powercorp
www.pcorp.com.au

Lord Howe Island Renewable Operations

Energy Supply Road-Map

Released:	**30/08/2011**
Version:	**RF**
Author:	**Gavin Bates**
Prepared for:	**Lord Howe Island Board**
By:	**Powercorp Operations Pty. Ltd.**

DYNAMIC POWER SYSTEMS
POWER CONTROL SYSTEMS

For further information or for new releases of this document please contact us at:

Powercorp Operations Pty. Ltd.
Export Drive, Darwin Business Park
Darwin, NT, 0828
Postal: PMB 88, Berrimah, NT, 0828
AUSTRALIA
ABN: 45 070 662 369
Tel: +61 (0) 8 8947 0933
Fax: +61 (0) 8 8947 0925
Email: mail@pcorp.com.au
Website: www.pcorp.com.au

Revision history:

Version	**Description**	**Comments**	**Created on/by**	**Reviewed by**
…	…	…	…	…
RB	Release Draft	10-step Phase 8	GLB	JZ
RC	Release Draft	Corrections and adjustments	GLB	
PD1	Internal Draft	Apply feedback from customer	GLB	
RD	Release Draft	10-step Phase 8	GLB	
PE1	Internal Draft	Minor corrections from the cusomter	GLB	
RE	Release Draft	10-step Phase 8	GLB	
RF	Release Draft	Updated graphs only	GLB	

EXECUTIVE SUMMARY

Powercorp has performed energy flow modelling for the Lord Howe Island power system to create a road-map for the island to integrate renewable energy generation into the system.

The board has previously taken the concept of adding renewable energy generation to the Lord Howe Island community and has received positive responses that have formed the “Guiding Principles for Renewable Energy on Lord Howe Island” document. The road-map supplied approaches the “tentative target of 75% renewable by 2025” by demonstrating that a 65% renewable energy power system in 2014 is achievable. Such a system is using just two medium scale Vergnet MP 275kW wind turbines and a total of 400kWp Solar PV, split evenly between LHIB funded and privately purchased.

For a preliminary target, the LHIB has set an initial goal of 20% of maximum demand, which is approximately 100kW. This initial goal is expected to be reached through the installation of privately funded roof-top Solar PV.

The provided energy supply road-map has assumed that funding is available for the installation of the generation equipment rapidly and demonstrated the on-going advantages of allowing demand controlled devices, including electric vehicles and “off-peak” hot water systems and air-conditioning.

The proposed system to be completed in 2014 complies with all parts of the Guiding Principles document, with the exception of the sizing and the machine type of the wind farm.

The modelling performed later in the document exposes the ability of the renewable augmented power system to “withstand” price shocks in the cost of diesel, reducing a 100% “price spike” in the cost of diesel from a 70% increase in energy costs down to a 25% increase in energy costs. In addition to reducing the rate of cost increase to supply electrical energy, once the power system upgrades are paid off (the timing varies, depending on the amount of payback that LHIB decides on, as well as the external grants available) in 2030, it is expected that the cost of a unit of energy will be in the order of less than half when compared to supplying the same energy by diesel generation only.

Earlier modelling has shown that the addition of a flow battery type energy storage system will be beneficial to the more effective integration of renewable energy, however the proposed 400kWh system represents slightly less than 2 hours of average consumption. Due to the uncertainty with the actual provision of the grant to purchase the energy storage system, it has not been included in final calculations, although the provision is expected to increase the use of renewable energy and decrease the consumption of diesel fuel.

It must be noted that the Levelised Cost of Energy (LCoE) calculated in the Net Present Value (NPV) section of the report is based on the actual cost of supplying energy to the LHIB, not the cost to the consumer as it does not include any rebates.

The target of 75% renewable energy by 2025 is technically achievable with a third wind turbine and larger amounts of energy storage and demand response installed on the island. However at today’s cost of energy storage this case would not represent the lowest Levelised cost of energy compared to the 65% recommend target.

TABLE OF CONTENTS

EXECUTIVE SUMMARY .... **III**

ABBREVIATIONS AND DEFINITIONS .... **VII**

1 INTRODUCTION **1**

1.1 Background *1*

1.2 Scope of Works *1*

2 RENEWABLE ENERGY GENERATION **2**

2.1 Solar Photovoltaic (PV) Energy Technology *2*

2.2 Wind Energy Technology *6*
- 2.2.1 Horizontal Axis Wind Turbine 7
- 2.2.2 Vertical Axis Wind Turbines 8

2.3 Wave Energy *9*
- 2.3.1 Floating Buoy 9
- 2.3.2 Oscillating Water Column 10

3 ENERGY MANAGEMENT **11**

3.1 Energy Storage *12*
- 3.1.1 Lead Acid Batteries 12
- 3.1.2 Lithium Ion Batteries 13
- 3.1.3 Nickel Cadmium Batteries 13
- 3.1.4 Zinc Bromine Batteries 13
- 3.1.5 Sodium Sulphur (NaS) Batteries 14

3.2 Grid Stability *14*
- 3.2.1 Flywheels 14
- 3.2.2 Super capacitors 15

3.3 Energy Abatement and Recovery *15*
- 3.3.1 Solar Air-Conditioning 16
- 3.3.2 Waste Heat Absorption Chilling 16
- 3.3.3 Thermal Water Loops 17
- 3.3.4 Electric Vehicles 17
- 3.3.5 Time-of-use Tariff 19

4 ENERGY FLOW MODELLING **20**

4.1 Method *20*
- 4.1.1 Input Documents and Information 20
- 4.1.2 Process Applied 26
- 4.1.3 Output Items 27

4.2 Case Studies *27*

4.3 Notes On The Modelling 28
4.4 Results 28
4.5 Conclusions from the Base Modelling Results 33

5 NET PRESENT VALUE ANALYSIS 34

5.1 Method 34
5.1.1 Input Details 34
5.1.2 Cost Breakdowns 34

5.2 Results 36

5.3 Conclusions 38

6 LORD HOWE ISLAND ENERGY ROAD-MAP 39

6.1 Road-Map 39

6.2 Power Station Control System 41

6.3 Solar PV 42
6.3.1 Solar PV Installation 42
6.3.2 Solar PV Control 43

6.4 Wind Farm 43
6.4.1 Wind Farm Integration 43
6.4.2 Wind Farm Layout and Sizing 43
6.4.3 Wind Farm Construction 44
6.4.4 Further Modelling 44

7 REFERENCES 46

8 APPENDIX 47

8.1 Power Station Overview 47
8.1.1 Power Station Components 47
8.1.2 Power Station Operation 47

8.2 Component Details 49
8.2.1 Component Details - Existing 49
8.2.2 Component Details – Proposed 50

8.3 Environmental Data 54
8.3.1 PV Resource 54
8.3.2 Wind Resource 54

8.4 Electric Vehicles 55
8.4.1 Demand Managed Hot Water Systems 57

8.5 Economic Data 57

8.6 Model 60
8.6.1 Configuration 60
8.6.2 Model Assumptions 61
8.6.3 Model Verification 64

ABBREVIATIONS AND DEFINITIONS

Abbreviation	Description
AC	Alternating Current
BTU	British Thermal Unit
DC	Direct Current
DMD	Demand Managed Device
EDLC	Electric Double Layer Capacitor
EV	Electric Vehicle
HAWT	Horizontal Axis Wind Turbine
HIT	Heterojunction with Intrinsic Thin layer
kW	Kilowatt
kVAr	Kilovolt-Ampere Reactive
kWh	Kilowatt-hour, equivalent to 3,412 BTU
kWp	Kilowatt, peak
LHI	Lord Howe Island
LHIB	Lord Howe Island Board
LCoE	Levelised Cost of Energy
MW	Megawatt
NaS	Sodium-Sulphur (Battery)
PV	Photo-voltaic
RAPS	Remote Area Power System
RPM	Revolutions Per Minute
VAr	Volt-Ampere Reactive
VAWT	Vertical Axis Wind Turbine
VRLA	Valve Regulated Lead-Acid (Battery)

Abbreviation	Description
ZB	Zinc Bromine
ZBB	Zinc Bromine Battery

Definition	Description
DMD	A demand managed device is a load that is controlled intelligently by the power system, for example a pumping motor that is only run when there is available renewable energy.
HIT	A type of Solar PV cell manufactured by Sanyo that contains a thin-film (amorphous) solar cell “grown” on top of a mono-crystalline solar cell. The result is a cell with high efficiency and good high temperature performance.
Insolation	A measure of solar radiation energy received on a given surface area in a given time
LCoE	Levelised Cost of Energy – the average energy cost per unit over a 20 year period, including the escalated value of today’s money
kWh	A unit of energy
kW	A unit of power, equivalent to 1.34 horse-power
kVAr	A unit of reactive power
kWh/an	The amount of energy used over one year (per annum)
kWp	The power output measurement of a solar panel under peak irradiance conditions (note that this is higher than under typical conditions)
MW	A measure of power that is 1000 times of kW

1 INTRODUCTION

1.1 BACKGROUND

The Lord Howe Island Board (LHIB) has approached Powercorp to assist them with the successful design and integration of renewable energy generation into the Lord Howe Island (LHI) Remote Area Power System (RAPS).

The initial part of this project is to perform modelling on the options open to supplying renewable energy to Lord Howe Island. These options were then ranked in order of generation cost ($/kWh energy delivered) and then applied to an “Energy Supply Road-Map”.

This “Energy Supply Road-Map” shows when augmentation of the energy system should be considered, based against the potential increase of energy demand on the island.

1.2 SCOPE OF WORKS

This document covers three of the four scopes of work included in the Lord Howe Island consultancy:

1. Review of the Solar PV customer connection agreement (see other document)
2. HOMER/Energy Flow Modelling using renewable energy
3. NPV and financial analysis of proposed power system upgrades
4. Development of a Energy Supply Road-Map for LHI

2 RENEWABLE ENERGY GENERATION

This section of the document provides a brief overview of the two types of currently commercially available viable renewable energy generation devices. It also contains a brief overview of wave power generation, as a prelude to further investigations in the future.

2.1 SOLAR PHOTOVOLTAIC (PV) ENERGY TECHNOLOGY

The PV System considerations include the: PV Module, Direct/Concentrating technology, Mounting/Tracking, Inverter Technology and Connection Structure.

- *PV Module*: The three main types of photovoltaic cells are mono-crystalline, poly-crystalline and thin-film. There are also hybrid panels available such as the Sanyo HIT cells which use a combination of mono-crystalline and thin film technology.
    - *Mono-crystalline* panels consist of a number of cells which are single wafers of silicon. These panels have the highest efficiency[1] of the three types of panels and are generally more expensive. See Figure 2[2].
    - *Poly-crystalline* (multi-crystalline) panels consist of a number of cells of multiple silicon crystals. See Figure 1[3]. This results in a lower efficiency module than the mono-crystalline, at a lower cost.
    - *Thin-film* panels are composed of a thin layer of semiconductor material applied to a low-cost substrate such as plastic or glass. The active materials may be amorphous silicon, Copper Indium Gallium Selenide (CIGS), Copper Indium diSelenide (CIS) or Cadmium Telluride (CdTe), amongst others. See Figure 3[4].
    - Whilst the efficiency[1] of these panels is generally lower than either mono or poly-crystalline panels, the output is often superior under diffuse light conditions. These panels generally perform better at higher temperatures due to a lower temperature coefficient.

---

[1] NOTE: The efficiency of a panel relates to the relative area and supporting structure required to achieve the same output as an alternate photovoltaic panel. Therefore, generally an array composed of mono-crystalline will require less area than the poly-crystalline or thin-film technology.

[2] http://img.archiexpo.com/images_ae/photo-g/monocrystalline-photovoltaic-module-18050.jpg (acc. April 2010)

[3] AltE Store, http://www.altestore.com/store/descfiles/bp/bp375/bp375.jpg (acc. April 2010)

[4] AltE Store, http://www.altestore.com/store/descfiles/kaneka/gsa.jpg (acc. April 2010)

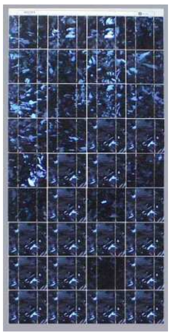


Figure 1: Poly-crystalline PV Module

Figure 2: Mono-crystalline PV Module

Figure 3: Thin-film PV Module

- *Direct/Concentrating Technology*: There are two main approaches for a PV panel to capture solar energy. One method is to capture the solar energy directly, such as flat-plate arrays (this includes rigid as well as flexible panels which may not be specifically flat) or indirectly via some concentrating medium (this may form part of the panel as with the SolFocus panels, see Figure 4[5] or additional to the panels such as a concentrating dish, see Figure 5[6]). Concentrating arrays focus the direct component of the solar radiation to maximise the power output and minimise the cell size. This technology does not use the diffuse component of the solar radiation. Using only the direct component of solar energy, concentrating arrays tend to drop output suddenly under cloudy conditions therefore favouring sites offering maximum clear days and minimum cloud.

Figure 4: Concentrating PV Array – SolFocus

Figure 5: Concentrating PV Array– Dish

---

[5] SolFocus http://www.solfocus.com/en/ (accessed April 2010)
[6] http://knol.google.com/k/-/-/1g0rrsoesmjko/dk53jz/solar-dishes.jpg (accessed April 2010)

- *Mounting/Tracking*: PV arrays may follow the path of the sun using single axis (see Figure 6[7]), double axis tracking or remain stationary as a fixed array.

  Tracking systems increase the output of a flat-plate array by approximately 20-30% but are more expensive to install and maintain.

  Tracking systems are generally not rated to withstand cyclonic conditions and other severe weather events and consume more area than fixed systems.

Figure 6: PV array with single axis tracking

- The simplest form of solar PV being fixed flat plate is considered in the modelling for this study due to the lower cost and cyclonic conditions.
- *Inverter Technology:* Inverters today are generally based on the "PV String" concept of interconnection. In this design the DC circuit is minimised and multiple small inverters are used to feed the output of multiple small strings of panels onto an AC collector circuit. Multiple inverters in this way offer multiple MPPT inputs to ensure maximum energy from a large PV array, especially during partial shading events. In an effort to appeal to the remote area power system market, many manufacturers are offering very wide tolerances on the frequency and voltage ranges with some offering up to a 4Hz operational window. Some manufacturers also offer "low voltage ride through" that allow the inverters to help the power system through faults and the ability to produce VArs to assist in maintaining power quality and reduce integration issues.

  The inverter units are virtually maintenance free, self-protecting to prevent damage during extreme events and have design lives of 20 years. More advanced units are able to deliver a programmable power factor, to ensure the reactive power capabilities of the diesel alternators are not over taxed when the solar is producing significant amounts of power.
- *Connection Structure:* PV arrays may be incorporated into a system as centralised or distributed installations. These are often, but not limited to, ground-mounted and roof-top installations respectively.
- *Distributed Installation:* Distributed installations attempt to take advantage of existing structures to reduce the cost of installation including grid connection.

  Disadvantages include; roof-tilt not facing the optimum direction, requiring structural roofing surveys, and potential reinforcement of the existing roofing. In addition, security of the installation may be an issue due to it being installed within the community and a lack of suitable roof space may constrict the maximum size of the array. The final issue involves

---

[7] http://www.solarserver.de/l8mimages/news/sunpower_solartracker.jpg (accessed April 2010)

monitoring of the plant if a significant amount of generation has been installed, as identified in the evaluation section of this report.

The benefits of distributed installations include reduced transmission losses, as generation is closer to point of consumption, and the reduced costs to connect to the grid as connection is generally already established. In addition, although the energy yield may be reduced due to non-optimal orientation, orientations towards the East show an increase in output over the early hours of the morning and a corresponding drop off later in the day. Orientations towards the West show a reduced output in the morning, following with a lengthened and increased output in the afternoon. These two features can be utilised to "flatten out" the solar peak and extending the time of day that solar energy is available at the cost of small reductions of yield (in the order of 5%).

- *Centralised Installation:* A centralised installation area can preferred for the installation of a substantial solar PV generation block, due to the reduction of unknowns and risks, the ability to use machinery to efficiently develop the area resulting in lower overall installation costs.

  In addition to this, the dedicated installation area allows for the use of more efficient inverters as well as the increased security of a purpose built perimeter fence.

  A cleared area adjacent to the power station would appear to have a usable space of around 1,000m^2 that would equate to an approximate installed capacity of 200kW of fixed PV solar panels.

  There is an expected community demand for the installation of up to 200kW on the rooves of existing private dwellings and commercial facilities. These include home-owners and business-owners that are keen to take advantage of private Solar PV installations to reduce their cost of energy. In addition, LHIB is investigating potential ownership structures to procure an additional 200kWp of Solar PV.

  It is noted that with inverter connected devices LHIB may required a 3-phase inverter with larger privately installed Solar PV installations. Although further modelling and investigation of the network will need to be performed to determine this level, it can be assumed the maximum single phase Solar PV will be less than 5kW.Availability and cost will determine which technology will provide the best returns and may prioritise a particular technology another. For example, mono-crystalline modules may provide better returns than the thin-film modules. As this choice is to be made by the resident installing solar panels on their own roof space, this topic will not be further investigated.

  The market availability in Australia is good for all technologies mentioned, excepting some types of concentrator systems which are still in the process of accessing the commercial arena. Under an IPP arrangement the PV technology may be subject to the experience and access of the IPP. The procurement process for the installation of Solar PV is often based on highest energy delivered per annum versus cost with performance clauses included in the supply contract.

2.2 WIND ENERGY TECHNOLOGY

The community of LHI has been consulted about the potential for the development of renewable energy and has produced the "Community Guiding" document.

In this document, it expresses interest in vertical axis wind turbines and multiple smaller wind turbines (of the sizes from 50kW to 100kW) rather than larger wind turbines. Powercorp has researched the available offerings, taking into account the remoteness of the island (requiring highly reliable or locally repairable equipment), the commercial nature[8] of the wind turbine procurement and the options for construction (both space for installation and the equipment available to install the wind turbines). From this search we recommend the use of the Vergnet MP Wind turbine for several reasons:

1. The Vergnet has been proven to work on remote area power systems in Australia[9]
2. The machines tilt-up and tilt-down nature allows for simple cost effective initial installation and follow-up maintenance
3. The "uncomplicated" nature of the wind turbines allows the day-to-day maintenance to be undertaken by a fitter or mechanic with training on the machines. Vergnet are able to offer this training either in Australia or France.
4. The local agent is based in Newcastle and is able to arrange for specialised mechanics to be dispatched for major maintenance intervals as well as Australian based phone support

It is noted that LHIB have requested the inclusion of some "wind capable" inverters in the authorised inverter connection list in order to allow private customers to install small wind turbines on their own premises. There is no expectation at this point to limit the choice of privately installable wind turbines to any particular type, however there will be size restrictions, both by physical height and power output.

As with other inverter connected devices, LHIB may require a 3-phase inverter with larger privately installed wind turbines. Although further modelling and investigation of the network will need to be performed to determine this level, it can be assumed the maximum single phase wind turbine will be less than 5kW.

Wind turbine technology is defined, broadly, by the following aspects:

- *Number of blades*: 2, 3

---

[8] The commercial nature of the procurement refers to the concept that the wind turbine will represent a capital investment in the power system. If the wind turbine is non-functional for what-ever reason, then not only does it not make a return on the investment during the period, but it is likely that an increase in diesel consumption will also occur, costing further money.

[9] Verve Energy, Coral Bay, Western Australia

- *Axis*: Horizontal, vertical (uncommon)
- *Rotor Position:* Up/Down wind - describing wether the turbine faces into the wind or away
- *Tower* : Tubular steel, concrete, latticed, guyed etc
- *Generator:* Affects the power, power quality and stability of the machine e.g. synchronous/asynchronous machines, geared/direct drive, direct/in-direct grid connection etc
- *Stall or Pitch regulated:* Controls the lift component on the blades.

2.2.1 HORIZONTAL AXIS WIND TURBINE

Figure 7: Vergnet MP 275kW wind turbines[10]

Figure 8 - WES18 (Lagerwey 18/80) Wind turbine

2.2.1.1 VERGNET MP 275KW WIND TURBINE

One of the few wind turbines suited to minimal construction requirements is a Vergnet wind turbine. Vergnet produces two turbines (275kW and 1MW models) which may be lowered in the event of severe weather, including tropical cyclones. The process of lowering is built in to the wind turbine installation and thus does not require a crane. This significantly reduces the maintenance costs, as the machine can be lowered to the ground making the maintenance much simpler and faster. The Vergnet turbine is a two-bladed, pitch regulated, down-wind machine mounted on a guyed tower with an articulated base. The generator is a two-speed, asynchronous machine.

The Vergnet machines are available on the market and provided certain conditions are met, it is likely that Vergnet would support an installation in this region. It is noted that some

---

[10] Vergnet http://www.vergnet.fr/index.php?option=com_content&task=blogcategory&id=27&Itemid=30 (acc. April 2010)

wind turbine manufacturers are loath to support installations in remote areas due to the high costs of maintenance. This must be negotiated with the wind turbine manufacturer before purchasing a wind turbine.

Powercorp notes that the Coral Bay power station (Western Australia) utilises three Vergnet MP 275kW wind turbines. This location provides an ideal place for members of the community or board to observe the wind turbines in operation and evaluate the potential environmental effects, including noise.

The Vergnet MP 275kW has a maximum rotation speed of 46RPM at maximum output and 31RPM at cut-in wind speed.

2.2.1.2 WES18 WIND TURBINE

The WES18 wind turbine suggested by the community for consideration is a version of the Lagerwey 18/80 wind turbine. The unit has been upgraded with synchronous generators and an inverter front end.

The unit has a rotational speed of 120RPM at maximum output and a minimum of 50RPM at cut-in wind speed.

A brief investigation into the unit has illustrated that there is no identified dealer or service agents for the devices in Australia, which may be problematic.

2.2.2 VERTICAL AXIS WIND TURBINES

The vertical axis wind turbine has a number of advantages over a horizontal axis wind turbine:

1. Maintenance of the generator can be easy by mounting at ground level
2. The VAWT appears to birds to be more of a “solid object” than a HAWT, leading to fewer bird strike issues
3. The lower linear speed of the blades on the turbine lead to a more quite machine

The vertical axis wind turbine (VAWT) has not been as popular as the horizontal axis wind turbine for a number of reasons:

1. Scaling of the VAWT up to larger sizes (such as 50kW – 100kW) has been problematic
2. Numerous installations have failed to reach the advertised economics, due to:
    a. Mechanical bearing failures
    b. Civil and structural failures
    c. Overstated wind yields
    d. Issues with mechanical pulsing due to rotor designs
    e. Issues with some designs starting from stand-still

For these reasons, Powercorp advises the LHIB to use horizontal axis wind turbines as the primary source of wind energy for the time being.

Figure 9 - Urban Green Energy 4kW VAWT[11]

2.3 WAVE ENERGY

Two types of basic technology have been developed to date:

1. Floating buoy
2. Oscillating Water Column

At this time, wave energy generators are considered to still be the development phase. We suggest that the technology is reconsidered once it has reached commercial maturity.

2.3.1 FLOATING BUOY

A buoy is connected to a generator which is fixed to the sea floor. The movement of the buoy up and down following the wave motion causes the generator to spin.

---

[11] http://peswiki.com/index.php/Directory:Urban_Green_Energy

The development of these systems has not yet reached commercial production.

2.3.2 OSCILLATING WATER COLUMN

An oscillating water column uses a specially designed air-turbine to capture the energy from wave motion.

One type of machine developed for this application is a Wells turbine which is similar to a steam or gas turbine, however the blades attached to the rotor are hinged in such a way that air flowing past in either direction causes the blades to alter angle and forces the turbine rotor to spin in one direction regardless of the direction of air flow.

A Wells turbine is attached to a wave chamber that is submerged near the shore line. The wave action moving forward and backwards near the opening of the chamber forces the column of trapped air in the duct backwards and forwards through the Wells turbine. This in turn creates pulses of renewable energy.

The technology requires further research, with a significant number of test installations in Europe suffering from catastrophic failures when the entire machine has been dislodged from its footings due to higher than expected wave action.

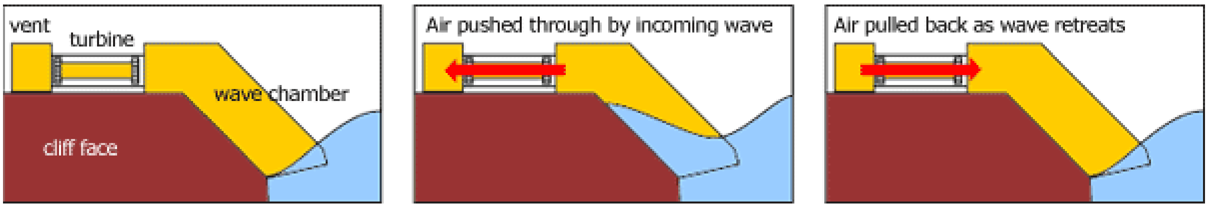


Figure 10: Operation of an Oscillating Water Column generator (http://www.fujitaresearch.com)

3 ENERGY MANAGEMENT

The goal of this section is to provide an overview of energy management technologies for the Lord Howe Island power system including:

1. Energy storage
2. Grid stability
3. Energy abatement and recovery

The three categories are defined as follows:

1. Energy Storage refers to the bulk storage of energy for periods of hours, in essence shifting load from one part of a day to another. Typically these systems have discharge and recharge times rated in hours.
2. Grid Stability refers to storing smaller amounts of energy that are available at high power levels to respond to changes in the frequency or other parameters on the network in order to stabilise the network – typically due to fault conditions or intermittency in supply from renewable energy generators. Typically these systems have discharge and recharge times rated in seconds.
3. Energy abatement and recovery systems generally store energy in forms other than electricity and can also collect energy from sources other than electricity. For example, collecting waste heat from the diesel generators and transforming it using absorption chillers not only uses energy that was discarded to transform it into a useful form, but this energy can then be piped around the community to reduce the electrical energy consumption by performing air-conditioning duties rather than performing the same task with electrically powered refrigeration.

Table 1 shows an overview of the energy storage technologies available, classifying each into those that are suitable for long-term energy storage and grid stability.

Table 1: Technologies offering energy storage or grid stability

Technologies	Grid Stability	Energy Storage
Battery - Lead Acid types		✔
Battery - Flow type batteries	✓	✔
Flywheel	✔	✓
Pumped Hydro		✔

Technologies	Grid Stability	Energy Storage
Super-capacitors	✓	
Thermal Storage[12]		✓

In the case of this exercise, due to the complexity of operating and maintaining steam systems, thermal storage will not include steam loop systems or other systems operating above the boiling point of water, or with energy being directly transformed back into electricity.

3.1 ENERGY STORAGE

Energy storage systems can add high value to an electricity system. Due to the time-variable nature of renewable energies, storage technologies can be used to balance the energy availability and stabilize the grid. In times of low demand and high input from of a renewable energy source, the storage can be charged. During periods of high demand and low input from the renewable energy source, the energy storage provides energy to the grid. Thus fuel, emissions and finally prices can be balanced. Furthermore, some electrical energy storage technologies may be used to provide reactive power, voltage and frequency control and emergency power during a power outage.

The most important energy storage systems involve chemical (e.g. batteries), mechanical (e.g. flywheels, pumped hydro), thermal or electrical (e.g. super capacitors) storage.

Over recent years, many different battery technologies have entered the market. The most common type is the category of improved lead-acid batteries. With increasing attractiveness of energy storage in grid applications, flow batteries, flywheels and super-capacitors have an increasing market presence as well as other exotic emerging technologies.

As the natural environment at Lord Howe Island does not provide the possibilities for installing pumped hydro or compressed air storage plants, this report focuses on batteries, super capacitors and flywheels. Thermal energy storage is not considered given the unsuitability of this technology to small-scaled grids.

Note: At this stage the most suitable energy storage technologies for this system is likely to be either Lead-Acid, Zinc-Bromine Batteries or flywheel technologies, depending upon modelling outputs using more detailed information. These technologies are commercially available, mature and suited to remote area applications.

3.1.1 LEAD ACID BATTERIES

The most common form of electro-chemical energy storage is through a lead-acid accumulator. The science of the lead-acid battery is well known and the battery manufacturers are capable of accurately predicting the life-span of a battery bank given an expected usage pattern.

---

[12] Not including thermal systems above the boiling point of water.

In the family of lead acid batteries, the two most commonly used types are:

1. Flooded – is the same construction as the average car battery, with a liquid electrolyte. This requires frequent maintenance to ensure that the electrolyte does not boil off during recharging events and damage the cell.
2. VRLA – valve regulated lead-acid, commonly called a “gel cell” do not require as much maintenance as a conventional battery due to the lack of a liquid electrolyte. This feature can also restrict the ultimate current which the stack of cells can provide.

Current generation Lead Acid batteries are capable of being used in frequency regulation; however this kind of constant cycling can adversely affect the life-span of the batteries, especially in wind/diesel applications.

Current generation lead-acid batteries are able to achieve a round-trip efficiency in excess of 70%.

3.1.2 LITHIUM ION BATTERIES

Lithium Ion batteries have been popularised in small portable devices, such as laptops and mobile phones, for their relatively high energy density.

They require significant intelligence in the charging algorithms to prevent over-charging and the associated release of energy due to pack failure, in the form of fires. In addition discharges must be controlled in order to not over-heat the battery packs.

At this stage, no modelling with Lithium Ion batteries has been performed for the LHI energy supply road-map.

3.1.3 NICKEL CADMIUM BATTERIES

Nickel Cadmium batteries are available for large energy storage systems, but tend to have higher capital costs than Lead Acid batteries. In return, they have lower maintenance costs.

The Nickel Cadmium batteries also contain cadmium, which may not be compatible with the World Heritage status of LHI.

The largest industrial Nickel Cadmium battery system exists in Fairbanks, Alaska, where it is able to provide 27MW for up to 15 minutes while backup power systems are brought on-line in the event of an electricity transmission line failure from Anchorage.

3.1.4 ZINC BROMINE BATTERIES

The main advantage of the Zinc Bromine batteries is life-span. It is significantly better than the lead-acid and Zinc Bromine batteries are able to survive even regular “flattening” and still deliver a 15 year life span in the modelling.

Current generation ZB Batteries show quite slow response times (in the order of seconds) to fluctuations in power. As a result they are not suitable for frequency regulation in RAPS.

Current generation Zinc-Bromine Batteries are capable of round-trip efficiencies of 80%.

3.1.5 SODIUM SULPHUR (NAS) BATTERIES

Sodium sulphur (NaS) are constructed from molten metal. Its characteristics show very few self discharging processes and good efficiency (about 75%). The operating temperature is close to 300°C and production costs are relatively high.

At the moment, the Sodium Sulphur battery is only being supplied by one manufacturer in the world (NGK), discouraging its use at LHI.

Figure 11: NaS battery module[13]

3.2 GRID STABILITY

The topic of grid stability is essential in almost any system attempting to utilise intermittent renewable energy sources capable of producing more than 15% of the annual energy consumption of the site. At Lord Howe Island this is approximately 550kWh annually, or more than 200kW of installed PV solar capacity. Note that this does not mean that the solar installation does not need control, as in the event of extremely low consumer demand or the failure of one or more feeders the system will require the output of the solar generator to be reduced to prevent a reverse power fault on the generators. In the case of Lord Howe Island, any installed Solar PV over 100kW will require control in order to not compromise the power quality of the power system.

Modelling of the stability requirements for the Lord Howe Island project is outside of the scope of this report, however it is an important consideration and the installation of a combined 400kW PV Solar array will certainly require some kind of stabilisation. This can be provided either by additional devices such as a Super Capacitor buffer or flywheel.

Figure 12: Flywheel Energy Storage

3.2.1 FLYWHEELS

In contrast to batteries, flywheels are a mechanical energy storage device. By spinning a mass, a high amount of energy can be stored dependent on the weight of the mass and the spinning speed. Today’s most common flywheel is made of steel with magnetic bearings in order to reduce friction which causes losses. Ether filled with helium or evacuated, losses are at about 5%-15%. An

---

[13] NGK- http://www.ngk.co.jp/english/products/power/nas/principle/index.html (acc. May 2010)

alternator is directly connected to the axis of the flywheel to change the speed of the flywheel by charging and discharging. More exotic flywheel spin at speeds exceeding 30,000rpm and are constructed from composite materials.

3.2.2 SUPER CAPACITORS

Super Capacitors are also known as Electric Double Layer Capacitors (EDLC), can also be used like flywheels for short term energy storage. They can provide very quick responses to load steps but currents are limited because of the heat they create on the electrodes. Compared to batteries the cycle life is quite long, however it is not infinite.

3.3 ENERGY ABATEMENT AND RECOVERY

Energy storage provides one option for utilising additional renewable energy, for the times when there is more renewable energy than consumer demand. Energy storage is not cost free – not only the capital costs of purchasing, installing and maintaining the equipment, but also there is a “round-trip efficiency” – the amount of energy that is recoverable from the energy storage device, compared to the amount of energy place in the device. In the case of batteries, this can be as low as 70%, meaning that stored energy can have an additional 30% cost to get it back.

An energy efficient option is to be able to schedule special types of load, such that when excess renewable energy is available these loads can be told to run. The product of their operation is often consumed at a later time, implying that some kind of “energy storage” is still involved – just in a different form that was going to be performed during normal operation.

An example is desalinating sea-water using a reverse osmosis process. The output of the process is potable water that is generally stored in a tank. The reverse osmosis process is interruptible[14] and can be run or stopped with little notice. The concept of changing the control of the desalinator would be as follows:

1. When excess renewable power is available, run the desalinators until the potable water storage tanks are as full as possible (i.e. 99%) and then run them once the water drops as small an amount as possible (i.e. 95%)
2. When excess renewable power is not available, only run the desalinators when the tank is virtually empty (5%) and even then fill them up only the minimum amount that is possible (i.e. 15%)

---

[14] There are physical and economic limitations as to “how” interruptible this process is, which can be easily dealt with using some intelligent process control programming.

A scheme like this will work fine with existing systems, however further advantage can be gained by monitoring the operation of the system and re-sizing the tank. For example, increasing the tank capacity will allow the system to run for longer between periods of excess renewable energy without using diesel fuel to refill.

Other similar processes include:

1. Bore water pumping
2. Cool-room refrigeration
3. Air-conditioning
4. EV charging

As Powercorp is recommending the trial of both demand controlled EV charging and demand controlled air-conditioning, a demand control system, installed in the premises with the facilities will be required. This “smart metering” cost will be met by the consumer. It should also be noted that if these trials are eventually approved, they will be “controlled” and performed in steps, starting (potentially) from just a few installations.

In addition to smart demand management, energy consumption abatement is also an efficient solution to reducing diesel fuel consumption. As LHI has already put in place energy efficient lighting and home insulation programs, many of the measures have already been performed. We briefly cover a few remaining options.

3.3.1 SOLAR AIR-CONDITIONING

Current solar thermal air-conditioning technologies are broken down into two separate groups:

1. Absorption chilling – using the hot water collected from a solar thermal installation to drive a ammonia (or similar) absorption chilling system
2. Adsorption system – using a desiccant wheel to absorb moisture from the intake air to a ventilation system and then using the heat from a solar thermal installation to expel the moisture from the desiccant

The solar absorption system has been utilised in many locations, however it faces some issues, mainly to do with the quality of available water, the quality of the heat available and issues to do with the removal of energy from the separated working fluids before re-absorption

A new solar adsorpotion system is currently under development and commercialisation by the CSIRO in Newcastle.

3.3.2 WASTE HEAT ABSORPTION CHILLING

One of the options for a significant reduction of the potential peak demand of the electrical system due to refrigerative air-conditioning is to use the combined concepts of a water loop between the power station and nearby buildings and a chilling system powered by waste heat from the generators.

As the effectiveness of these loops is largely based on the economics of pipe construction and the fact that the amount of heat is significantly reduced due to renewable energy generation it is not recommended to pursue this concept further for LHI.

3.3.3 THERMAL WATER LOOPS

Thermal water loops are an excellent way of storing thermal energy that can either not be utilised at the place in which it is generated, or not at the time it is generated.

Both heated water and chilled water are pumped around areas as large as a whole town in various locations and Powercorp has experience from the automation and wind integration project at the Antarctic base of Mawson. There heating loops and "opportunistic" heating of the loop by means of heat recovery from the diesel generators and electrical excess wind energy when the wind is blowing.

The lower cost of recovered heat cooling may also make a community "cold store" more economically feasible.

It is noted that LHI is currently using SolarHart solar hot water heaters with centrally-controlled off-peak electric hot water boosters, which also fit into this same category, as excess renewable energy can be "opportunistically" fed into these systems throughout over the 24 hour period. As it is expected that the electric booster thermostat is set to a lower temperature than the solar collectors are capable of heating during sunny days, the electrical and renewable energy consumption of the hot water systems will be less in summer than in winter, retaining the advantage of the solar collection.

As the effectiveness of these loops is largely based on the economics of pipe construction and the fact that the amount of heat is significantly reduced due to renewable energy generation it is not recommended to pursue this concept further for LHI.

3.3.4 ELECTRIC VEHICLES

The LHIB has identified that one significant consumer of diesel fuel apart from power generation on the island is personal transportation in the form of cars. These "devices" can potentially allow the power system some significant options in providing energy over the evening.

1. Excess renewable energy can be supplied to charge the electric vehicles over the evening (assuming most vehicles are "plugged in" at night) and a special tariff attached to this type of charging
2. Some kind of "safety feature" will be required to guarantee the owner a minimum level of charge for each night – this will require some "smart grid" features to be able to measure the power begin consumed by the vehicle
3. As the technology matures, it is envisaged that electric vehicles will be fitted with "controllable charging" that would allow the smart meters in the home to ask the vehicle to charge at a slower rate, rather than stopping the charging, in order to be able to more evenly apply excess renewable energy across more electric vehicles

It is noted at this early stage that there are many options for how the electrical vehicles can be charged to take the best advantage of the renewable energy that is available. In addition, depending on the battery technology, there may be different optimal schemes for charging (such as set value continuous charging until full, versus variable power charging). It is expected, as each vehicle is expected to have a relatively low individual charging power demand, that it will be possible to schedule the charging of each vehicle separately, as the power system is only concerned with the over-all accumulated power of all of the vehicles. Air Conditioners

Although Air Conditioners are not allowed on the island, they do offer the option to shift electrical load if and when excess renewable energy is available.

Uncontrolled installation of air-conditioning has presented large problems to the Australian NEM, with the peak power demands causing havoc on hot summer days in both Victoria and South Australia over previous years.

A well maintained air-conditioner in a suitable building with a sensible temperature set-point poses little problem to the energy consumption of the power system, running for as little as 10% of the time to maintain the temperature in an appropriate space. The major problems of running air-conditioners is that as the ambient temperature rises, more of the units will attempt to run at the same time, causing an overload of the power system.

Powercorp is proposing to trial the installation of air-conditioners with a smart-grid control system that will allow the power system to dispatch the air-conditioners to consume up to the maximum available excess renewable energy. This excess renewable energy is energy that would otherwise not be used (that is, the wind turbines would be instructed to pitch their blades to catch less of the wind and the Solar PV installations would be instructed to reduce the current provided by the inverters) and is normally lost, reducing the value of the renewable energy generation. In this case it can be diverted for use with the air-conditioners by identifying when this excess renewable energy is available[15]. In the event of a sudden power output reduction from the renewable energy generation, the air-conditioners will be instructed to immediately disconnect allowing the thermal power station to run without holding spinning reserve, thus not increasing the fuel consumption of the power station. Further modelling of a communications system will be required, however it is expected that the majority of the air-conditioners will be able to be stopped in under a 1 second.

As there is a correlation between high Solar PV output and high demand for air-conditioning, with a considerable installation of Solar PV, it is envisaged that the air-conditioning load would be able to be fed nearly entirely from renewable energy, especially if energy storage is available.

It should also be noted that if the power system is in distress (for some reason requiring the use of the backup diesel generator) then the power system would disable all air-conditioning, enabling using the same sized diesel emergency backup engine as is currently installed.

It is noted that using a power station controlled regime for air-conditioning may reduce the occupant comfort to some degree during certain periods. This would need to be evaluated by a trial installation to ensure that the resulting performance of the air-conditioners is acceptable.

---

[15] The identification includes statistical calculations, such as determining the likely 5 minute average renewable generation output to attempt to make sure that an air-conditioner, once turned on is likely to run for a minimum period of time (such as 5 minutes) before having to be turned off again.

3.3.5 TIME-OF-USE TARIFF

With the installation of smart-grid infrastructure, it would be possible for LHIB to begin charging on a variable tariff, depending on the time or day, or how much renewable energy was available at the time.

This can be implemented in a number of different ways, to allow the community of LHI to reduce their energy costs and provide energy management benefits and peak demand reduction benefits to the LHIDS:

1. The installation of “smart circuits” in the home – such as for the solar hot water boosters. These circuits are only energised when there is excess wind energy available. Other appliances that could be controlled in this manner include:
    a. Swimming pools
    b. Electric vehicle charging (addressed in the previous section)
2. The installation of “smart power sockets” in the home. These sockets may have an additional switch that allows the socket to automatically determine when power should be supplied, for example:
    a. When excess renewable power is available (due to signals from the power system)
    b. At certain pre-determined times of the day (such as from 10PM to 4AM)
    c. All of the time (most expensive)
3. The installation of smart tariff meters. These are capable of accumulating power consumption to the various tariffs across the day automatically.

The first two options provide the consumer with automatic controls over how much the user pays for energy. The smart power socket empowers the consumer such that if the device really needs to be run, then they can change the setting or plug the device into a conventional socket – making it obvious that the use of this device will cost more than usual.

These two features empower the consumer to be able to save money on their electrical energy bills whilst assisting the LHIDS in controlling the required investment in expanding the power network.

Time-of-use tariff metering has come under fire in places where they have been installed, mostly as consumers have not fully understood the implications of their use. This can potentially be due to a number of causes, including:

1. Overly enthusiastic energy retailer salespeople, over emphasising the potential savings whilst not demonstrating the potential increase in energy costs if changes were not made to the energy consumption patterns of the consumer
2. Customers mis-understanding the requirements of them to change their energy consumption habits in order to maintain their pre-TOU tariff energy costs

    LHIB must of course keep in mind that any tariff that reduces the rate paid by consumers will lead to a reduction in revenue to the LHIB. The combinations of cost of generation must be considered when planning a tariff structure.

4 ENERGY FLOW MODELLING

The energy flow modelling for LHI has been performed using HOMER as the modelling tool.

4.1 METHOD

Using various tools (where necessary), the supplied data from LHIB was imported into HOMER and several test cases were developed. The results have been compiled into this document.

4.1.1 INPUT DOCUMENTS AND INFORMATION

This chapter lists all of the information, such as documents and simulation-files that were used to create the model this report is based on.

1. LHI Power Consumer Demand, including:
    a. Average domestic consumer consumption for 2010, supplied as "Consumption Summary Export 01-07-2010.xls"
    b. Consumer load profiles from 2010[16], supplied as a series of "[MONTH]10_Sum.CSV" files. The data set was also down-sampled from the supplied 1 minute samples to 10 minute averages
2. Wind data from the 2002 Wind Turbine Supply Tender
    a. Specifically wind data from the year 2000 was used.
3. Existing station fuel consumption for the year 2010, supplied as "Monthly Generation, Fuel and Maximum Demand.doc"
4. Existing power station specifications, including:
    a. Engine specifications
    b. Engine hours
    c. Existing demand management system (hot water system), estimations of energy storage potential and expected maximum demands

The case studies selected to run with load growth to include the following additional load demand:

1. Electric Vehicles and charging stations (Up to 50 vehicles)
2. Air-conditioning (Up to the equivalent of 450x 1kW AC units)

Note that these installations are hypothetical, designed to show their potential usefulness using modelling that has significant intrinsic assumptions. If the board deems that these are allowed on the Lord Howe Island power system, restrictions on use will be applied by an automated means, such as a Time-Of-Use tariff or a specific electrical socket in the home that is activated when excess

---

[16] "Gaps" in the data from 2010 have been patched using an amalgamation of load data from 2009, 2008, 2007 and 2006.

energy is available. In addition to this, there will be a limited trial phase to determine the accuracy of the modelling, prior to any discussion about further roll outs. This additional load represents an energy consumption increase of 7.3% of current consumption.

It should be noted that the escalation of 3% per year equates to increasing the energy consumption of the island by 75% over 20 years which may not be realistic at this point in time.

For the energy flow modelling, no escalation in load was used. The escalations in load were only used in the NPV and final road-map construction. The final road-map construction used a total energy consumption escalation of 7.3% over 20 years.

It is noted that any smart-grid controllers installed at customers locations will be paid for by the customer, although LHIB will retain full control rights of the equipment.

An existing grant application for the purchase of 200kW of Zinc Bromine Batteries energy storage is expected to be returned shortly, with the installation of the batteries expected late 2012 or early 2013 if the application is successful. Details of this energy storage device are included later in this document.

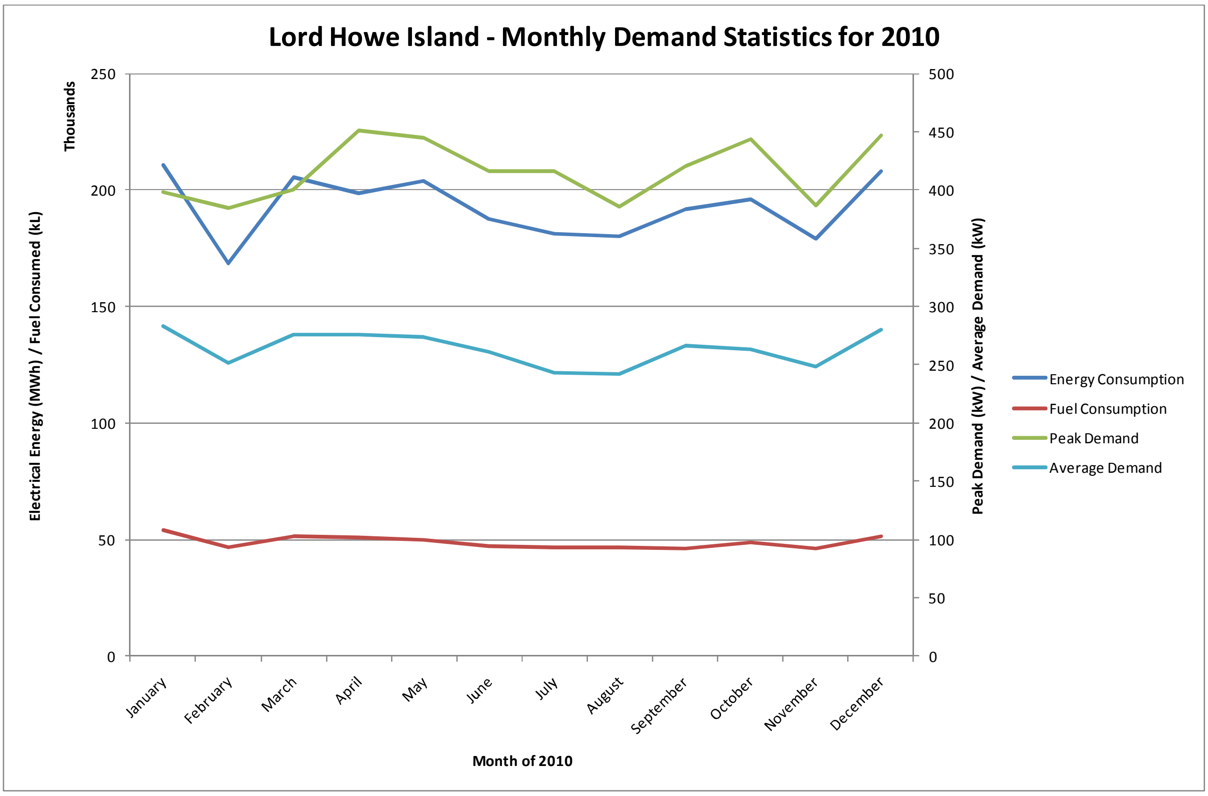


Figure 13 - Load Statistics for 2010 Demand Data

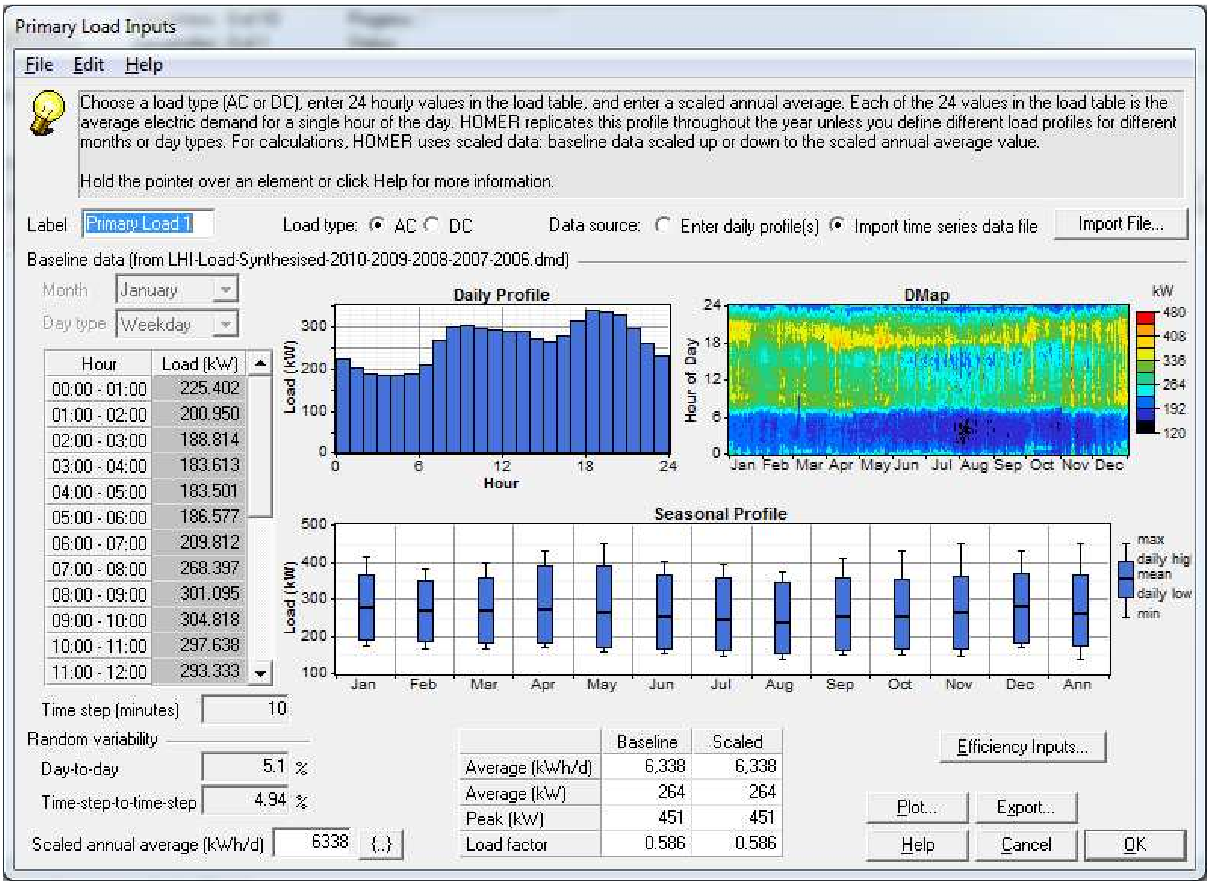
Impact of load growth

The potential demand growth for energy on the LHI distribution system are threefold:

1. Required increase of base-load generation (specifically the purchase of a fourth Detroit Diesel Series 60 300kW generator) to ensure that the power system can still reliably deliver power with one diesel generator unavailable

2. Required replacement of the existing 425kW backup generator to ensure the one machine can cope with the increase in demand in an emergency situation
3. The replacement of some distribution assets that will not be able to cope with the increase in demand, including:
    a. Power cabling
    b. Transformers
    c. Switchgear

As the proposed load growth is limited to controlled assets (specifically EV's and air-conditioning) it may be unnecessary to increase the size of the generators in the near future. Any increase in load will be controlled such that the generation assets available will not be overloaded and the available excess renewable energy will be distributed between the devices.



Choose a load type (AC or DC), enter 24 hourly values in the load table, and enter a scaled annual average. Each of the 24 values in the load table is the average electric demand for a single hour of the day. HOMER replicates this profile throughout the year unless you define different load profiles for different months or day types. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value.

Hold the pointer over an element or click Help for more information.

Label: Primary Load 1
Load type: ● AC ○ DC
Data source: ○ Enter daily profile(s) ● Import time series data file

Baseline data (from LHI-Load-Synthesised-2010-2009-2008-2007-2006.dmd)

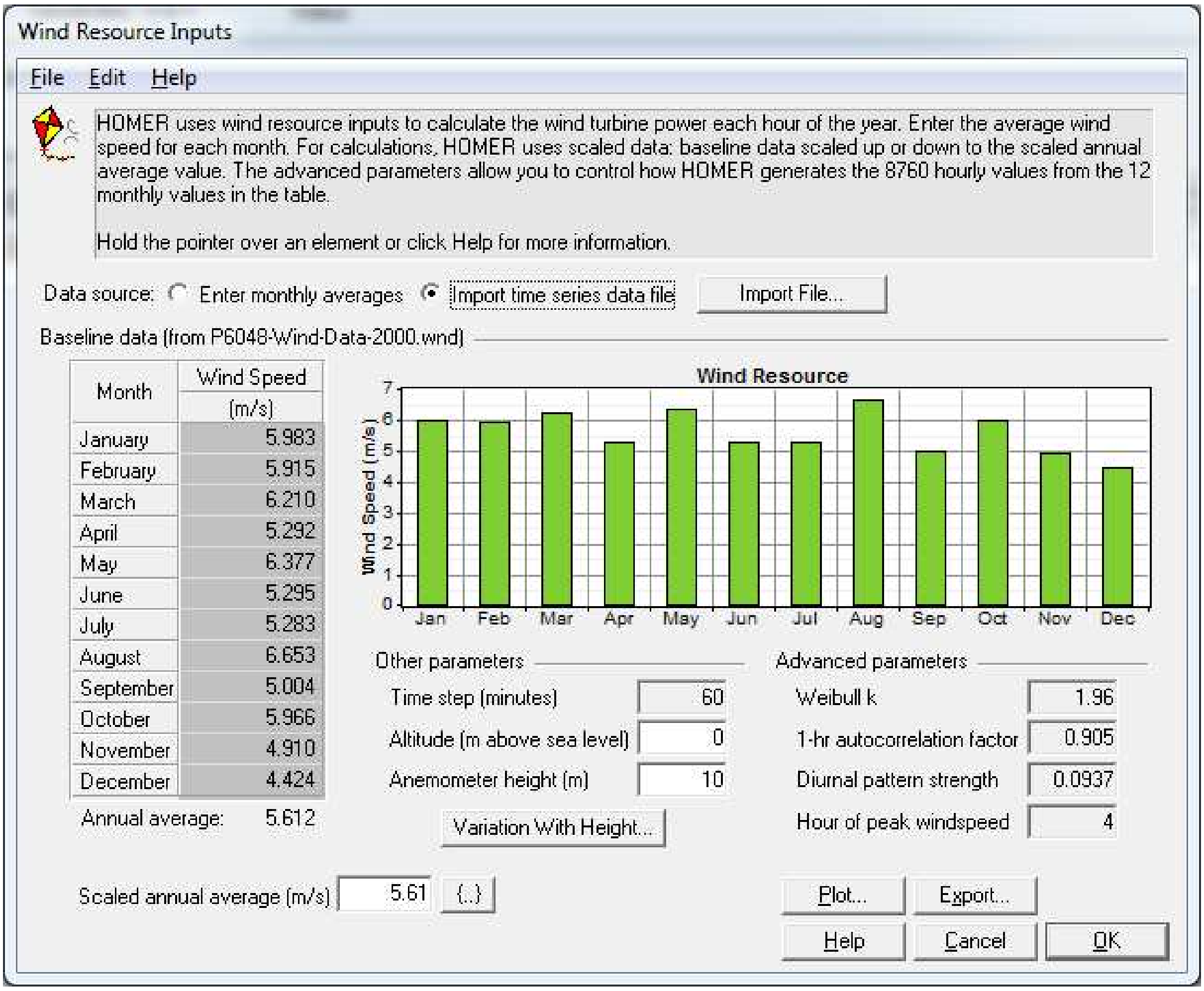
Month: January
Day type: Weekday

Hour	Load (kW)
00:00 - 01:00	225.402
01:00 - 02:00	200.950
02:00 - 03:00	188.814
03:00 - 04:00	183.613
04:00 - 05:00	183.501
05:00 - 06:00	186.577
06:00 - 07:00	209.812
07:00 - 08:00	268.397
08:00 - 09:00	301.095
09:00 - 10:00	304.818
10:00 - 11:00	297.638
11:00 - 12:00	293.333

Time step (minutes): 10
Random variability
Day-to-day: 5.1 %
Time-step-to-time-step: 4.94 %
Scaled annual average (kWh/d): 6338

	Baseline	Scaled
Average (kWh/d)	6,338	6,338
Average (kW)	264	264
Peak (kW)	451	451
Load factor	0.586	0.586

Figure 14 - Demand profile as input into HOMER



HOMER uses wind resource inputs to calculate the wind turbine power each hour of the year. Enter the average wind speed for each month. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value. The advanced parameters allow you to control how HOMER generates the 8760 hourly values from the 12 monthly values in the table.

Hold the pointer over an element or click Help for more information.

Data source: ○ Enter monthly averages ● Import time series data file [Import File...]

Baseline data (from P6048-Wind-Data-2000.wnd)

Month	Wind Speed (m/s)
January	5.983
February	5.915
March	6.210
April	5.292
May	6.377
June	5.295
July	5.283
August	6.653
September	5.004
October	5.966
November	4.910
December	4.424
Annual average:	5.612

Other parameters

Time step (minutes)	60
Altitude (m above sea level)	0
Anemometer height (m)	10

[Variation With Height...]

Advanced parameters

Weibull k	1.96
1-hr autocorrelation factor	0.905
Diurnal pattern strength	0.0937
Hour of peak windspeed	4

Scaled annual average (m/s) 5.61 {..}

Figure 15 - Wind profile as imported into HOMER

4.1.1.1 ELECTRIC HOT WATER SYSTEMS

The LHIDS uses ripple-control to activate electric hot water boosters attached to the Solar Hart solar hot water services around the island at times of lower electrical demand. This has been simulated by using HOMER’s “Deferred Load” feature. This particular feature defines the following things:

1. How much energy is served to these devices every day (adjustable per month) in kWh
2. How much energy these devices can store over the day in kWh
3. The maximum amount of power that these devices can consume in kW
4. The minimum amount of power that these devices can consume in % of maximum power

From the information supplied by LHIB, the following parameters have been estimated:

1. There are 164 controlled electric hot water services on the LHIDS
2. At an average power of 2.4kW, this relates to a maximum uncontrolled demand of 393kW
3. Each electric hot water service is run for twice a day in winter for a total of 2 – 3 hours, leading to an equivalent energy storage of 1,025kWh

4. Each electric hot water service is run for less than an hour during the summer, with an estimated electrical hot water energy consumption of 205kWh/day
5. Each electric hot water service is run for between 2 and 3 hours per day in winter, with an estimated electrical hot water energy consumption of 1,025kWh
6. The minimum electric hot water services on-line is 1 unit, or 0.6%[17]

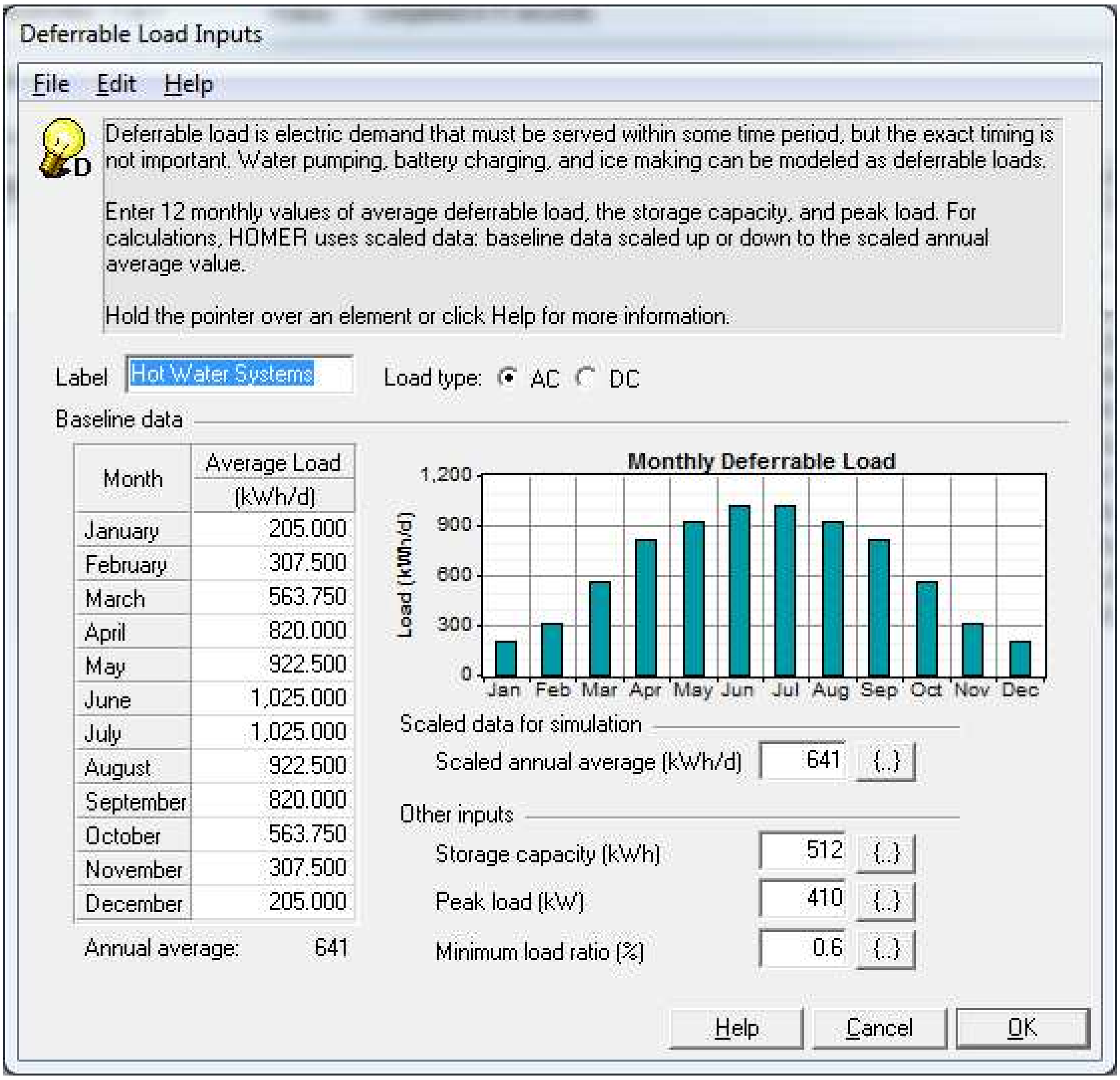
The amount of demand in each month has been modulated between the estimated summer and winter consumptions.

It is noted that the reduction of electrical hot water demand in summer is partially due to less loss from the storage tank, cooler showers and much more solar energy being collected.

The configuration of HOMER to model the electric hot water services is as follows.

---

[17] The minimum unit on is set to 1 unit due to the HWS characteristic of uncontrollably turning themselves off once they have achieved their maximum temperature set-point. Although HOMER will allow any amount of power between this number and 100%, depending on the available excess energy, it is understood that the actual system has a number of ripple-control frequencies that impose a minimum number of HWS per frequency.



Deferrable load is electric demand that must be served within some time period, but the exact timing is not important. Water pumping, battery charging, and ice making can be modeled as deferrable loads.

Enter 12 monthly values of average deferrable load, the storage capacity, and peak load. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value.

Hold the pointer over an element or click Help for more information.

Label: Hot Water Systems

Load type: ● AC ○ DC

Baseline data

Month	Average Load (kWh/d)
January	205.000
February	307.500
March	563.750
April	820.000
May	922.500
June	1,025.000
July	1,025.000
August	922.500
September	820.000
October	563.750
November	307.500
December	205.000

Annual average: 641

Scaled data for simulation

Scaled annual average (kWh/d): 641

Other inputs

Storage capacity (kWh): 512

Peak load (kW): 410

Minimum load ratio (%): 0.6

Figure 16 - Ripple-Control Hot Water Services as modelled in HOMER

4.1.1.2 ASSUMPTIONS ON INSTALLATION OF EQUIPMENT

The following upgrades have been assumed to be happening:

1. The installation of 100kW of private Solar PV during/by the year 2012
2. The installation of 100kW of private Solar PV by then end of year 2013

It is also assumed that the installation of the wind farm cannot be completed before 2014, after the 12 months detailed wind study and a minimum of 12 months to design and build the wind farm.

It is also noted that no load growth is expected until after 2014 when excess renewable energy is available.

The ZBB energy storage device by way of example has been included in some of the modelling to demonstrate the difference that it can make.

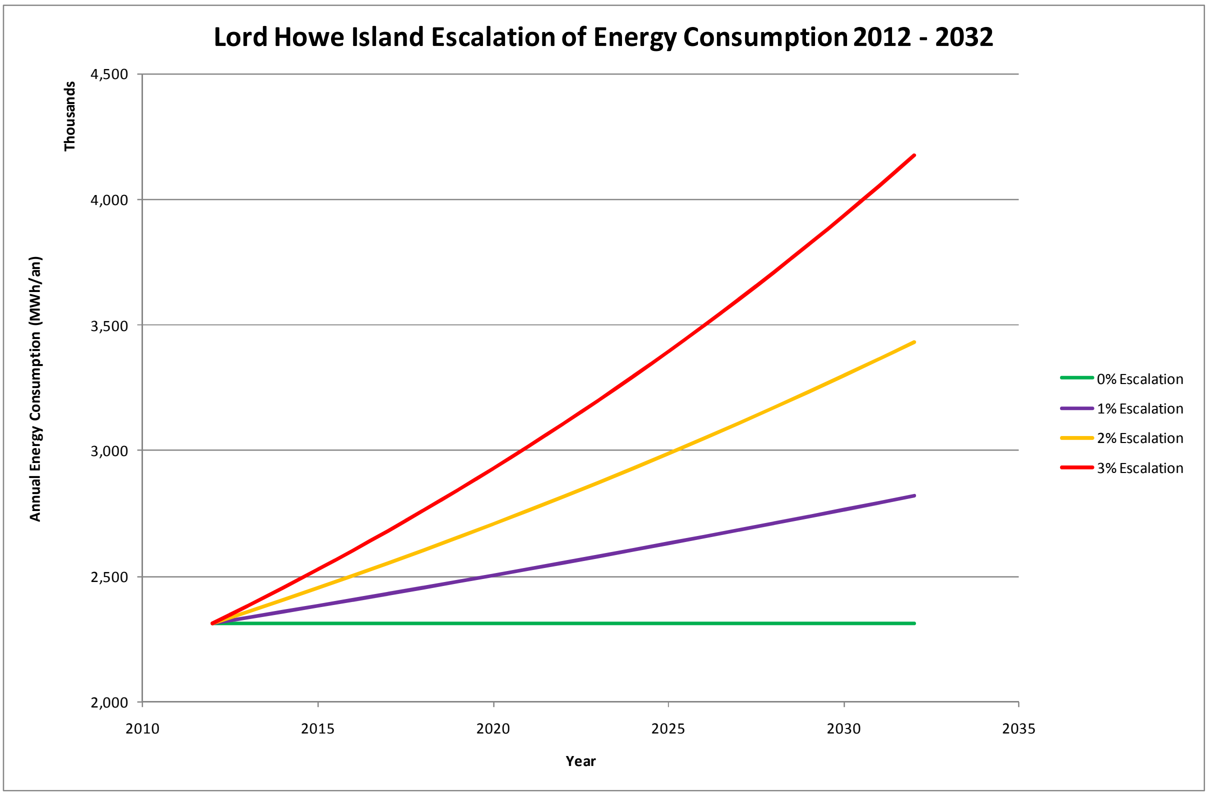


Figure 17 - Escalated Energy Consumption for Lord Howe Island

4.1.1.3 POWER STATION INFORMATION

The Power Station consists of:

1. 3x 300kW Detroit Series 60 diesel generators
2. 1x 425kW Perkins/FG Wilson/Caterpillar backup diesel generator
3. Generator controls are Woodward EGCP-2
4. Central SCADA platform is based on CITECT
5. A central PLC controls the feeders, load shedding as required
6. A PLC (power line carrier) communications system to activate electric hot water boosters as required

It is noted that there is not any form of communication to the remote sub-stations/transformers located around the island.

4.1.2 PROCESS APPLIED

Powercorp have utilised the HOMER energy flow modelling programme to model the amount of energy supplied by the proposed renewable generation.

Each of the following case studies have been modelled with the required load growths as sensitivities in the modelling.

4.1.3 OUTPUT ITEMS

The following information is available from the HOMER modelling:

1. Energy values for each of the year-groups, including:
    a. Solar PV consumed per year
    b. Wind energy consumed per year
    c. Energy flow in and out of the energy storage system, including losses
2. Capital expenditure requirements
    a. Installation of the wind farm
    b. Updating the control system to take into account the addition of renewable energy generation
    c. Any extra capital required for Solar PV to be installed by the LHIB (in addition to the expected private installations by LHI residents)
    d. Interest on funds borrowed
3. Operations and Maintenance expenditure, on the following equipment:
    a. Diesel generators
    b. Wind Turbines
4. Diesel fuel consumption of the system

4.2 CASE STUDIES

The case studies to be applied are:

1. Verification Case – This case will form the base case to measure the improvement of fuel consumption and energy costs against. The fuel consumption of the model will be adjusted to meet the actual fuel figures for the year that the load data was recorded in
2. Base Case + Solar PV – This case will examine the potential renewable energy contribution as well as the maximum renewable penetration for the expected Solar PV domestic/commercial Solar PV installation. This model is expected to allow the examination of any potential difficulties with minimum loading on generators during low consumer demand and high insolation periods
3. Base Case + Wind Turbines – This case will examine the addition of wind turbines to the existing power system design. This will show the amount of renewable energy that could be consumed
4. Base Case + ZBB + Solar PV – This case will examine how the ZBB energy storage (expected to be installed later in 2012) will affect the installation of domestic/commercial Solar PV installations. The ZBB energy storage system is rated at 200kW peak power output with 400kWh energy storage
5. Base Case + ZBB + Wind Turbines – This case will examine how the ZBB energy storage will affect the installation of wind turbines and show how much extra renewable energy will be usable due to the energy storage

6. Base Case + ZBB + Wind Turbines + Solar PV – This case will examine how the interaction of the Wind Farm and Solar PV energies affect the excess energy generated.

After showing which configurations are able to provide near the desired 70% renewable energy contribution, these models will have load growth escalations and deferrable demand devices (such as hot water systems and future developments) applied to them.

4.3 NOTES ON THE MODELLING

The modelling contains some assumptions, as outlined below:

1. The ZBB Energy Storage System is assumed to not be able to run the power system in diesel off due to the slow response time to changing output power
2. All systems containing a Vergnet wind turbine require grid stabilisation to be effective
3. Flywheel energy storage systems of sufficient power (500kW+) are able to run the power system in a diesel-off state when sufficient wind (and potentially bulk energy storage from the ZBB battery) is available. In the event of a failure of the renewable energy generators, the grid stabilisation will provide power to run the power system while a diesel generator is started
4. No maintenance, installation or replacement costs for the Solar PV are attributed to LHIB
5. Minimum diesel generator output has been limited to 30%

4.4 RESULTS

The initial series of HOMER models are designed to focus on showing how much benefit each of the renewable energy generation systems provide, as well as the energy storage system.

The base case model for the year of 2010 has shown an energy consumption of 2,313MWh/an with an associated diesel-fuel consumption of 585kL.

It should be noted from the results that the addition of a certain percentage of renewable energy to the power system does not equal that level of fuel saving, as (in many cases) operating the diesel generators away from their highest efficiency points and thus reducing the specific fuel efficiency of the generators. Fortunately in most cases, the amount of fuel saved from the lower loading operation out-weighs the reduction of fuel efficiency; however the result is not 1:1.

Additional modelling has been performed to include the smaller scale wind turbines that the community desires to have examined. This compares the number of wind turbines required to equal the larger turbines for energy.

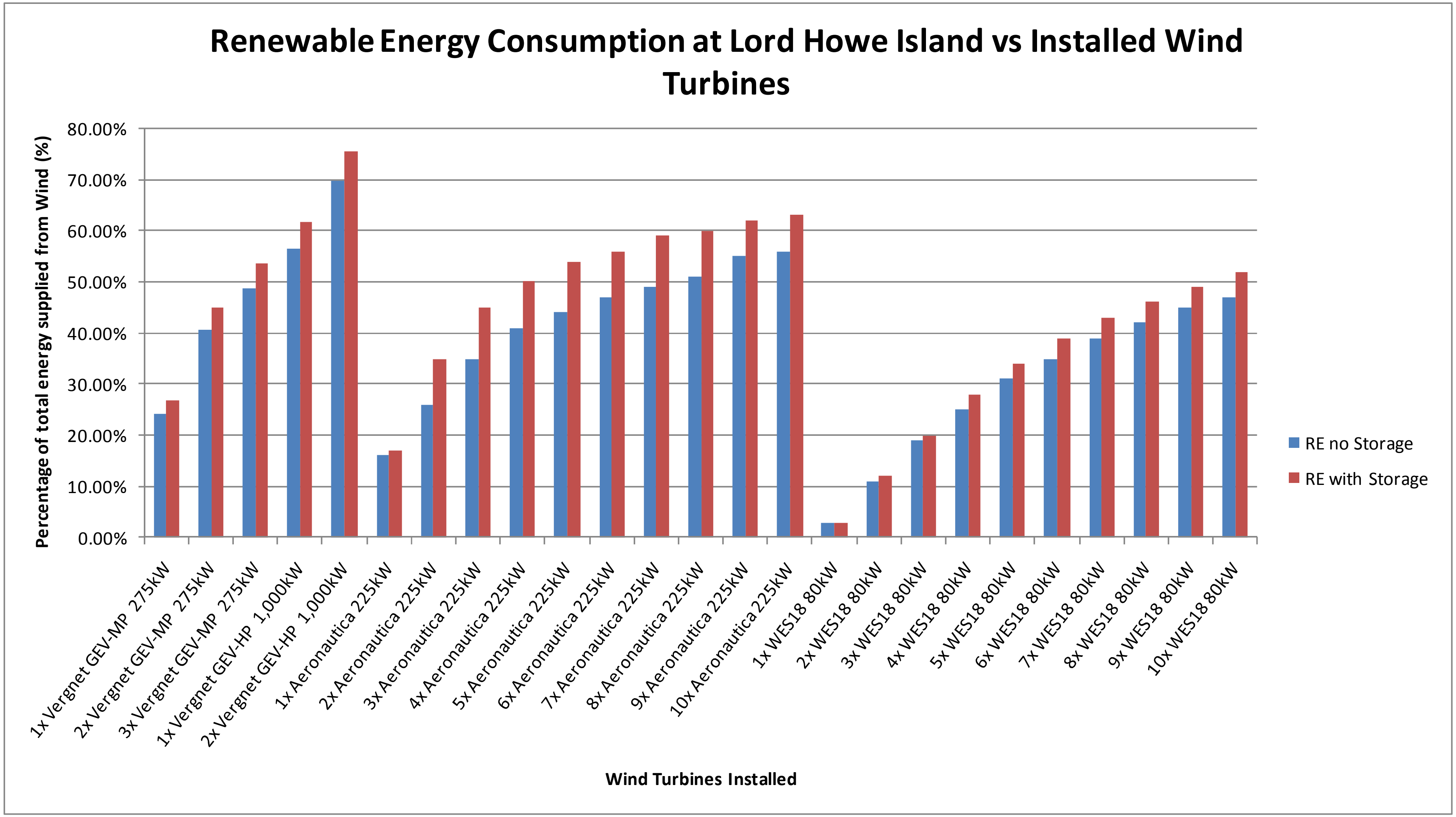


Figure 18 - Comparison of wind turbine model outputs

The following results have been obtained from the energy flow modelling:

Table 2 - Results from the HOMER modelling

Case	Description	Fuel Used (L/an)	Fuel Saved (%)	CO2 (kg/an)	Solar RE (kWh/an)	Wind RE (kWh/an)	Consumption (kWh/an)	Excess RE (kWh/an)	RE (%)
1	Base Case	585,432	0%		0	0	2,313,507	0	0%
2a	Base Case + 50kW PV	572,835	2%	1,508,462	82,209	0	2,313,507	0	4%
2b	Base Case + 100kW PV	560,246	4%	1,475,311	164,418	0	2,313,507	20	7%
2c	Base Case + 150kW PV	548,317	6%	1,443,899	246,626	0	2,313,507	4,333	10%
2d	Base Case + 200kW PV	539,186	8%	1,419,855	328,837	0	2,313,507	26,882	13%
2e	Base Case + 400kW PV	522,543	11%	1,376,027	657,674	0	2,313,507	246,962	18%
3a	Base Case + 2x 275kW WTG	339,287	42%	893,455	0	1,527,454	2,444,907	453,724	44%
3b	Base Case + 3x 275kW WTG	293,741	50%	773,516	0	2,291,326	2,444,907	1,032,731	51%
3c	Base Case + 1x 1,000kW WTG	271,902	54%	716,007	0	2,748,534	2,576,307	1,252,531	58%
3d	Base Case + 2x 1,000kW WTG	189,434	68%	498,842	0	5,497,069	2,576,307	3,672,951	71%
4a	Base Case + ZBB + 50kW PV	572,835	2%	1,508,462	82,209	0	2,313,507	0	4%
4b	Base Case + ZBB + 100kW PV	560,169	4%	1,475,110	164,418	0	2,313,507	0	7%
4c	Base Case + ZBB + 150kW PV	546,475	7%	1,439,048	246,626	0	2,313,507	0	11%
4d	Base Case + ZBB + 200kW PV	530,468	9%	1,396,898	328,837	0	2,313,507	0	14%
4e	Base Case + ZBB + 400kW PV	459,938	21%	1,211,168	657,674	0	2,313,507	0	28%
5a	Base Case + ZBB + 2x 275kW WTG	311,357	47%	819,905	0	1,527,454	2,444,907	332,399	49%
5b	Base Case + ZBB + 3x 275kW WTG	264,179	55%	695,670	0	2,291,326	2,444,907	894,343	57%
5c	Base Case + ZBB + 1x 1,000kW WTG	238,828	59%	628,913	0	2,748,534	2,576,307	1,106,263	64%
5d	Base Case + ZBB + 2x 1,000kW WTG	154,571	74%	407,036	0	5,497,069	2,576,307	3,508,366	77%
6a	Base Case + ZBB + 50kW PV +2x 275kW WTG	295,091	50%	777,072	82,209	1,527,454	2,444,907	352,554	51%
6b	Base Case + ZBB + 50kW PV +3x 275kW WTG	249,985	57%	658,294	82,209	2,291,326	2,444,907	922,926	59%

Case	Description	Fuel Used (L/an)	Fuel Saved (%)	CO2 (kg/an)	Solar RE (kWh/an)	Wind RE (kWh/an)	Consumption (kWh/an)	Excess RE (kWh/an)	RE (%)
6c	Base Case + ZBB + 50kW PV + 1x 1,000kW WTG	225,063	62%	592,666	82,209	2,748,534	2,576,307	1,137,106	66%
6d	Base Case + ZBB + 50kW PV + 2x 1,000kW WTG	114,486	80%	380,479	82,209	5,497,069	2,576,307	3,553,145	79%
6e	Base Case + ZBB + 100kW PV +2x 275kW WTG	281,884	52%	742,293	164,418	1,527,454	2,444,907	374,674	54%
6f	Base Case + ZBB + 100kW PV +3x 275kW WTG	238,468	59%	627,964	164,418	2,291,326	2,444,907	953,223	61%
6g	Base Case + ZBB + 100kW PV + 1x 1,000kW WTG	213,464	64%	562,122	164,418	2,748,534	2,576,307	1,169,558	68%
6h	Base Case + ZBB + 100kW PV + 2x 1,000kW WTG	135,987	77%	358,099	164,418	5,497,069	2,576,307	3,598,940	80%
6i	Base Case + ZBB + 150kW PV +2x 275kW WTG	270,022	54%	711,057	246,626	1,527,454	2,444,907	398,482	56%
6j	Base Case + ZBB + 150kW PV +3x 275kW WTG	228,057	61%	600,549	246,626	2,291,326	2,444,907	984,653	64%
6k	Base Case + ZBB + 150kW PV + 1x 1,000kW WTG	203,408	65%	535,641	246,626	2,748,534	2,576,307	1,203,862	70%
6l	Base Case + ZBB + 150kW PV + 2x 1,000kW WTG	128,507	78%	338,400	246,626	5,497,069	2,576,307	3,646,795	81%
6m	Base Case + ZBB + 200kW PV +2x 275kW WTG	259,067	56%	682,207	328,837	1,527,454	2,444,907	424,287	59%
6n	Base Case + ZBB + 200kW PV +3x 275kW WTG	218,418	63%	575,167	328,837	2,291,326	2,444,907	1,018,124	66%
6o	Base Case + ZBB + 200kW PV + 1x 1,000kW WTG	194,030	67%	510,944	328,837	2,748,534	2,576,307	1,240,268	71%
6p	Base Case + ZBB + 200kW PV + 2x 1,000kW WTG	121,755	79%	320,622	328,837	5,497,069	2,576,307	3,696,645	83%
6q	Base Case + ZBB + 400kW PV +2x 275kW WTG	214,658	63%	565,265	657,674	1,527,454	2,444,907	551,872	67%
6r	Base Case + ZBB + 400kW PV +3x 275kW WTG	179,512	69%	472,713	657,674	2,291,326	2,444,907	1,172,330	73%
6s	Base Case + ZBB + 400kW PV + 1x 1,000kW WTG	158,084	73%	416,288	657,674	2,748,534	2,576,307	1,408,400	78%
6t	Base Case + ZBB + 400kW PV + 2x 1,000kW WTG	96,118	84%	253,111	657,674	5,497,069	2,576,307	3,915,132	87%

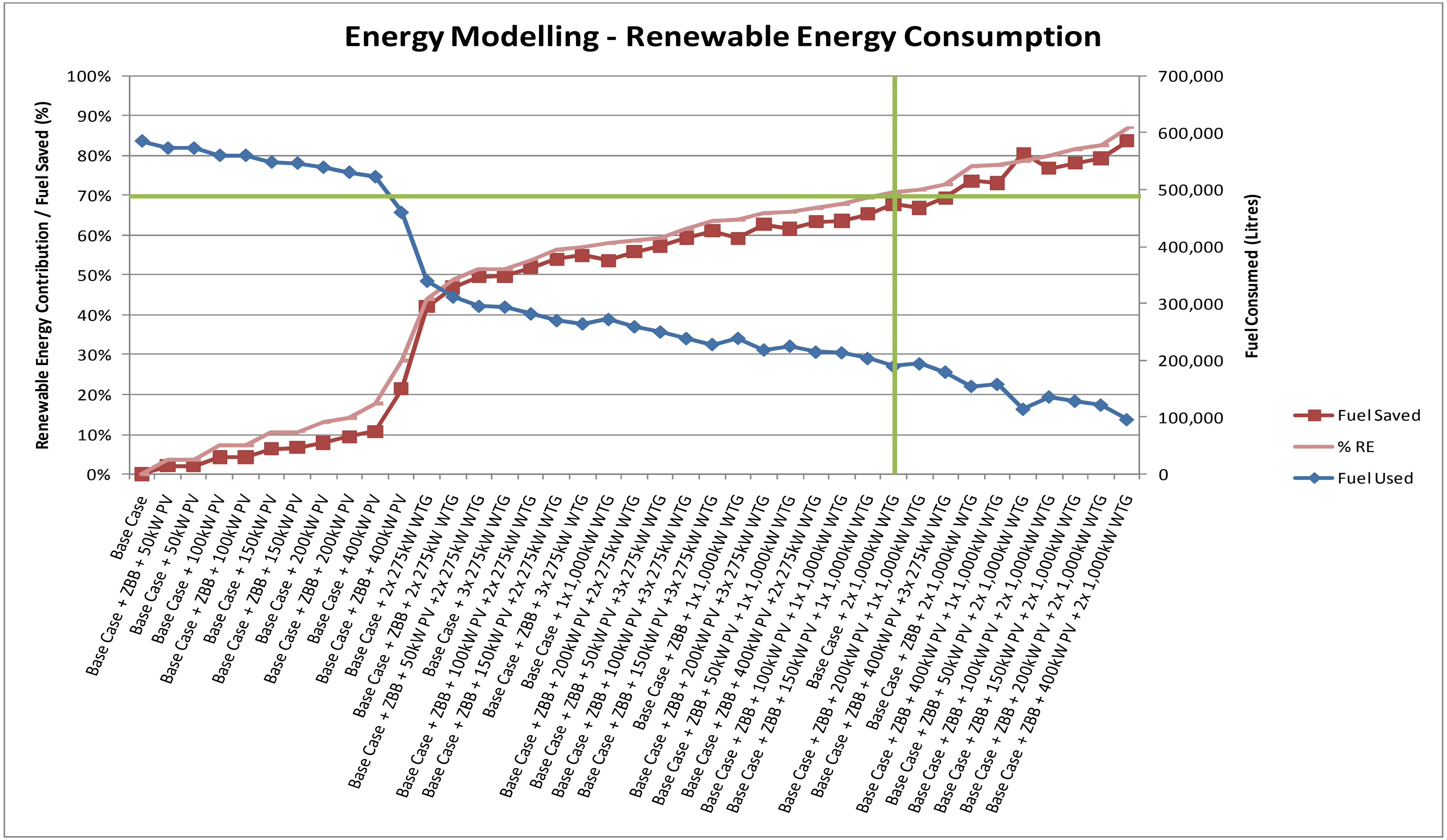


Figure 19 - HOMER modelling results, sorted by RE utilised

4.5 CONCLUSIONS FROM THE BASE MODELLING RESULTS

From the energy flow modelling conducted:

- Building of a wind farm should be the top priority of the LHIB as it represents the lowest LCOE
    - Installation of a 2 unit, 550kW wind farm will produce enough energy to provide for at least 40% of the current demand, whilst producing a further 500kWh per annum for use in energy storage processes (i.e. hot water heating, electric vehicle charging, etc)
    - Installation of a 3 unit, 825kW wind farm will produce enough energy to provide for at least 50% of the current demand, whilst producing a further 900kWh per annum for use in energy storage and deferred load processes. It is clear that not enough physical space is available at the selected plot North of the airport for a 3-turbine wind farm and the 3rd unit will have to be installed nearby.
- Installation of Solar PV funded by the LHIB will not provide as good a return on investment as wind turbines
    - Domestic demand for the installation of Solar PV is estimated to provide up to 200kWp of Solar PV
    - A further 200kWp could be installed by LHIB in order to increase renewable energy to the islands power supply and also provide an increased diversity of energy sources
    - As community concerns will put an upper limit to the number and size of wind farms on the island, LHIB should consider the installation of community Solar PV
    - System control of the Solar PV at the first tranche of 100kW does not appear to be a problem, as the minimum load after 07:00AM on any day (from the modelling demand data) is always greater than 185kW. After the second 100kW tranche of Solar PV is installed, the power system will more than likely require control of the Solar PV generation to prevent instability during sunny days where the consumer load is low.
- The ZBB energy storage system is useful when combined with renewable energy generation
    - Only has an effect once more than 200kWp of solar is installed
    - Some additional benefits can be achieved when using cycle-charging (i.e. running the diesel generator at 100% output, using the excess to charge the ZBB energy storage system)
    - When combined with the larger wind turbine combinations, more energy storage may be useful

5 NET PRESENT VALUE ANALYSIS

The Net Present Value analysis takes into account the:

1. Capital cost of the new equipment
2. Financing costs for borrowing the capital cost from commercial institutions
3. Operations & maintenance costs
4. Replacement costs for generators that reach the end of their service life
5. Fuel consumed (from Energy Flow Modelling)
6. Existing fuel subsidy from the NSW Government and the expected staged phase-out of this subsidy
7. Cost of constructing the new power station and decommissioning the current power station
8. The cost of new components for the existing wireless transmission system

To provide a Levelised Cost of Energy (LCoE) or the average cost figure over the 20 years, escalated into today's dollars.

The values for energy and operations & maintenance costs have been calculated by HOMER in the previous section.

5.1 METHOD

Powercorp has constructed an NPV model using Microsoft Excel. This model takes into account:

1. Escalation of maintenance costs, fuel costs and replacement of equipment costs
2. Degradation of the output of Solar PV generation equipment over the life span
3. The need to replace generators based on their operating hours
4. Escalation of load over the period

The output from the HOMER energy flow modelling is inserted into the NPV spreadsheet and the sheet calculates the various fuel and cost escalations for the following 20 years.

5.1.1 INPUT DETAILS

It is assumed that the power system upgrades in these cases are 50% funded by LHIB and 50% funded from grants or equivalent external funding.

In the case where private Solar PV is included (200kWp and less) then the costs for purchase, installation, commissioning and maintenance are expected to be borne by the consumer and not LHIB. It is also noted that any energy exported into the LHIB system from the private Solar PV installations is not counted towards the saleable quantity of energy.

5.1.2 COST BREAKDOWNS

The following estimates were used in calculating the capital expenditure:

1. One Vergnet MP 275kW wind turbine installed: $800,000
2. One kilowatt (peak) of private Solar PV installed: $0
3. One kilowatt (peak) of community bulk (>100kW) Solar PV installed: $6,500
4. One ZBB Energy Storage System (200kW, 400kWh): $820,000
5. One PowerStore Grid Stabilising Flywheel (500kW): $750,000
6. Expandable distributed control system with distributed smart grid: $650,000

5.2 RESULTS

The following results were found from the NPV model:

Table 3 - Results of NPV modelling

Item	Case	Initial % RE (2012-16)	Final % RE (2027-31)	Capital Expenditure	LCoE ($/kWh) 50% Subsidy	LCoE ($/kWh) 0% Subsidy
1	Verification Case/Base Case	0.0%	0.0%	$0.0m	$0.622/kWh	$0.622/kWh
2a	Base Case + 200kWp Private Solar PV + 200kWp Community Solar PV + 200kW/400kWh ZBB Energy Storage + 2x Vergnet GEV-MP 275kW Wind Turbines 0% Load escalation, 11.2% demand controlled loading	64.1%	61.6%	$5.12m	$0.416/kWh	$0.558/kWh
2b	Base Case + 200kWp Private Solar PV + 200kWp Community Solar PV + 200kW/400kWh ZBB Energy Storage + 2x Vergnet GEV-MP 275kW Wind Turbines 0.5% Load escalation, 11.2% demand controlled loading	67.1%	61.8%	$5.12m	$0.462/kWh	$0.599/kWh
3a	Base Case + 200kW Private Solar PV + 200kW/400kWh ZBB Energy Storage + 3x Vergnet GEV-MP 275kW Wind Turbines 0% Load escalation, 11.2% demand controlled loading	69.7%[18]	67.6%	$5.92m	$0.404/kWh	$0.568/kWh

---

[18] This percentage figure is lower than the previous non-escalated figure due to using the 5 year step modelling method. The figure represents average renewable energy contribution between 2012-2016.

Item	Case	Initial % RE (2012-16)	Final % RE (2027-31)	Capital Expenditure	LCoE ($/kWh) 50% Subsidy	LCoE ($/kWh) 0% Subsidy
3b	Base Case + 200kWp Private Solar PV + 200kWp Community Solar PV + 200kW/400kWh ZBB Energy Storage + 3x Vergnet GEV-MP 275kW Wind Turbines 0.5% Load escalation, 11.2% demand controlled loading	73.8%	69.3%	$5.92m	$0.442/kWh	$0.600/kWh
4a	Base Case + 200kWp Private Solar PV + 200kWp Community Solar PV + 200kW/400kWh ZBB Energy Storage + 1x Vergnet GEV-HP 1,000kW Wind Turbines 0% Load escalation, 11.2% demand controlled loading	75.7%	73.8%	$5.92m	$0.340/kWh	$0.504/kWh
4b	Base Case + 200kWp Private Solar PV + 200kWp Community Solar PV + 200kW/400kWh ZBB Energy Storage + 1x Vergnet GEV-HP 1,000kW Wind Turbine 0.5% Load escalation, 11.2% demand controlled loading	79.0%	74.4%	$5.92m	$0.383/kWh	$0.541/kWh
5a	Base Case + 200kWp Private Solar PV + 200kWp Community Solar PV + 200kW/400kWh ZBB Energy Storage + 2x Vergnet GEV-HP 1,000kW Wind Turbines 0.0% Load escalation, 11.2% demand controlled loading	84.2%	83.1%	$8.32m	$0.349/kWh	$0.580/kWh
5b	Base Case + 200kWp Private Solar PV + 200kWp Community Solar PV + 200kW/400kWh ZBB Energy Storage + 2x Vergnet GEV-HP 1,000kW Wind Turbines 0.5% Load escalation, 11.2% demand controlled loading	89.9%	86.4%	$8.32m	$0.371/kWh	$0.594/kWh

5.3 CONCLUSIONS

Although the three turbine Vergnet GEV-MP 275kW wind farm can produce the desired 70% renewable energy generation (in combination with Solar PV, grid stabilising flywheels and long term energy storage), further modelling has been performed indicating that the addition of 200kW community based Solar PV to the expected 200kWp private Solar PV installations, with a two turbine Vergnet 275kW wind farm can also produce nearly as much renewable energy contribution, with potentially enough excess energy to service demand controlled air-conditioning and electric vehicle charging. This also allows for future expansion through the addition of the third turbine should other uses for the excess energy become apparent.

The potential installation site North of the airport, near the proposed new thermal power station would be ideal, as the two turbines could be installed in the existing space, without any additional clearing, except for access clearances. At this location, the wind turbines are expected to be far enough away from any dwellings as to preclude any noise problems.

It has been noted that the selection of the Vergnet MP 275kW wind turbine is a deviation from the community guidelines, which suggest the installation of VAWT or HAWT machines less than 100kW. Some modelling has been done earlier to show that at least eight WES80 wind turbines would be required to match the output of two of the MP 275kW turbines. If these units were aligned in two rows of 4 to match the available shape of the clearing, with an absolute minimum spacing of 5 rotor diameters (leading to 76m minimum distance between blade-tips) would require a space larger than 304m long and 112m wide. This is as opposed to the minimum space for the two Vergnet MP 275kW turbines, which has a minimum requirement of 224m long and 32m wide with 5-rotor diameters inter-machine spacing.

It should also be noted that the Vergnet MP 275kW wind turbines have a significantly slower maximum rotation speed.

The final points are that the suggested improvements, whose base components have been subject to the NPV analysis, have shown to be financially beneficial in separate portions. These portions have been then separated and re-applied in the road-map and the costs of energy per year calculated to create the energy supply road-map for Lord Howe Island.

6 LORD HOWE ISLAND ENERGY ROAD-MAP

From the combination of the energy flow modelling and the NPV analysis, Powercorp has determined that the following combinations of renewable energy generation are recommend:

1. Private Solar PV installations distributed through the island of a cumulative total of approximately 200kW
2. Community Solar PV installations for a cumulative total of approximately 200kW
3. A wind farm installation of 550kW – 825kW, requiring grid-stabilising equivalent to at least 60% of the output power of the wind farm[19]
4. Energy storage capacity of approximately 400kWh with a maximum export of 200kW and a maximum import capability of 200kW

6.1 ROAD-MAP

Powercorp has constructed an “energy supply road-map” graph to illustrate the suggested installation of equipment at LHI to maximise the available renewable generation without sacrificing power quality.

Note that the cost of energy illustrated on the graph is an energy unit (kWh) for each year figure, not the LCoE over 20 years.

A copy of this road-map is included in this document for convenience, a full scale A1 copy has been supplied separately.

---

[19] The grid stabilising requirements can be better defined by a dynamic modelling study. This estimate is based on the previous performance measurements of Vergnet GEV-MP 200kW wind turbines at Coral Bay.

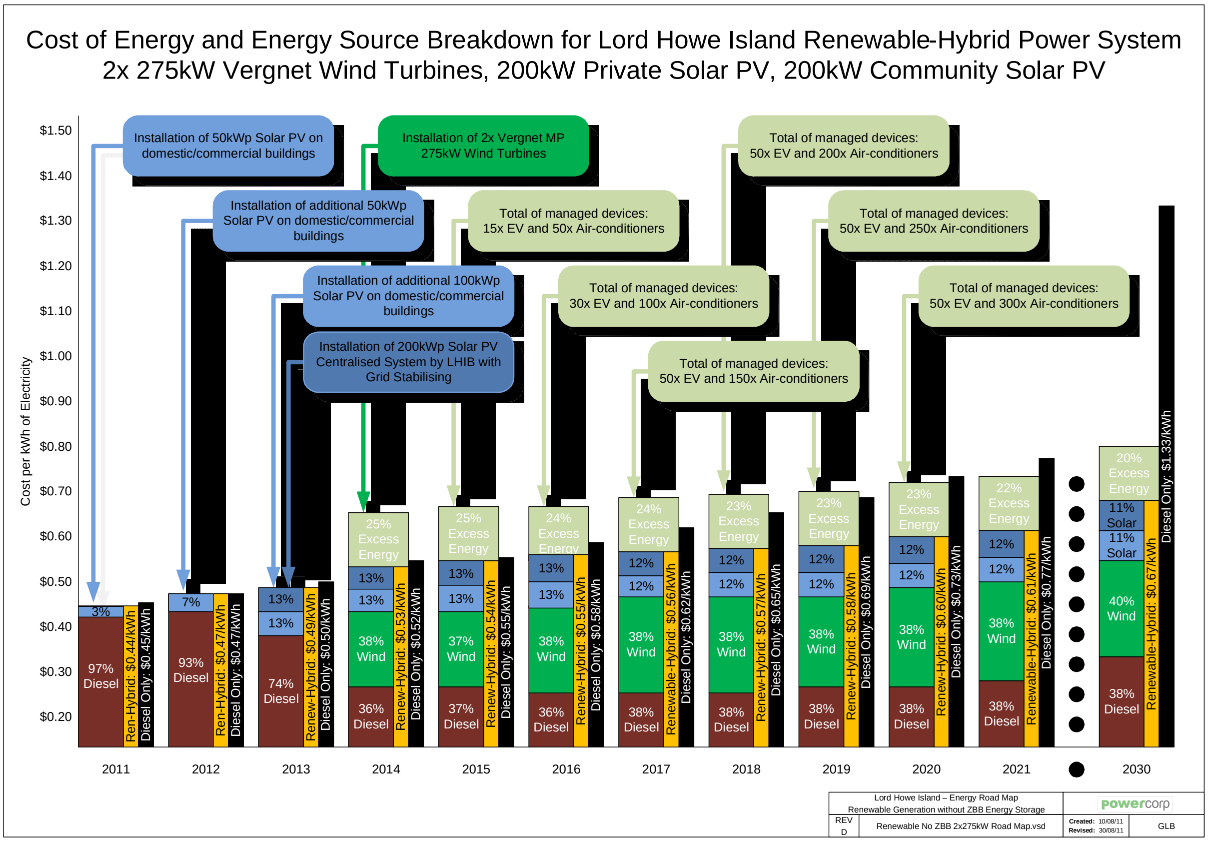


Figure 20 - Lord Howe Island Energy Supply Road-Map for 2x 275kW Vergnet MP wind farm

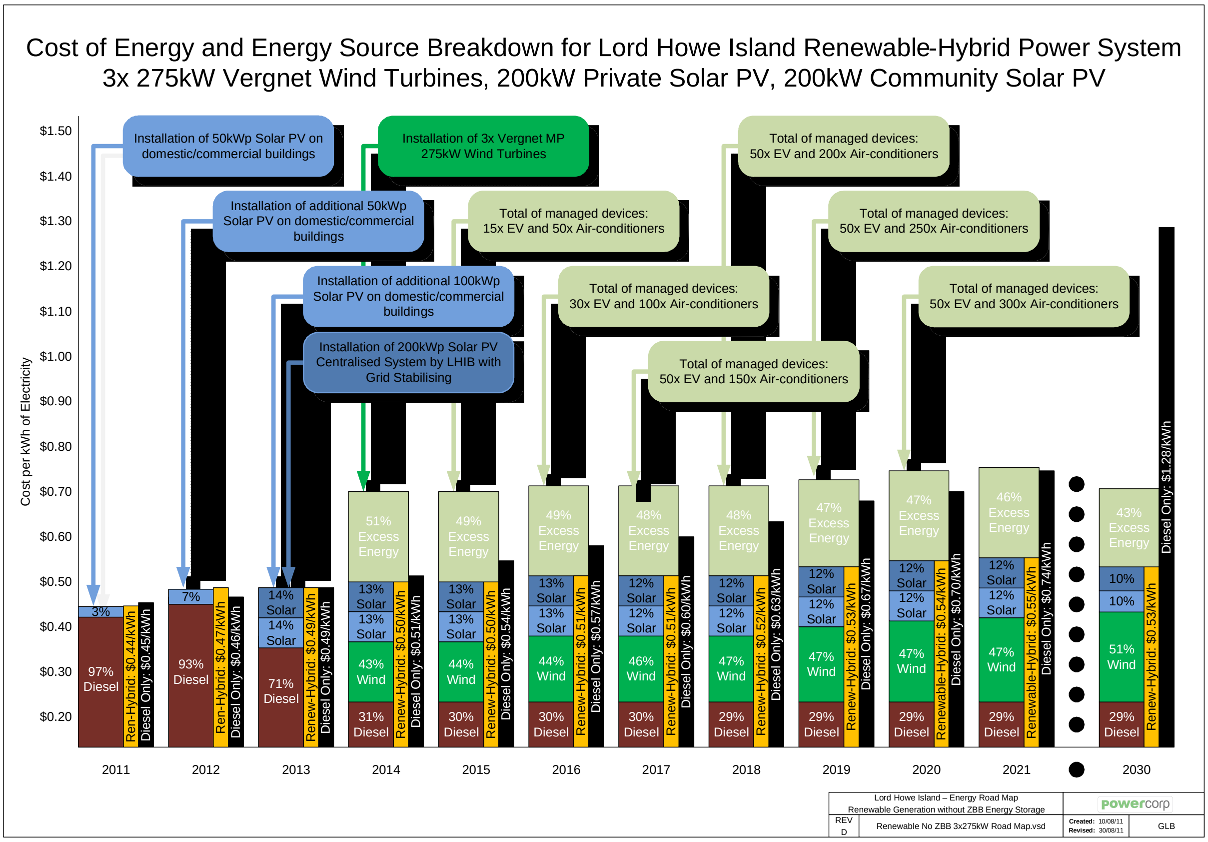


Figure 21: Lord Howe Island Energy Supply Road-Map for 3x 275kW Vergnet MP wind farm

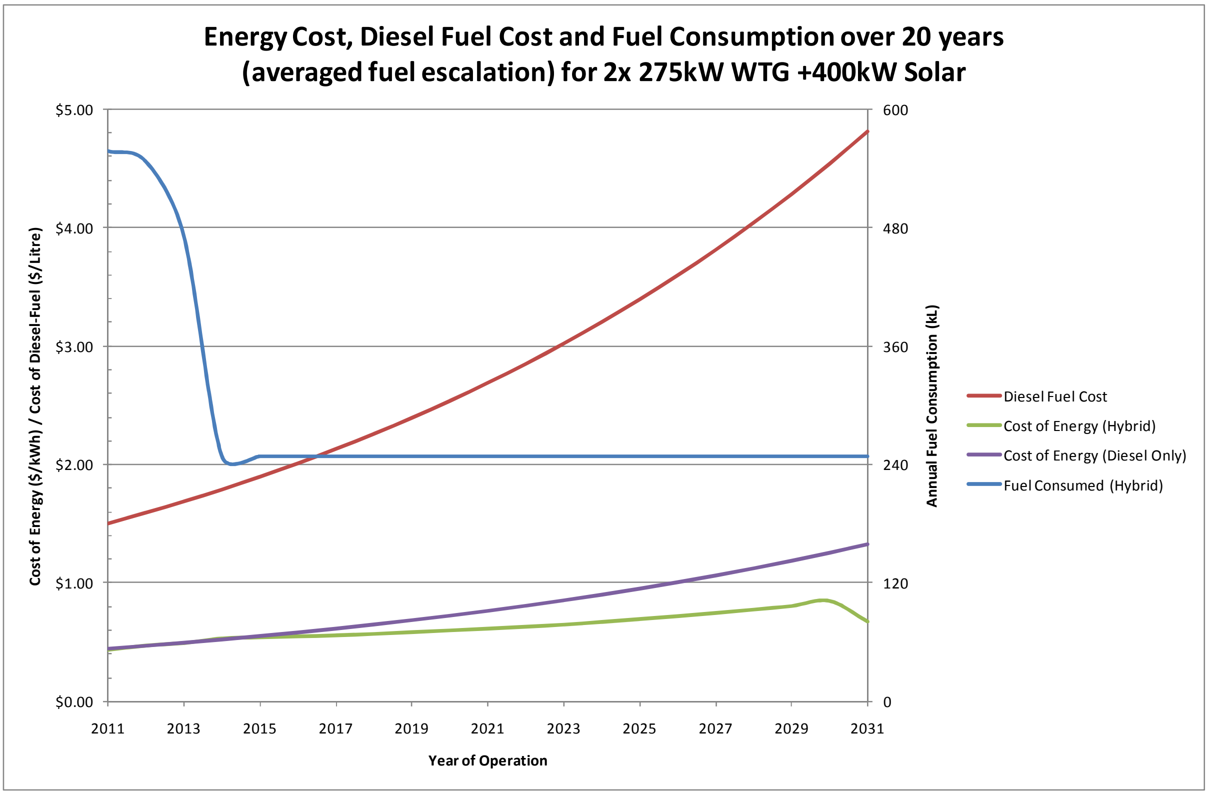


Figure 22 - LHI Modelled Fuel cost, energy cost and fuel consumption over 20 years

6.2 POWER STATION CONTROL SYSTEM

In 2012, the existing power station is scheduled to be replaced with a new facility to be constructed North of the airport hill. At this time, LHIB should consider replacing the existing control system in order to be ready for the additional renewable generation that is to be added.

The new control system must be able to:

1. Monitor and control the Solar PV and wind farm installation in order to limit the amount of energy generated at times when the demand is insufficient to consume all of the load[20]
2. Monitor and control the proposed ZBB Energy Storage system in order to utilise the ability to store energy long-term for the best result
3. Monitor and control the existing demand management device (Westinghouse Ripple control system)

---

[20] This functionality can potentially be integrated into a “smart grid” metering and control system to be retro-fitted at a later date

4. Provide an interface to a more advanced "smart grid" interface, potentially allowing for commercial/industrial/domestic load monitoring and control, along with Solar PV monitoring and control

For the purposes of modelling, a figure of $650,000 has been used for the design, procurement, installation and commissioning of a control system. This cost is an estimate for the entire system of components, including a level of "smart grid" integration at residential and domestic dwellings.

As a distributed control system is expandable, the first instance installation will not cost that much. A simple three diesel generator and 3 feeder control system with SCADA would have a capital cost in the order of $175,000. Further expansions, such as the control of Solar PV and wind turbines can be expanded through the introduction of more controllers, preserving the investment in the control system. Note that as the Powercorp Distributed Control System is also programmed modularly, no further reprogramming of the controllers is necessary, just the modification of some parameters built into the software.

6.3 SOLAR PV

The modelling shows that the installation of up to 200kWp of privately funded Solar PV will provide an initial output of approximately 320MWh/an of energy, dropping down to 260MWh/an over a 20 year life-span. With no wind-turbines installed, this 200kWp of Solar generation will be entirely consumed.

Beyond the 200kWp of privately funded Solar PV, it is also recommended that LHIB install some "community" Solar PV, with an additional figure of 200kWp allowing minimal excess energy when combined with the privately installed Solar PV.

6.3.1 SOLAR PV INSTALLATION

Powercorp advises that the following installation tranches for the privately installed Solar PV on residential/commercial properties be set aside:

1. Phase 1: 100kW in no fewer than 5 separate installations starting from late 2011.
2. Phase 2:The remaining 100kW in no fewer than 5 separate installations after the installation of the new power station and the new control system that is able to curtail the operation of the Solar PV as required (expected end of 2012)

Powercorp also suggests that expressions of interest should be sought across both of the tranches at the same time, then the LHIB can allocate each separate connection request to a tranche in order to be able to geographically spread the installations and gain the additional stability and reduced rate of power change that this provides.

Note that it is advised to map each of the desired installation locations and to use as wide a dispersed area for each tranche as is possible to take advantage of the positive effects of dispersing the Solar PV generation across the island.

6.3.2 SOLAR PV CONTROL

After the installation of the first tranche of Solar PV, it is expected that direct control of the Solar PV installations will not be required. The control and monitoring must still be connected in order to prove the system. This may be most cost effectively provided by allowing for one or two large solar plant (for example, 20kW) and connecting communications for this system to the power station control system.

6.4 WIND FARM

The modelling results suggest that a wind farm consisting of two 275kW turbines manufactured by Vergnet will provide in excess of 40% of the energy for the island. A further third turbine can be installed to supply additional excess energy for use in an expanded demand managed device programme.

At this stage, Powercorp is unable to advise the LHIB of a suitable wind turbine as small as 80kW – 100kW due to a lack of confidence in the machines that are currently available in the marketplace.

6.4.1 WIND FARM INTEGRATION

The integration of the wind farm will require an updated or replacement control system for the power station. In addition, the size of the proposed wind installation combined with the small size of the power system mandates that further grid stabilisation will be necessary.

Options for this grid stabilisation will require real power and are limited to devices such as:

1. fast-acting batteries (i.e. not flow batteries, but lead-acid or nickel-cadmium)
2. super-capacitor based grid stabilisation devices
3. flywheel based grid stabilisation devices

In the energy modelling, Powercorp PowerStore devices have been used to model the parasitic effects of adding such stabilisation whenever a wind farm option has been modelled.

6.4.2 WIND FARM LAYOUT AND SIZING

The identified suitable area for the wind farm is quite area constrained by virgin bushland all around. The available space is approximately 300m long and perhaps 50m wide. This locks the design of the wind farm in without too much room to move.

The initial concept of the installation of two Vergnet MP 275kW wind turbines is suitable to fit into this space with an optimal energy yield, as the minimum distance between wind turbines is more than 10 rotor-diameters (or 270m in the case of the MP 275kW machine). This inter-machine spacing reduces the effect of energy loss between wind turbines in a wind farm due to turbulence created by the wind hitting the first turbine and moving on to the next turbine.

It is unlikely that there will be enough space in the selected “possible wind site” to install a third wind turbine. As the proposed two wind turbine solution provides nearly all of the energy required (when combined with Solar PV) it is recommended to proceed without the third turbine and evaluate the results. Siting options for the third can be examined if the community desires to install the third turbine.

Figure 23 - Possible Wind Farm Siting

6.4.3 WIND FARM CONSTRUCTION

The chosen Vergnet wind turbines will require a small crane during the installation. In addition, excavation of the site will need to take place in order to allow the pouring of the foundation. The existing LHIB crane should be large enough to be used for this project.

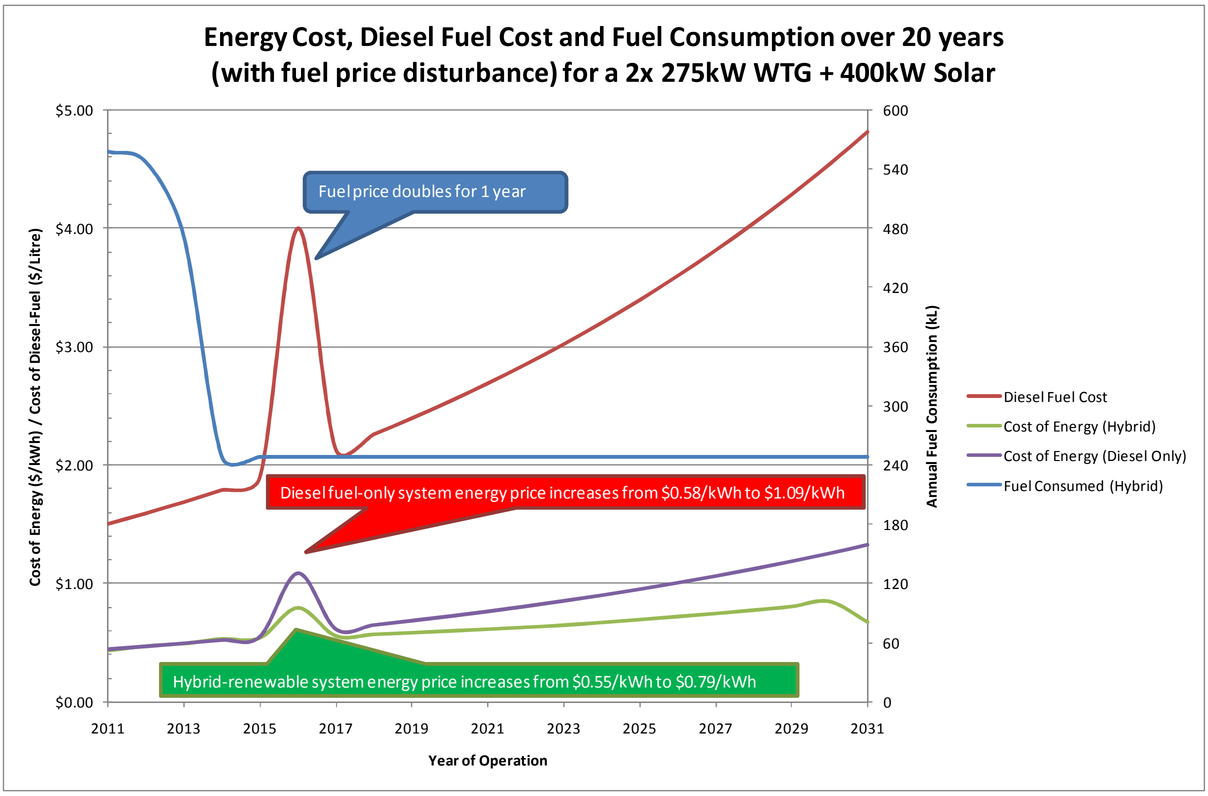
Given the small size of the wind farm, it is unlikely that a specific sub-station would be built, rather it would use kiosk style transformers mounted at the base of the wind turbines. This will probably be the most cost effective option for power reticulation at the site.

6.4.4 FURTHER MODELLING

Some additional modelling was performed to illustrate how the hybrid-renewable power system would be more isolated against fuel price "shocks" than a straight diesel-fired power station.

As a possibility, the modelling was modified to include a temporary price doubling of diesel fuel in 2016, with the doubled price lasting for one year. The results showed that the energy cost of the conventional diesel-fired power system would increase from $0.69/kWh to $1.22kWh, or by nearly

70%. The renewable-hybrid power station energy cost also rises (due to the 24% of energy being supplied by the diesel generators) but from $0.43/kWh to only $0.63/kWh, or an increase of just more than 25%.


Energy Cost, Diesel Fuel Cost and Fuel Consumption over 20 years (with fuel price disturbance) for a 2x 275kW WTG + 400kW Solar

Fuel price doubles for 1 year

Diesel fuel-only system energy price increases from $0.58/kWh to $1.09/kWh

Hybrid-renewable system energy price increases from $0.55/kWh to $0.79/kWh

Figure 24 - Energy cost modelling including fuel price disturbance

7 REFERENCES

8 APPENDIX

8.1 POWER STATION OVERVIEW

8.1.1 POWER STATION COMPONENTS

The following information has been used in order to construct the energy flow model:

1. Existing System
    - Diesel Plant - Total installed capacity: 1,350 kW
2. RE/Diesel System
    - Diesel Plant - Total installed capacity: 1,350 kW
    - Wind Plant
    - PV Plant
    - Energy Storage
    - Flywheel

    To be determined

The specifications of each component of the station are detailed in this section. Any assumptions such as component efficiencies, Model number etc, are indicated.

8.1.2 POWER STATION OPERATION

POWER STATION OPERATION - EXISTING

The following information relates to the operation of the existing power station:

- Spinning Reserve (Operating Reserve) is maintained at approximately 40kW.
- Minimum load ratio for the diesel generators @ 30%, provided there is sufficient load to meet this requirement
- There is a minimum of one generator maintained online

POWER STATION OPERATION – PROPOSED

The following *assumptions* relate to the operation of the proposed RE/Diesel power station:

- Spinning Reserve (Operating Reserve) is maintained at approximately 40kW with an additional 100% of PV output and Wind Turbine output. This can be adjusted to a less conservative figure once experience has been gained with the system. Note that this is a trade-off between system reliability (number of outages) vs. extent of fuel savings

- Minimum load ratio for the diesel generators @ 30%, unless there is not sufficient load to meet this requirement
- Diesel-off mode is enabled

8.2 COMPONENT DETAILS

8.2.1 COMPONENT DETAILS - EXISTING

8.2.1.1 THERMAL POWER PLANT - DIESEL

Table 4: Diesel Generator Station (Existing, as of 2010)[21]:

Generator Identifier	# 1	# 2	# 3	# 4
Nominal Power kW	300	300	300	425
Model	Detroit Series 60	Detroit Series 60	Detroit Series 60	Unknown
Total Installed Capacity kW	1,350			
Fuel Type	Diesel			
Fuel Consumption (L/hr) 100% 75% 50%	 63.4 47.5 31.7	 63.4 47.5 31.7	 63.4 47.5 31.7	Not Modelled
Maintenance cost ($/hr)	$10.00	$10.00	$10.00	Not Modelled

Table 5: Fuel Characteristics:

Fuel	Diesel
Properties*	
Energy Content (MJ/kg)	45.6[22]
Density (kg/m^3)	850[23]
Carbon Dioxide Equivalent	0.0026827

---

[21] Information supplied by LHIB

[22] ABARE http://www.abare.gov.au/interactive/09_auEnergy/htm/appTWO.htm (acc. May 2010)

[23] Syngas http://www.syngas.com.au (acc May 2010)

(t CO_2e/L)	

* Fuel Properties assumed

8.2.2 COMPONENT DETAILS – PROPOSED

It should be noted that the equipment detailed here is selected to investigate the performance of different technologies and not offered as recommendations. Final equipment selection will depend upon the performance of the technology, the suitability to the region and upon the customer.

8.2.2.1 PHOTOVOLTAIC TECHNOLOGY

Two types of PV panels are assessed for performance under temperate weather conditions – thin-film and Mono-crystalline.

Table 6: Component Details - Photovoltaic Modules – Thin-film

Type	Thin-film CdTe
PV Module	FS-277
Manufacturer:	First Solar
Module Size	77.5 W
Module Efficiency	11.1%[24]
NOCT	40°C[25]
Temperature Coefficient	-0.25 %/°C[26]

Table 7: PV Inverter

Type	Site Rating
Inverter Module	Mini-Central 8000TL
Manufacturer:	SMA

---

[24] First Solar (via email April 2010)

[25] http://www.icaro-srl.eu/downloads/Fotovoltaico/Data%20Sheet%20First%20Solar.pdf (acc. April 2010)

[26] First Solar Data Sheet, http://www.firstsolar.com/Downloads/pdf/Datasheet_s2_NA.pdf (acc. April 2010)

Type	Site Rating
Nominal AC Output:	8,000W
Efficiency Max Average	~98%[27] 97%[28]

8.2.2.2 WIND TECHNOLOGY

Table 8: Wind Turbine Generation – Vergnet GEV-MP 275kW

Manufacturer		Vergnet
Model		GEV MP
Number of turbines		TBD
Rated Power	kW	275 kWp
Tower height	m	55m

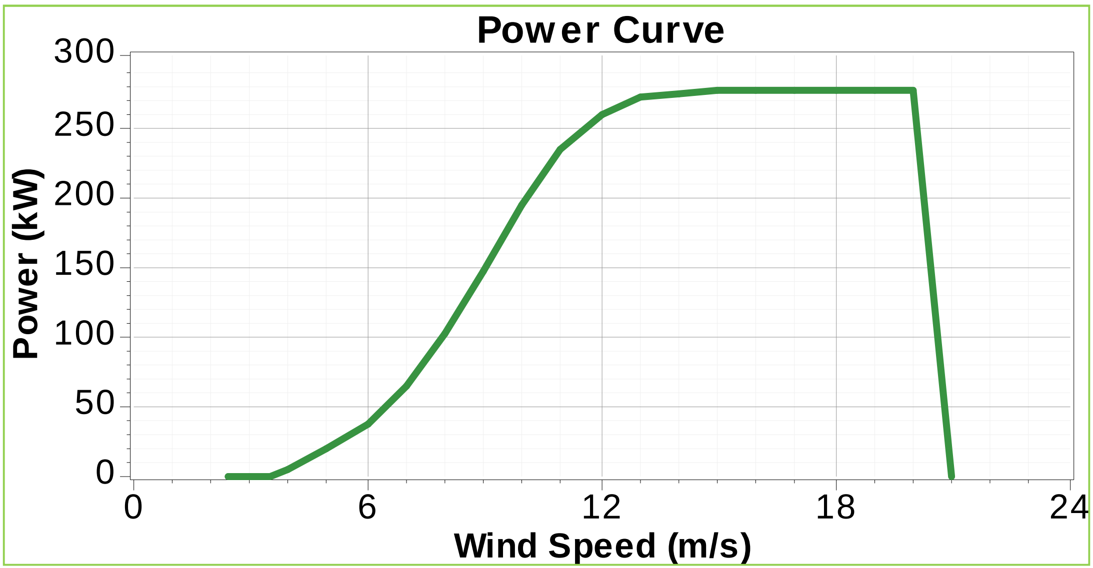


Figure 25: Vergnet MP 275kW Power Curve[29]

---

[27] SMA http://www.sma-australia.com.au/en_AU/products/solar-inverters/sunny-mini-central/sunny--mini-central-6000tl-7000tl-8000tl.html (acc May 2011)

[28] Go Solar California, http://www.gosolarcalifornia.ca.gov/equipment/inverter_tests/summaries/SMA SB8000TL-US.pdf (acc May 2011)

[29] Vergnet Product Brochure, www.vergnet.fr (accessed Jan 2010)

Table 9: Wind Turbine Generation – Vergnet GEV-HP 1,000kW

Manufacturer	Vergnet
Model	GEV HP
Number of turbines	TBD
Rated Power kW	1,000 kWp
Tower height m	70m

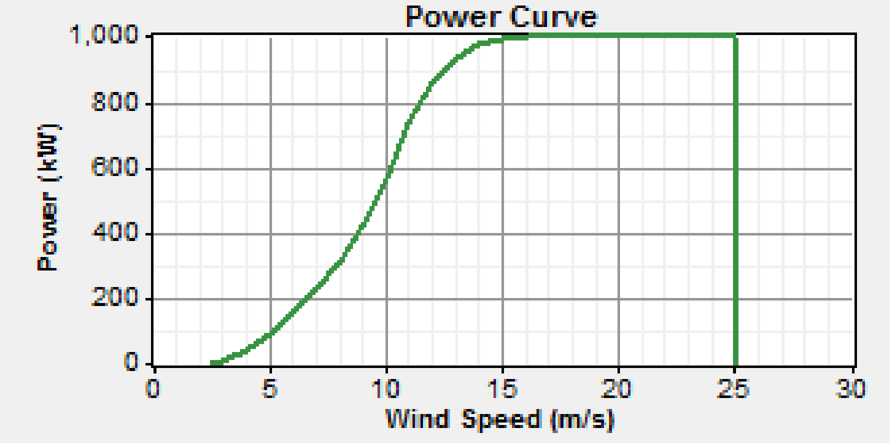


Figure 26: Vergnet HP 1,00kW Power Curve[30]

8.2.2.3 ENERGY STORAGE TECHNOLOGY

Table 10: Component Details - Batteries

Technology	Zinc Bromine
Manufacturer	Zest Energy - ZBB
Model	ZESS500
Capacity (Ah @ C_{rating})	500kWh
Life Expectancy (HRS OR CYCLES OR YEARS)	2000 full cycles OR 20years

---

[30] Vergnet Product Brochure, www.vergnet.fr (accessed Jan 2010)

8.2.2.4 ENABLING TECHNOLOGY

Table 11: Component Details - Flywheel

Rated power	500kW
Pmin Flywheel	-500kW
Pmax Flywheel	500kW
Maximum Energy of Flywheel	18MWs
P loss Flywheel (permanent losses even if P=0 kW)	15kW$_{max}$ Note: Includes losses from inverter/flywheel and air-cond.
Spinning reserve of Flywheel*	500kW*
Total energy of Flywheel	18MWs
Energy Level saved for spinning reserve	70% (12.6MWs)**
P step load capability Flywheel	0-1000kW depending on actual Flywheel power (Pstep_cap= 500kW -P_Flywheel_act)

*This assumes 70% of the flywheel energy is available for Spinning Reserve (12.6MWs), through the inclusion of a safety factor this will ensure that 500kW will be available for 21 sec.

**Assumed

8.3 ENVIRONMENTAL DATA

8.3.1 PV RESOURCE

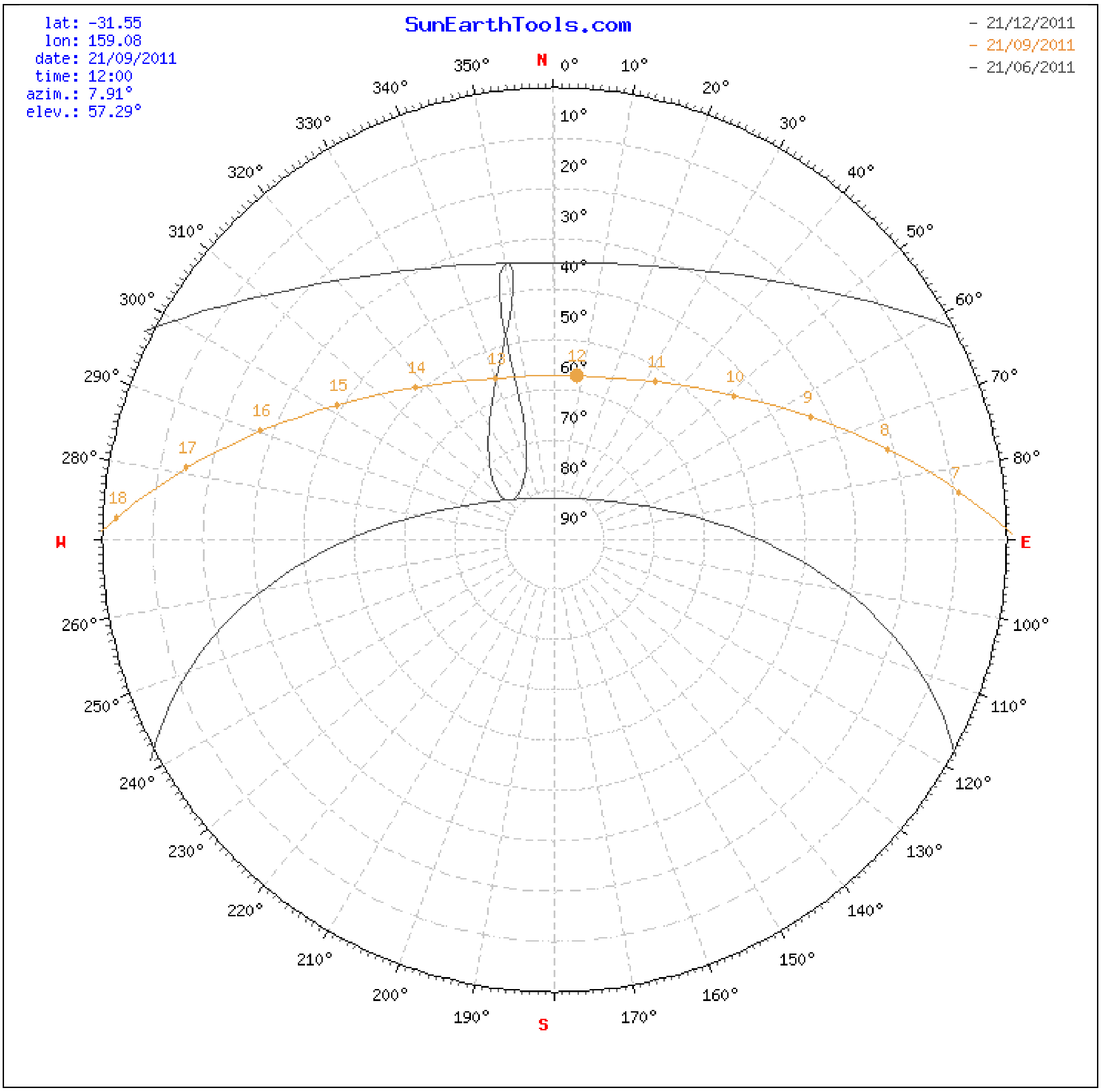


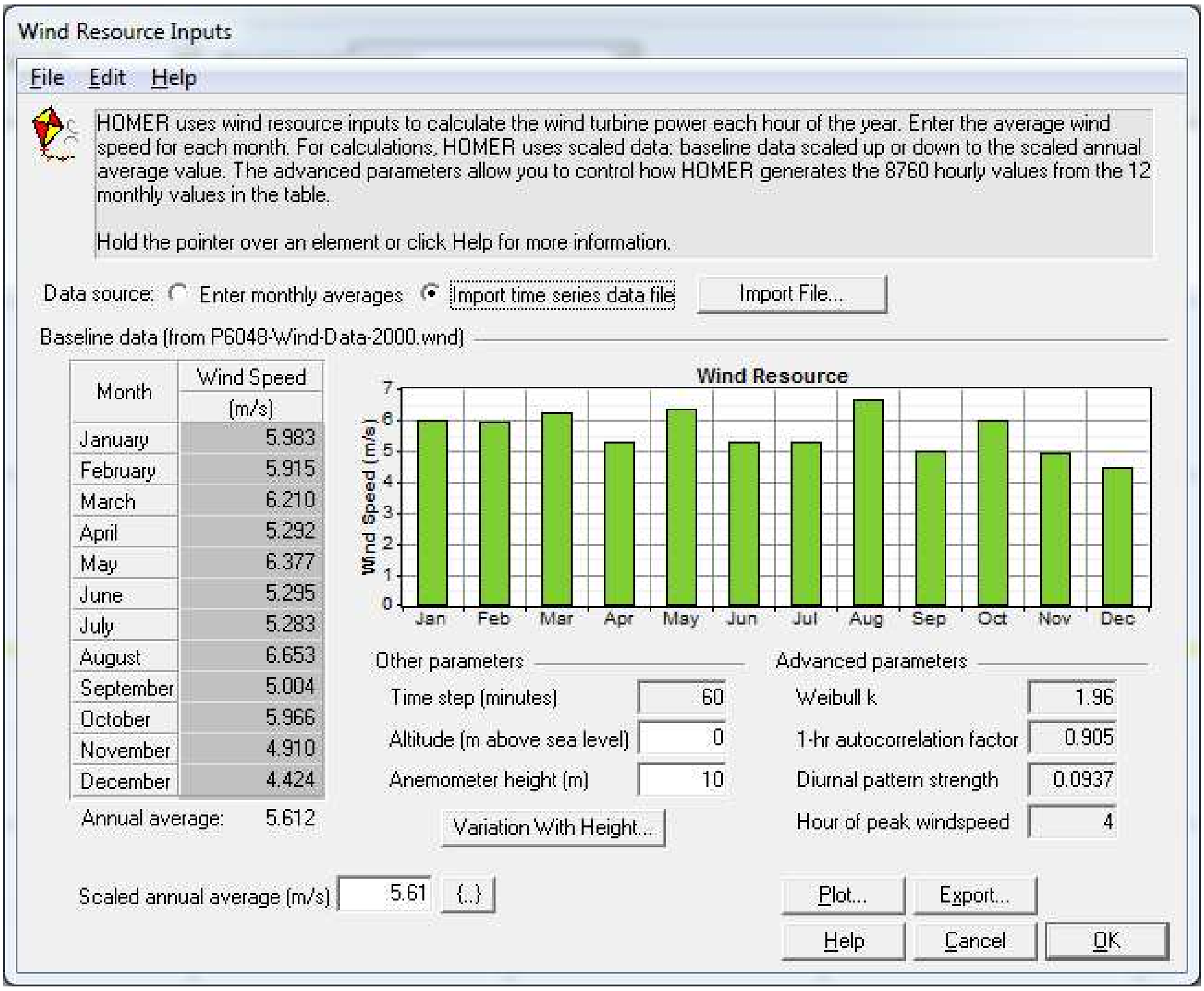
Figure 27: Sun Location across the year for Lord Howe Island (www.sunearthtools.com)

The location of the sun over the horizon for Lord Howe Island is illustrated in Figure 27.

8.3.2 WIND RESOURCE

Annual average wind speed (2000) at 10m = 5.61 m/s.

Data was sourced from the BOM data supplied in the previous tender to supply wind turbines to Lord Howe Island.



Wind Resource Inputs

HOMER uses wind resource inputs to calculate the wind turbine power each hour of the year. Enter the average wind speed for each month. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value. The advanced parameters allow you to control how HOMER generates the 8760 hourly values from the 12 monthly values in the table.

Hold the pointer over an element or click Help for more information.

Data source: ○ Enter monthly averages ● Import time series data file

Baseline data (from P6048-Wind-Data-2000.wnd)

Month	Wind Speed (m/s)
January	5.983
February	5.915
March	6.210
April	5.292
May	6.377
June	5.295
July	5.283
August	6.653
September	5.004
October	5.966
November	4.910
December	4.424
Annual average:	5.612

Other parameters

Time step (minutes)	60
Altitude (m above sea level)	0
Anemometer height (m)	10

Advanced parameters

Weibull k	1.96
1-hr autocorrelation factor	0.905
Diurnal pattern strength	0.0937
Hour of peak windspeed	4

Scaled annual average (m/s) 5.61

Figure 28: Average Monthly Wind Speed @ 10m (2000)

8.4 ELECTRIC VEHICLES

For modelling purposes, it was assumed that the number of electric vehicles on the island would increase to a maximum level of 50 units.

From discussions with LHIB, an average of 3,000km/year has been assumed for the total distance travelled for each vehicle, or an average of 57.7km/week. A third assumption is that the vehicle has enough range to only require charging once per week (that is it has a usable range of 70km or greater), although the vehicle is expected to be plugged in multiple times per week. This allows us to assume that across the year 100% of the charge for the vehicle will be able to be delivered from the excess renewable energy, when it is available.

The quoted energy efficiency for a Tesla Roadster (a high-performance battery powered EV) is approximately 8km/kWh of charge. If we assume that the EV's running on Lord Howe Island are half as efficient (that is, they are more utility vehicles, carry two or more people and have better ground clearance for light off-road duty) we would obtain an efficiency figure of 4km/kWh.

For the entire fleet of 50 units, this equates to 150,000km per year for an energy consumption of 37,500kWh/an. This equates to approximately 14.4kWh/vehicle/week or 187.5kWh/vehicle/quarter.

Referring this quarterly energy consumption value back to the "Consumption Summary Export 01-07-2010.xls" document supplied, this compares favourably with the detailed EV recharging installations (198kWh) at the time, assuming a full 12 weeks of operation in the quarter.

The modelling for these vehicles will be done outside of HOMER where the amount of excess energy is significantly more than required for the running of the vehicles.

Figure 29 – Nissan Leaf EV[31]

Figure 30 - Electric Utility Vehicle[32]

---

[31] http://www.nissan.com.au/webpages/about/Electric_vehicles.html

[32] http://www.rei.net.au/pdf/electric_utility_vehicle_brochure_170311.pdf

8.4.1 DEMAND MANAGED HOT WATER SYSTEMS

The LHIDS has previously introduced ripple control on the existing base of hot water systems. From the data supplied, it is not possible to accurately quantify the consumption across the year, so we are required to make some assumptions.

The primary assumptions relate to the number of installed services and the size of the heating/boosting elements.

It is assumed that every “Domestic” connection will have one hot water service, with an element size of 4kW. It is also assumed that on average, the hot water service runs twice a day for a total of 1 hour. Any non-domestic connections are assumed to have any hot water services (including electric kettles) non-controlled and therefore not part of the demand managed hot water system calculation.

This leads to an installed capacity of 178 units, for an uncontrolled peak demand of 712kW. The consumption would be 260MWh per year, or approximately 11.3% of annual energy.

This load will be modelled in HOMER using a “deferrable” load with a daily consumption of 712kWh and a “storage” level of half that (356kWh) to simulate running the hot water systems twice per day. The maximum demand will be 712kW with a minimum demand of 0%.

Note that the base-case model will not have the “deferrable” load enabled, as the demand data already includes the load deferred to times when LHIDS has been able to support the load.

For a single household, this works out to be approximately 368kWh/quarter, or nearly 32% of the average energy consumption of 1,200kWh/quarter.

8.5 ECONOMIC DATA

Some economic data was supplied by LHIB. Any assumptions/simplifications of the information received form LHIB are noted.

Note: Capital costs are installed costs including control, installation etc

Table 12: Diesel Generator Costs

Generator Identifier	# 1	# 2	#3	# 4
Nominal Power kW	300kW	300kW	300kW	425kW
Model	Detroit Series 60	Detroit Series 60	Detroit Series 60	Not Modelled
Total Installed Cap. kW	900kW prime, 1,350kW emergency			
Fuel Type	Diesel			
Capital $	N/A			
Replacement Costs* $	100,000	100,000	100,000	160,000

O&M * $/hr	10.00	10.00	10.00	12.50
Accum. Op Hours	0	0	0	0
Life Expectancy Hrs	100,000			

*Assumed

Table 13: PV Module[33]

PV Technology	Thin-Film
Mounting – Type	Fixed
Capital*	$6.5/Wp
Replacement*	$6.5/Wp
O&M*	$0.10/W/yr

* Assumed

Notes: Capital costs are installed costs including modules, array frames and are based on a flat plate, fixed array. Refer to Figure 31, for the trend in PV Module Costs 2001-2010.

Note that as the Solar PV systems are to be purchased and maintained by the customer, these costs were not used in the modelling.

---

[33] PV @ $4.7/W for mono-crystalline panels, ref http://www.solarbuzz.com/Moduleprices.htm (accessed May 2010)), Foundations/ install costs etc ~ $2/W. Final delivery costs may change this figure given the remote location.
Note: Thin-film PV panels are generally cheaper per watt than mono-crystalline panes. Thin-film currently have a purchase cost as low as ~$1.7/W. The figure of $4.5/W used in this report may seem a conservative figure, yet when taking into consideration the quality of panels and particularly the installed costs of the array, given the remote location, the use of $6500/kW figure is considered reasonable, until final costings are sought.

These costs are balanced against an initial price indication provided for such an installation of $5/W ±20%= 4-6 $/W, provided without detailed knowledge of the site.

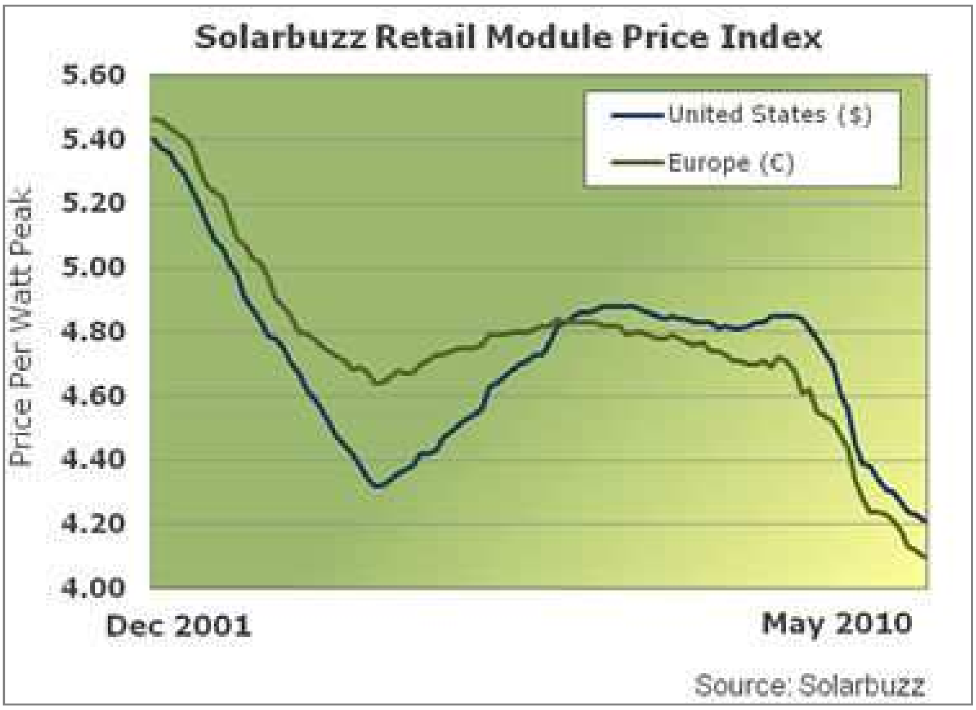


Figure 31 : PV Module Costs Trend 2001-2010[33]

Table 14: Inverter Costs[34]

Capital	$0.70/Wp
Replacement	$0.70/W
O&M	$0.01/W/yr

Notes: Replacement costs cover the replacement of the inverter(s) every 10years

Table 15: Battery Costs

Technology	Zinc Bromine
Manufacturer*	Zest Energy - ZBB
Model	ZESS50
Capital	$400,000
Replacement (electrodes)	$40,000
O&M	$15,000 per year

*Assumed

---

[34] PV Inverter ~$0.70/W - based on information from SMA @ ~$0.6/W in 2009 and http://www.solarbuzz.com/Inverterprices.htm (acc May 2010).

Table 16: Flywheel Costs

Capital*	$/500kW	$750,000
O&M*	$/yr	35,000

* Assumed

Table 17: Fuel Costs - Delivered

Diesel Fuel	$/L	1.50

Table 18: Additional Taxes

Carbon Tax (CO2e)	$/t	0*

*Assumed – as the current legislation only affects the 500 largest polluters in Australia

Table 19: Economic Input

Nominal Discount Rate (WACC)	%	12.2*
CPI	%	2.5%
Fuel Price Index	%	6.0%
REC Price Index	%	5.0%
Project Life	yrs	20

* Real (effective) Interest Rate ~ 9.5%

8.6 MODEL

8.6.1 CONFIGURATION

The system at Lord Howe Island is modelled as shown in Figure 32.

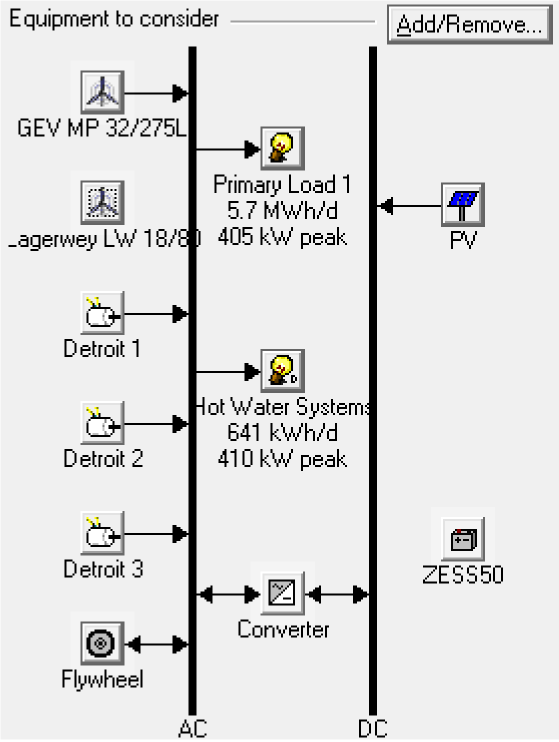


Figure 32: Investigating the potential system configuration – Lord Howe Island

8.6.2 MODEL ASSUMPTIONS

Diesel Generation

- Step-load capacity of the diesel generators is assumed to be suitable for the load conditions.
- Total life of the generators is expected at 100,000 hrs
- Minimum loading on the diesel generators assumed at 30%, provided load conditions allow.

Fuel

- It is assumed that the fuel costs provided by LHIB, as shown in Table 20, are not inclusive of delivery costs, excludes GST and is inclusive of the fuel tax credit (ex-excise).

Table 20: Fuel Costs

Average Diesel Cost $/L	$1.00
Average Delivery Cost $/L	$0.50

- The fuel cost of $1.50/L is applied in the modelling exercise with sensitivities applied to the indexation of fuel costs across the life of the project.
- Table 21 illustrates the annual increase in fuel price for three different rates of inflation. FPI is assumed at 6.0% (3.5% higher than CPI).

- Data from the Australian Institute of Petroleum list the average TGP (Terminal Gate Price) for Diesel fuel for the period 2004 – 2009 as shown in Table 21.

Table 21: Average Diesel TGP - Darwin (2004-2009)

Year	**Average Diesel TGP (inc of GST)**	
	Regional Average Darwin	Annual Change %
2004	100.5	
2005	117.8	+17%
2006	131.8	+12%
2007	127.7	-3%
2008	155.4	+22% MAX
2009	116.9	-25% MIN
	Average	**+ 4.6%**

To put the historic escalation rate shown in Table 21, into context, noting the volatility and variation in fuel costs that are inevitable.

Flywheel System

- The parasitic load is expected at around 360kWh/day as parasitic load at maximum operating speed is 15kW. Therefore, assuming that the Flywheel does not operate at max velocity 100% of the time, this still incorporates some additional losses.

Solar PV

- It is assumed that there is no shading on the array.
- It is assumed that the panels have an efficiency of 13% at standard test conditions
- De-rating Factors:
  - Soiling ~ 0.93[35]
  - Module Mismatch ~ 0.98[36]
  - Wiring ~0.98
  - Availability ~ N/A
  - Age - Guaranteed 90% at Year 10, 80% at 25 years[26]

---

[35] http://www.xantrex.com/web/id/227/DocServe.aspx (acc May 2010)
[36] PV Watts, http://rredc.nrel.gov/solar/calculators/PVWATTS/system.html (acc May 2010)

See Figure 33 for the discreet steps used when modelling the de-rating of the First Solar panels.

Solar PV Inverters

- The DC/AC conversion efficiency of the inverters is assumed to be 96% on average, which is less than both the measured figures quoted on the "Go Solar California" reports and the data supplied by the manufacturer
- The units are able to supply the rated power (8,000kVA) up until 40degC, whereby they start to de-rate until their final temperature cut-out of 60degC. As the ambient temperatures at Lord Howe Island do not exceed 40degC, energy loss due to temperature de-rating of the solar inverters has not been taken into account.

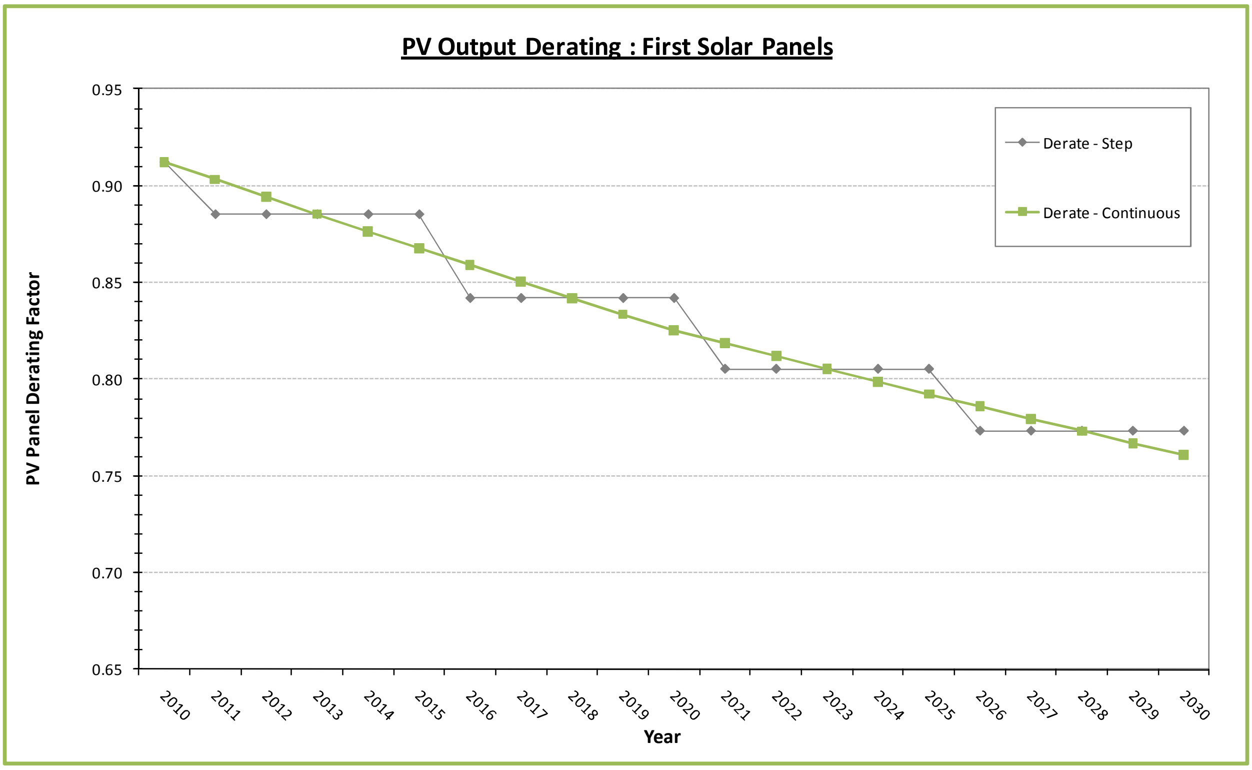


Figure 33: PV De-rating - First Solar Panels

Load

- It is assumed that all 'out of town' residences are connected to the main electricity grid.
- The data obtained from site was amended to cover out of range and missing data points. The load profile from this data is used in the modelling exercise.
- All loads are balanced.
- Load Growth – was estimated to be a maximum of 3.0% per annum for the 20-year period from 2008. This growth rate was applied across the 20years of which the project is to be assessed. To simplify the modelling exercise the load growth was simplified into 4 discreet

steps rather than a continuous steady increase, see Figure 34. It is assumed the RE/Diesel system is installed in 2010 and 2011 is Year 1 of the project.

Figure 34: Lord Howe Island Load Growth - Discreet vs steady growth

Station Operation

- Power quality is assumed to be retained in each of the system configurations – this will need to be confirmed through further modelling of the dynamic and transient system behaviour.

Simulation

- The simulation was performed on a 10min time step, given the resolution of data available

8.6.3 MODEL VERIFICATION

Results of the HOMER model based on the system currently operating on Lord Howe Island were verified using fuel consumption figures supplied by LHIB, see Table 22.

Table 22: Model Verification 2010 load figures

2010 Month	Energy Consumption	Fuel Consumption	Peak Demand	Average Efficiency	Average Demand
January	210,500	54,000	398	0.257	283
February	168,750	46,850	385	0.278	251
March	205,350	51,400	400	0.250	276
April	198,600	50,900	451	0.256	276

2010	Energy	Fuel	Peak	Average	Average
May	204,000	49,700	445	0.244	274
June	187,650	46,950	416	0.250	261
July	181,200	46,700	416	0.258	244
August	180,000	46,450	386	0.258	242
September	191,700	46,200	420	0.241	266
October	195,900	48,650	444	0.248	263
November	179,100	46,000	387	0.257	249
December	208,200	51,350	447	0.247	280
Annual	**2,310,950**	**585,150**	**451**	**0.254**	**264**
Modelled	2,313,507	585,432	451	0.253	264