date has found that the model performed well.

F.2.1. How the CETO 5 System Works

The CETO system operation is defined as managing the conversion of wave energy into electricity.

The "principle of operation" of the Onshore Plant is to utilise wave energy for the production of electricity. In essence this requires the management of the following energy conversions:

- Hydrodynamic to mechanical (waves excite the Unit via the Buoyant Actuator (BA))
- Mechanical to hydraulic (within the Unit, BA drives the seabed-mounted Pump via the Tether)
- Hydraulic to mechanical (hydraulic fluid drives hydraulic motors onshore)
- Mechanical to electric (hydraulic motors drive generators to supply electricity to the local grid).

The first of these processes is passive and governed by the frequency response of the BA to incident waves. The remainder are actively controlled by the Process Control System (PCS).

A high level functional arrangement of the Onshore Plant is shown on Figure 136 below. Each Unit is accompanied by a local hydraulic management module called a 'Pod'. The high pressure fluid exiting the three Pods is aggregated into the High Pressure Delivery Pipeline (HPDP). On the low pressure circuit, the fluid from the Low Pressure Return Pipeline (LPRP) is distributed back to the Pods. The HPDP, LPRP and communications and control cables traverse the 3.2 km between the Pods and the Onshore Plant.

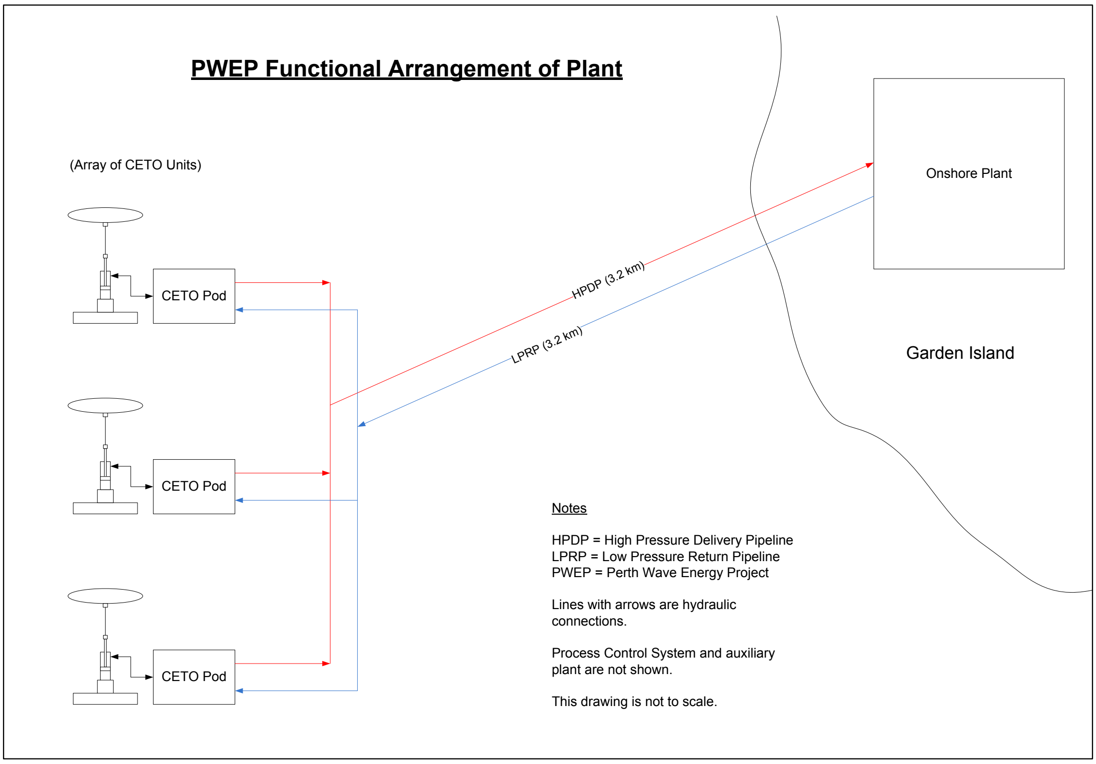


Figure 145: PWEP Functional Arrangement

F.2.2. Operational Management

The Onshore Plant was manned at all times using day and night shift by a Plant Operator. The Plant Operator were mostly based on site, although, at the discretion of the Project Operations Manager, the Plant Operator was at times able to monitor the Onshore Plant remotely (generally at night).

The Plant Operator workstation is shown below (Figure 137). This is the main interface for operating and monitoring the plant other than the physical controls on the equipment. The left-hand screen shows the S+ HMI used to control the plant. The right-hand screen shows the MAX software used for data monitoring.

Figure 146: Plant Operator Workstation

Figure 147: Plant Operator and Process Engineer and Operator's Plant Control Interface (HMI)

Figure 148: Carnegie Staff Inspecting Onshore Plant Hydraulics

F.3. Current CETO development

Carnegie is now looking to the future, having successfully completed the Perth Wave Energy Project (PWEP), which achieved over 14,000 hours of deployment across all 4 seasons over its 12 months of operation, making it the longest continuous period of operation of any in-ocean wave energy project in the world.

Carnegie sees wave energy as a clear way to help secure energy security beyond the current mix of renewables. Wave energy is largely an untapped resource to which Carnegie has found peaks at times after the normal solar and wind peak each day. Additionally, as wave power is driven by wind which occurs from far away, it has the ability to capture energy from far afield and as such, is a collator of energy from beyond the local area.

Carnegie are now working on the detailed design of the 6th Generation of the CETO technology, which for the first time will move electrical generation offshore, to occur within the units themselves. Unlike previous generations of the CETO technology, CETO 6 will not be connected by a pipeline to shore, with the pipeline to be replaced by an electrical export cable.

This improvement, along with many others incorporated in the CETO 6 design, will mean that the amount of infrastructure required for the installation and operation of the units will be greatly reduced.

In addition to design improvements reducing infrastructure and the associated installation costs, the CETO 6 design is a significantly larger unit than the CETO 5, with the buoy nearly doubling in diameter. As a result, the amount of energy captured in any given sea state should increase by a factor of 4.

F.3.1. *CETO 6 Technology*

CETO 6 was conceived to create a more powerful, lower LCOE CETO system than CETO 5. The main change was to incorporate the hydraulic-electric conversion equipment inside the BA that was previously located onshore in CETO 5. Whilst the CETO Pump has also been inverted and placed in the BA, this has no meaningful effect on the hydraulic system behaviour or performance.

In order to illustrate the evolution from CETO 5 to CETO 6, Figure 140 correlates the components between the generations. It can be seen that the onshore components from CETO 5 have been moved into the BA in CETO 6 with the exception that the power conditioning equipment has been separated from the Variable Speed Drive (VSD) and remains onshore.

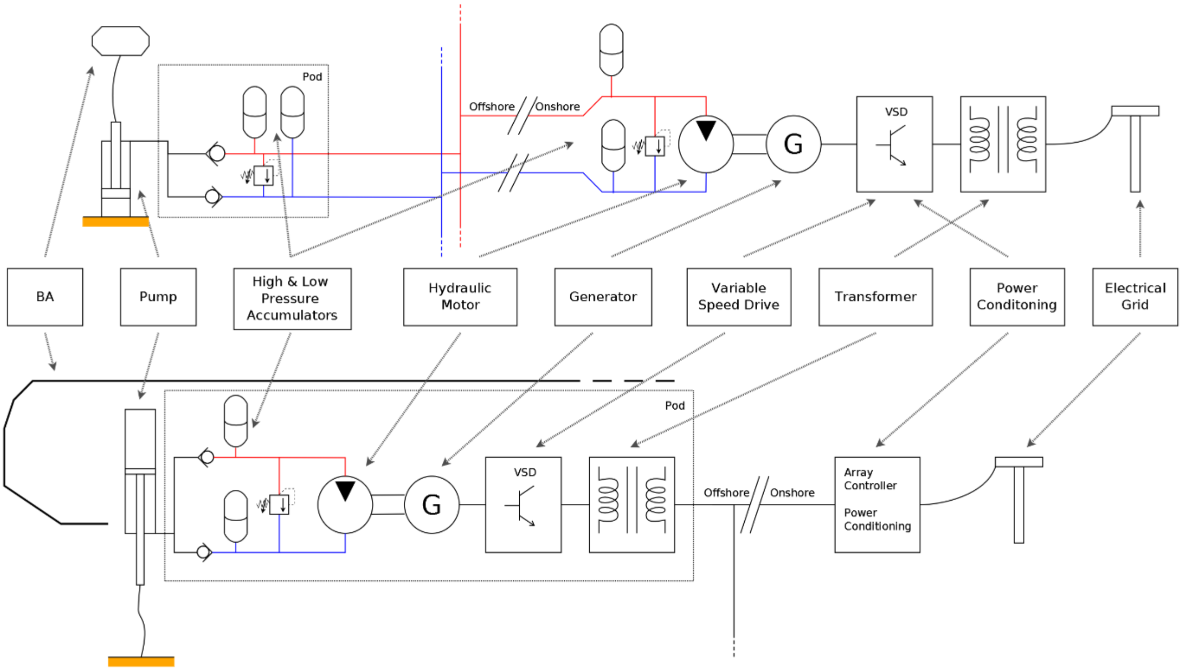


Figure 149: Component correlation between CETO 5 (top) and CETO 6 (bottom)

CETO 6 is based fundamentally on the same principles as previous CETO generations, using a submerged BA to drive a hydraulic cylinder which pressurises the working fluid. This fluid drives a hydro-electric system located inside the BA, thereby producing power offshore for export via subsea cables to the electricity network. This configuration is illustrated in Figure 141.

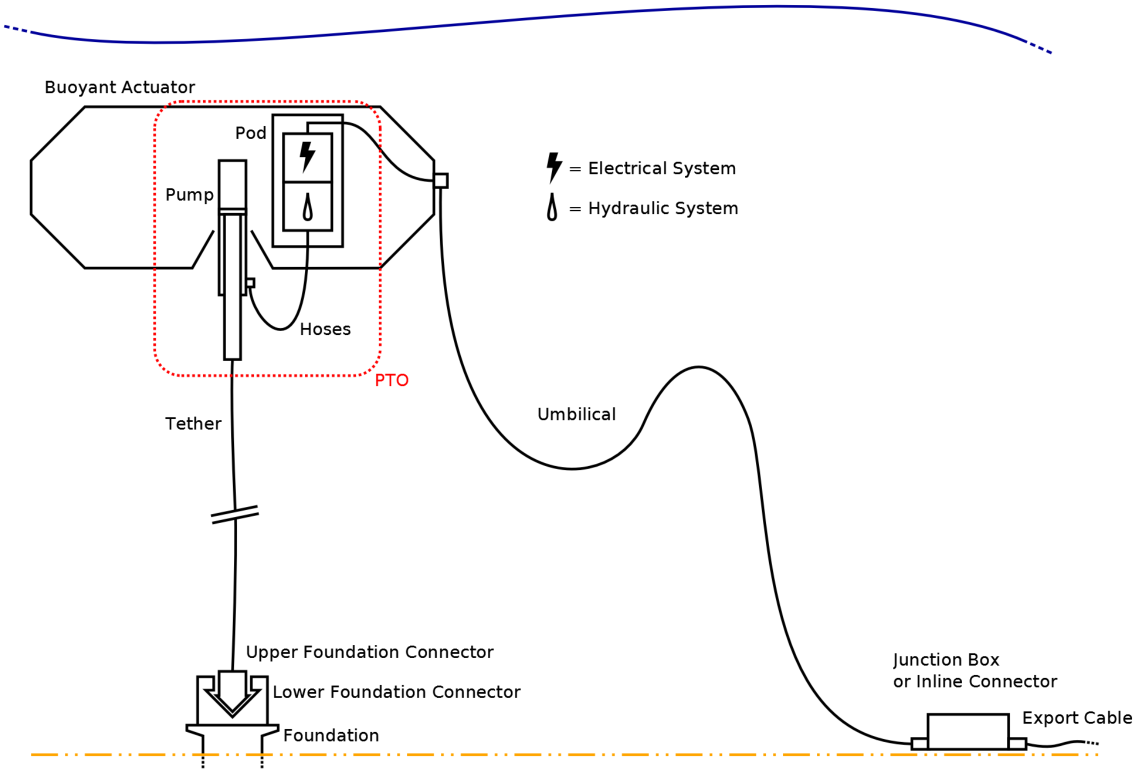


Figure 150: CETO 6 Technology Schematic

F.4.Project Pipeline

A key part of Carnegie's commercialisation strategy is the development of a project pipeline beyond the current CETO 6 Garden Island project that enables a continuation of R&D and product performance improvement, in addition to increasing the scale of the projects to improve the economics.

Carnegie has a dual market focus for early commercial projects:

- UK/Europe – making use of multiple grid-connected, pre-consented wave energy sites with tariff support mechanisms in place.
- Islands – whereby Carnegie is building relationships with a number of islands aimed at making islands “CETO ready” while Carnegie makes CETO “Island ready”.

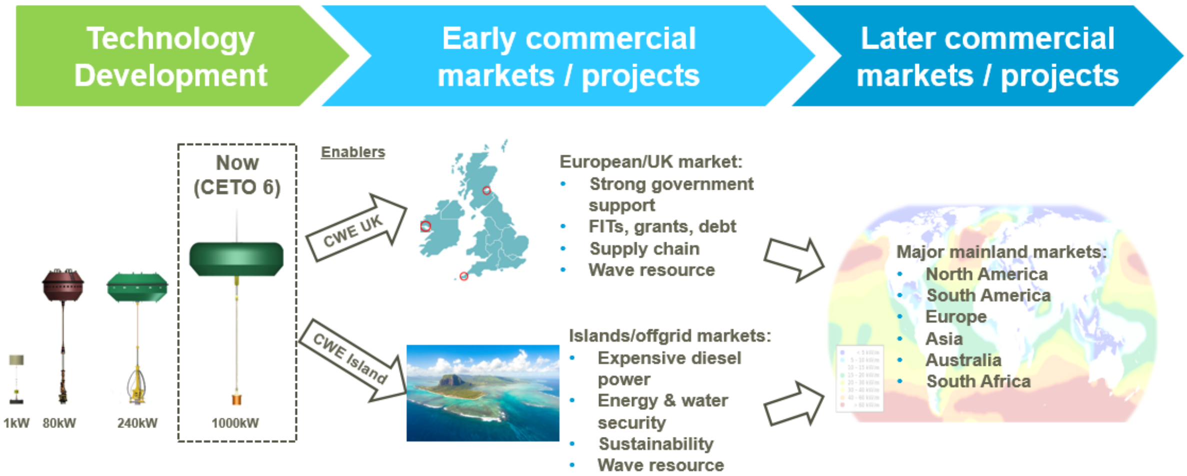


Figure 151: Carnegie Dual Market Focus

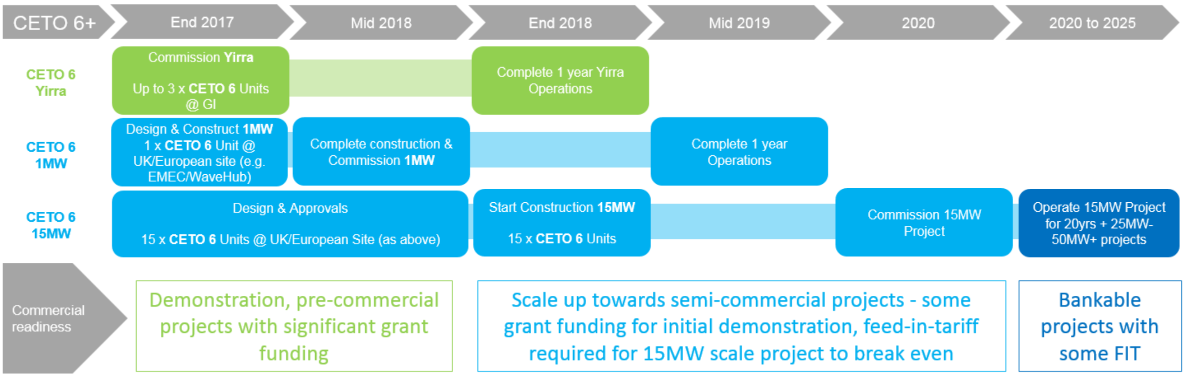


Figure 152: Timeline of initial CETO 6 projects

F.4.1. CETO 6 Garden Island

The first demonstration of the CETO 6 technology will be the Yirra Project at Garden Island at a location beyond Five Fathom Bank, in higher energy water than was experienced for the CETO 5 Units in the Perth Wave Energy Project (PWEP) (Figure 144) . This will be the first installation of CETO 6 technology representing a step change in the capacity of the wave energy converters used by Carnegie.

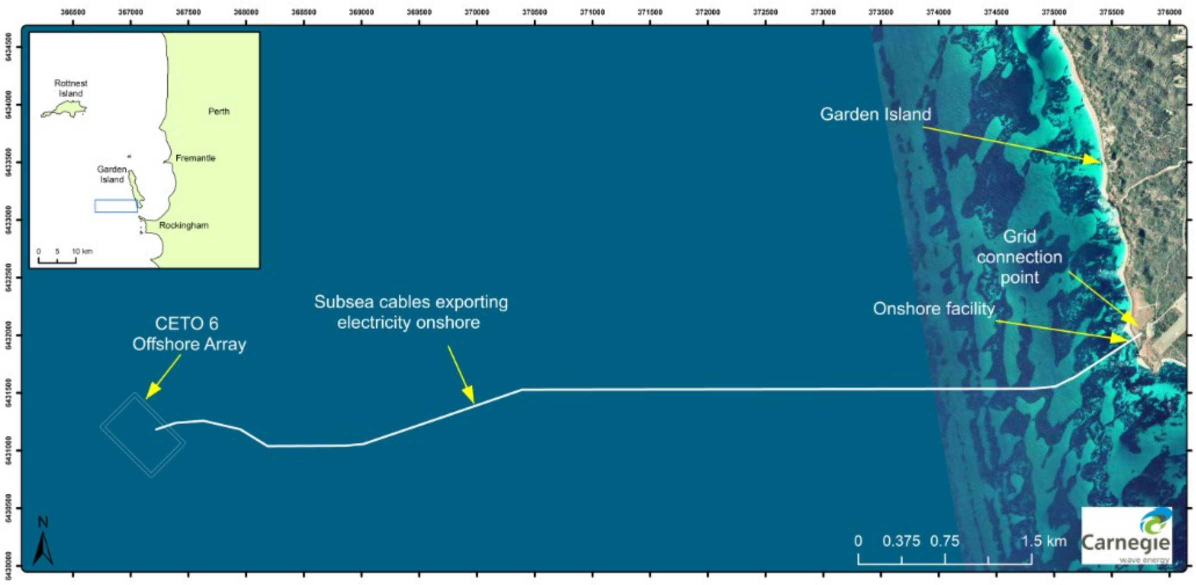


Figure 153: CETO 6 Wave Array, Development Areas and Conceptual Layout

F.4.2. 1-3 MW UK Demonstration Project

The first demonstration of the CETO 6 technology at a UK site is expected to be at either Wave Hub in Cornwall or EMEC in Scotland. Both of these sites are grid connected, and as such are pre-consented and will reduce the amount of upfront capital cost for a project. Both sites are high wave resource sites, with increased tidal variation from the Garden Island site. A UK site has been chosen due to the availability of tariff support, in the form of Contracts for Difference, of approximately £305/MWh ($620/MWh), in addition to grant funding available from both the UK and European Governments. This installation is planned to demonstrate that the CETO technology is able to be adapted to handle the additional tidal height required to operate in European waters.

F.4.3. 15 MW UK Project

The initial 1-3MW UK demonstration project would then be expanded at the same site to add a further 12-14 CETO 6 units, to create a wave farm of 15MW. This would be the first commercial scale CETO 6 project, based upon a UK supported tariff of approximately $620/MWh.

F.4.4. 25-50MW UK and European Projects

Subsequent to the 15MW Project in the UK, the achievement of a reduction in LCOE will enable the roll-out of larger scale CETO 6 projects. Initially it is expected that these projects will be based in the UK with higher tariff support, however as the LCOE reduces further, this will enable the technology to be cost competitive in other European countries with tariff support for marine renewable energy, albeit less than the UK. Ireland, for example currently has a tariff of €220/MWh ($340/MWh) for ocean energy, and a target of 1.5GW of installed wave and tidal energy by 2030. Many other European countries, including France, Portugal and Denmark, have established a combination of ocean energy test sites, roadmaps for increasing deployment and/or tariff support.

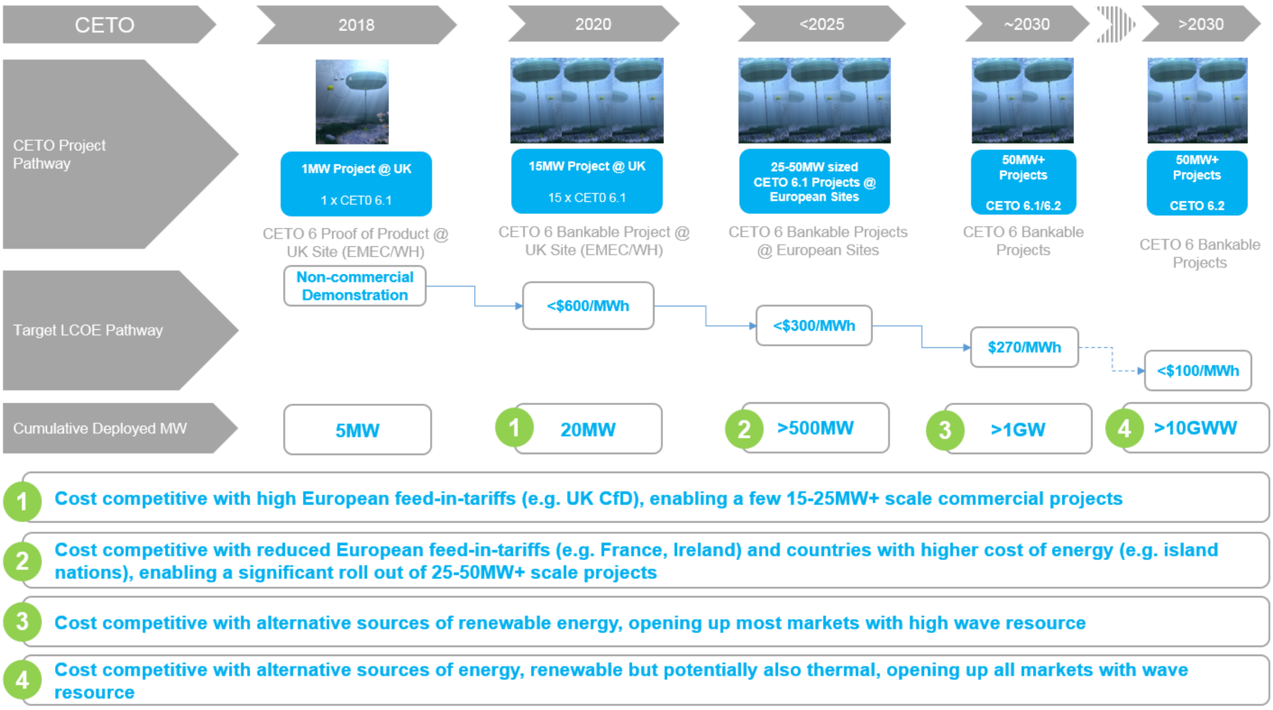


Figure 154: Deployment rate against LCOE target

It is therefore expected that on this basis, approximately 500 CETO 6 Units will have been deployed in UK or European waters within the next ten years.

F.4.5. Commercialisation Strategy

Carnegie's mission is to commercialise CETO in order to establish a profitable cash flow derived from the third party deployment of CETO projects in Australia and internationally. Carnegie aims to become net cash flow positive as quickly as possible without compromising either safety or quality or the long term value of the CETO technology to both Carnegie's 9,000 Australian shareholders and Australia.

Carnegie's commercialisation strategy is built upon four key drivers, which are:

- A superior, differentiated technology

CETO remains one of a small number of advanced wave technologies globally to be in-ocean operationally tested at a commercial scale. The PWEP was the world's first grid-connected wave energy array that also produced water, and demonstrated both the reliability and robustness of the technology, in addition to building upon the considerable in-house operational experience.

The CETO technology has significant operation and maintenance (O&M), robustness and survivability advantages because it is fully submerged, can generate power either onshore or offshore and utilises proven, robust, oil and gas industry and hydroelectricity equipment. Its ability to operate in both medium and deep water using either subsea electrical cables or hydraulic pipelines means it can capture a large share of the market. Additionally, it is the only wave energy technology to have produced directly desalinated freshwater.

- Cost competitive CETO technology

As outlined above, building upon the in-ocean operational experience to date and the engineered simplicity and robustness of the CETO 6 technology, CETO will be a cost competitive wave energy technology in a wide range of markets. CETO will be cost competitive initially in island markets and government supported markets such as Europe and then in mainland low cost markets such as South America, Asia and Australia. CETO will come down the cost curve due to improved efficiencies driven by advanced control systems and significant economies of scale driven by project size and CETO unit capacity.

- Sufficient access to capital

Carnegie cannot commercialise CETO without sufficient and timely access to capital from the private and government sectors. Carnegie has recently raised a further $7.5m in an oversubscribed funding round, bringing the total capital raise to $86m of Australian equity in the last 8 years, in addition to a recently signed $21m debt facility with an Australian commercial bank (CBA), and matched funding through government grants. As part of the UK project pipeline outlined below, Carnegie has already been engaging with government agencies and investors with regards to access to grant funding and an AIM listing in 2016, to ensure that sufficient funding is in place to facilitate the continued deployment of CETO 6 project

- An enormous untapped market for wave energy internationally

Whilst ocean energy is still an emerging sector, it has long been recognised as an essential part of the renewable energy mix, with a worldwide theoretical potential of wave power calculated as 29,500 TWh / year.

Wave energy, like other power technologies based on renewable resources, is widely available throughout the world and can contribute to reduced energy import dependence. Wave power is also important as it improves security of energy supply, as it is draws from an additional source than other renewables and consumes no water. As local air pollution and extensive use of fresh water for cooling of thermal power plants are becoming serious concerns in hot or dry regions, these benefits of wave become increasingly important.

Further, wave energy plays an important role in the power mix, because of the fact that the peaks of wave power tend to occur at different times to those of both wind and solar power. The fact that wave power peaks at other times to different renewables allows for supply of power when other sources are not available, or when their output is reduced. This makes wave energy well suited to integration in multi renewable source microgrid systems.

Appendix G. Island of Mauritius – Marine Parks

Mauritius currently has two legislated marine parks, the Balaclava and Blue Bay marine parks shown below.

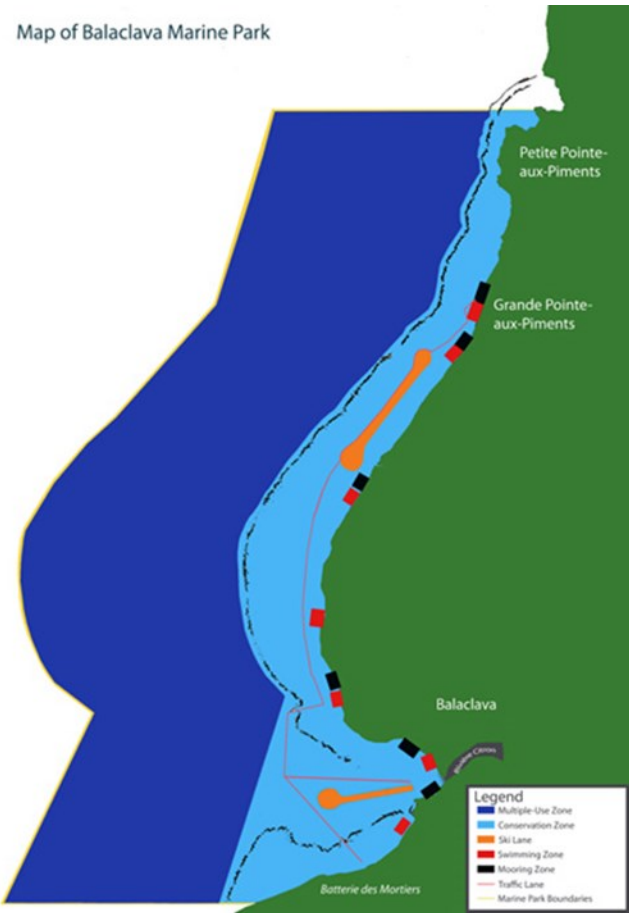


Figure 144: Map and zoning for Balaclava Marine Park

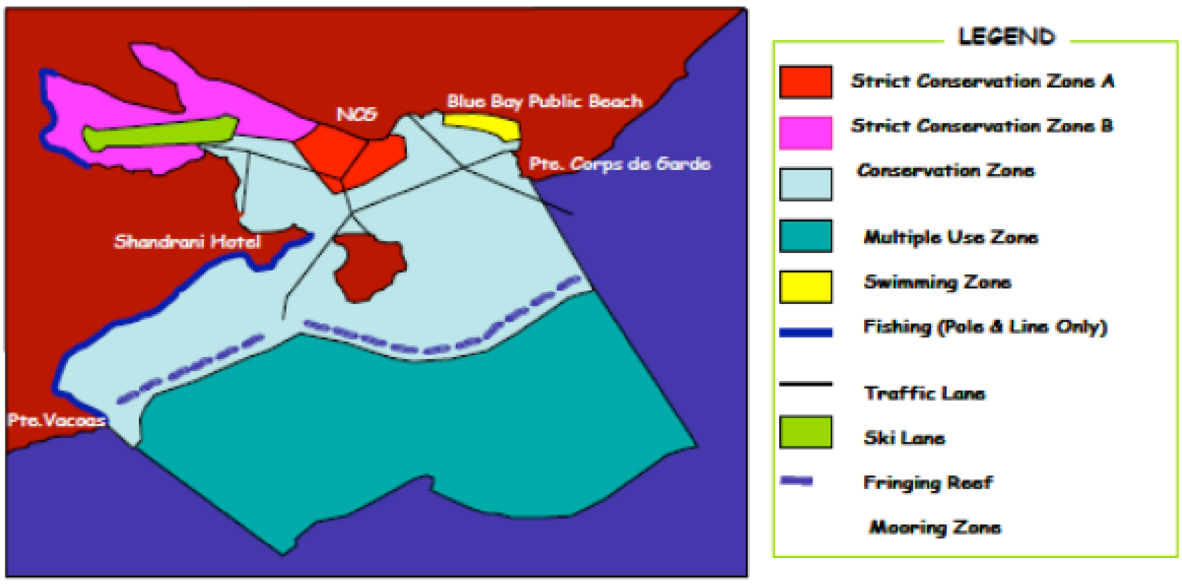


Figure 156: Map and zoning for Blue Bay Marine Park

Appendix H. How does AGC work?

The AGC loop will maintain control only during small and slow changes in load and frequency. It will not provide adequate control during emergency situation when large megawatt imbalances occur. First let's look at AGC as it applies to a single generator supplying power to a local service area.

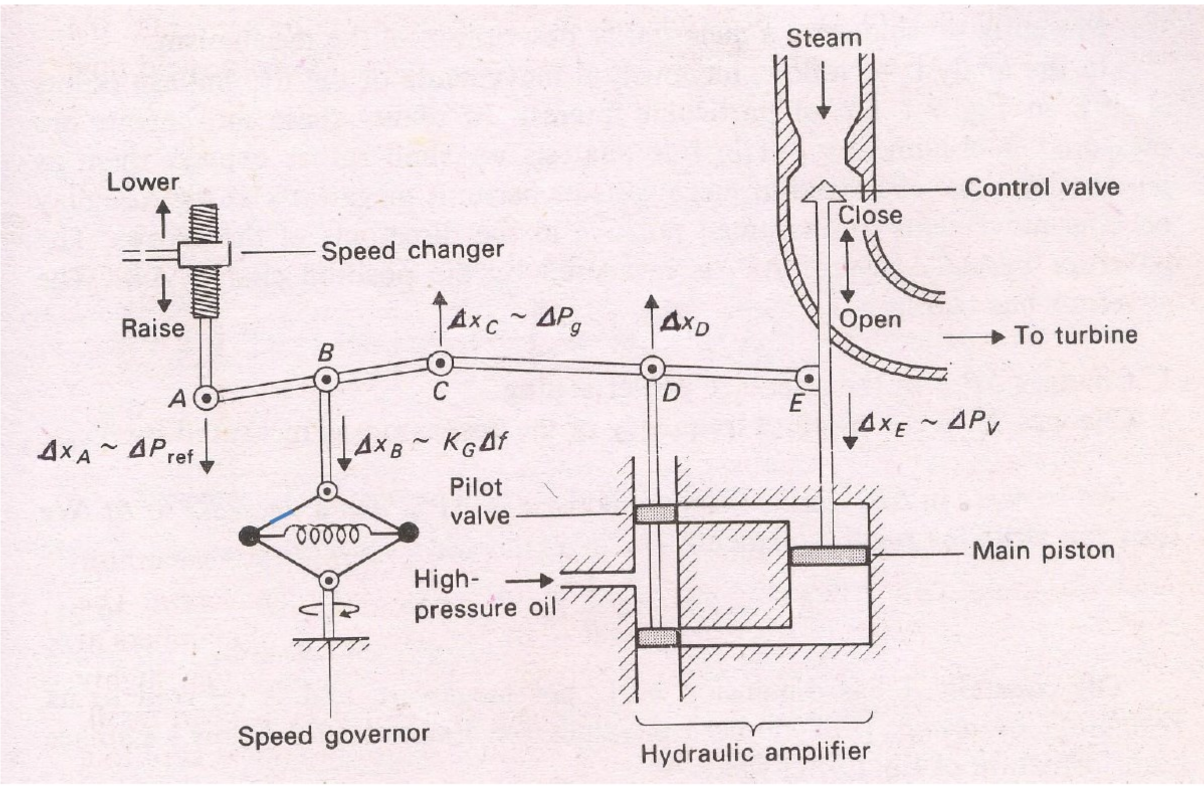


Figure 157: Functional diagram of real power control mechanism of a steam generator.

The real power control mechanism of a generator is shown above (SRN n.d.), the mechanisms include:

- Speed changer
- Speed governor
- Hydraulic amplifier
- Control valve.

They are connected by linkage mechanism. Their incremental movements are in vertical direction. In reality these movements are measured in millimeters; but in our analysis we shall rather express them as power increments expressed in MW or p.u. MW as the case may be. The movements are assumed positive in the directions of arrows.

"A" moves downwards; "C" moves upwards; "D" moves upwards; "E" moves downwards. This allows more steam or water flow into the turbine resulting incremental increase in generator output power.

When the speed drops, linkage point "B" moves upwards and again generator output power will increase.

The input to the governor has two inputs: Speed Input and Power Reference. The equivalence of a diesel generator is the volume of diesel fuel injected into the engine which in turn increases the power output from the generator and this in turn increases the system frequency.

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R} \Delta f$$

Equation 1 - Differential Equation for relationship between kW and f

Typically the frequency control in Mauritius is performed manually by the operators. The operators would observe the frequency indicator for the system and manually increase or decrease the output of the generation to adjust the frequency. Increase the power and the frequency would also increase. The reason for the frequency to change is that load itself is variable. As the load increases, the demand for the power would increase and this would load to frequency dropping. The CEB's grid code attempts to maintain system frequency at 50Hz +/- 2 Hz. When the operator monitors a frequency drop due to load increase he would manually increase the output of the power station to balance the frequency. The AGC offers an automated mechanism to perform this activity.

The renewable energy would be seen as a negative load effect to the overall load profile. The response is an oscillatory response with the system responding with delays as below

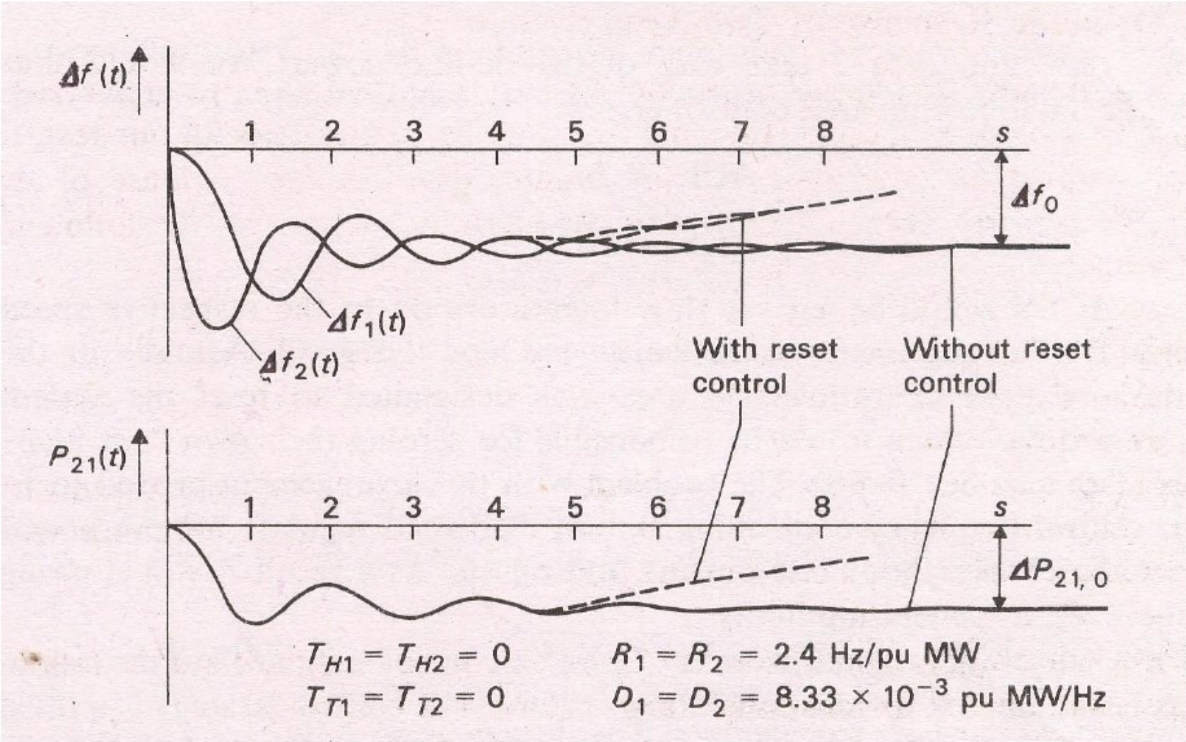


Figure 158: Dynamic system response after power injection

The AGC system is however is not able to deal with sudden changes in frequency due to the fact that diesel generators have limited step response. To manage sudden variations in delta frequency other strategies such as energy storage can be used as complementary strategies.

First, it is important to understand that generator sets are designed to run and, to be specific, they are designed to run with load. This may seem trivial, but loading a generator set properly is essential to availability, healthy engine operation and long engine life. The ideal operation targets of each generator set will depend on the application and rating. Generally speaking, standby- and prime-rated diesel generator sets are designed to operate between 50 and 85 percent of the full nameplate, while continuous-rated diesel generator sets are optimized between 70 and 100 percent load. Natural gas and biogas generator sets, independent of application and rating, are designed for operation between 70 and 100 percent of the nameplate rating (Catapillar 2014). Misapplying generator sets by underloading them for extended runs will impact product health, operation and uptime while increasing the opportunity for unplanned events and shutdowns.

Operating a diesel generator set at load levels less than 30 percent of rated output for extended time periods impacts the unit negatively. The most prevalent consequence is engine exhaust slobber, which is also known as exhaust manifold slobber or wet stacking. Engine slobber is a black, oily liquid that can leak from exhaust manifold joints due to extended low- or no-load scenarios. Running at high idle with little or no load reduces the heat in the cylinder, allowing unburned fuel and oil deposits to leak through the exhaust slip joints. Visible slobber does not necessarily indicate a problem with an engine, but it signals possible underloading concerns, low ambient temperatures or low jacket water temperature. In most circumstances, engine slobber alone, while unsightly, will not immediately harm an engine. However, slobber is a sign of underloading and could be an indication of other underloading effects. Long periods of light loading can lead to deposit build-up behind the piston rings, deposits developing inside the cylinders and, in extreme cases, cylinder liner polishing can occur. These conditions can lead to power losses, poor performance and accelerated wear of components, which can cause increased maintenance costs and unplanned downtime or failure.

Most significant is the failure of the units. In a system when units are under loaded in a short space of time could lead to the entire system collapsing initiated by protective relays in the system.

Dealing with underloading is possible by allowing load control or saturation of the outputs from non-baseload generating sets. Advanced control systems are now available to allow for such fast responsive controls. For Mauritius, the water pumping and desalination plants are ideal controlled loads that can be matched to the output of the renewable sources.

Underloading your power system impacts many individual components as well as overall system performance. While the simple solution is ensuring that your operational load is above 50 percent of the generator set nameplate, actual site conditions, site requirements and site expansion do not always line up with initial system design plans. This makes system underloading prevalent in the power generation market, specifically in the standby market. To help minimize the effects of underloading, it is critical to have operation and maintenance plans in place to maintain the health and reliability of the complete system and your generator set (Catapillar 2014).

Appendix I. UPS versus BESS Operation

A common term used in the industry is Battery Energy Storage Systems (BESS). These systems typically include all components required for the full integration of the batteries to the power system.

A UPS typically operates in series with a load, see Figure 148. It makes use of a device called an automatic transfer switch (ATS) which detects loss of main and switches very fast to the battery supply. In doing so the inverter is typically not matched in frequency or power at changeover (i.e. the transfer is not bumpless/controlled). The ATS will detect the restoration of mains power and reconnect the load directly to the mains input, once again the transfer is not bumpless.

BESS operation is different in that the system is connected in parallel with the other generation sources (i.e. mains and emergency diesel generators), see Figure 149. The BESS also requires control signals to determine loss of mains while also sensing the mains frequency, voltage, and current. This allows the BESS to provide a controlled transfer from mains to battery supply and back again (i.e. the transfer is bumpless/controlled). When operating from battery the system will operate as a microgrid with all low priority loads being shed during the transfer from mains to battery.

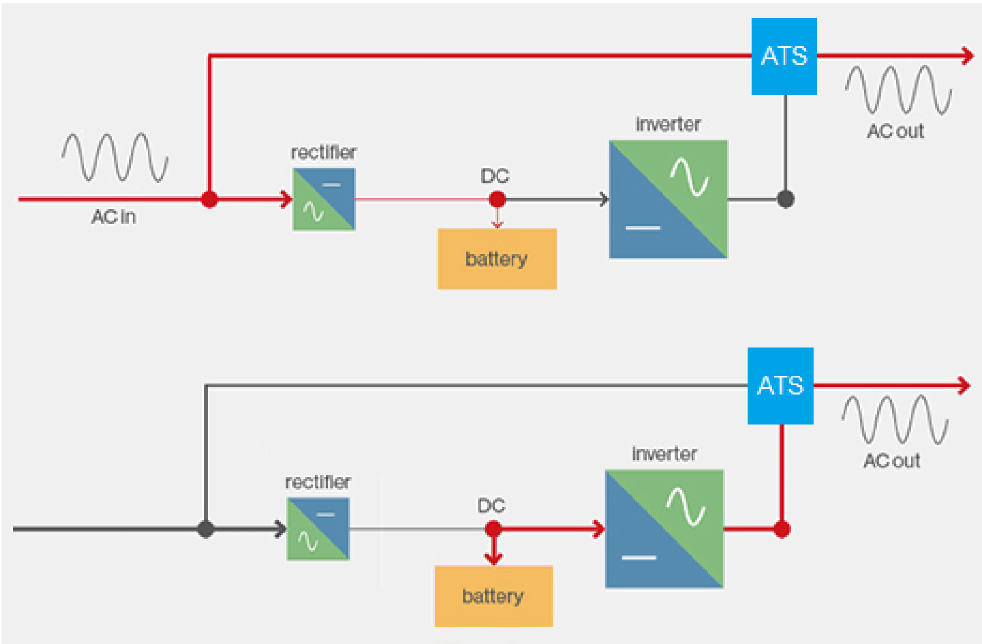


Figure 148: UPS operates in series with Load (diagram shows UPS with and without mains).

The BESS also has control over the emergency generators. Once mains are lost and the microgrid is formed, the BESS control system will start and sync the generators to match the BESS inverter thus transferring the load from the battery to the generators. Once mains have been restored, the BESS will transfer the loads back in a bumpless fashion, once complete the mains loss controller can reinstate low-priority loads.

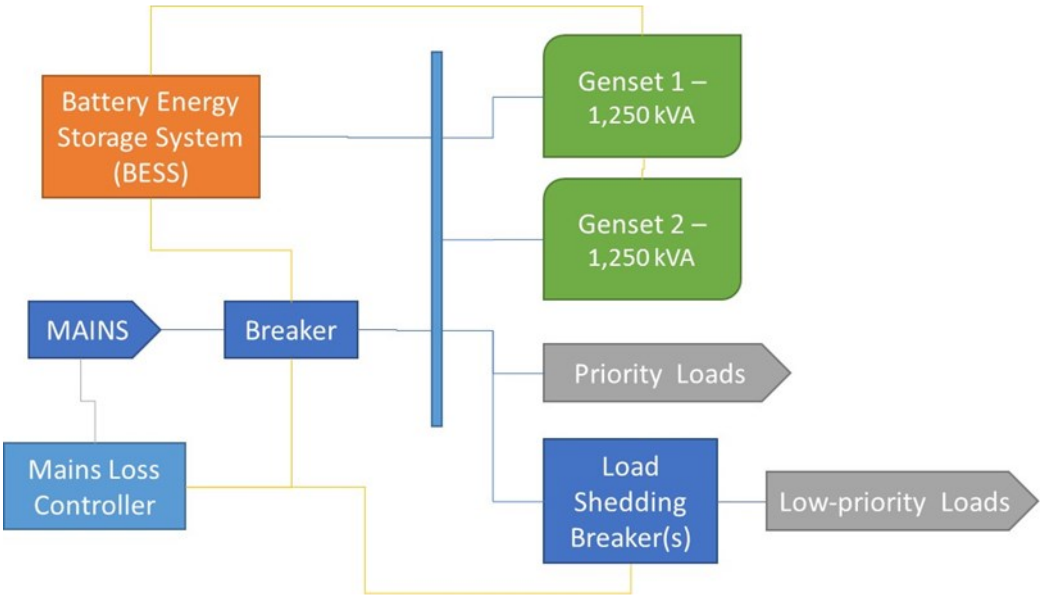


Figure 149 : Simplified SLD for a BESS/microgrid