SUSTAINABLE ENERGY MANAGEMENT FOR A SMALL RURAL SUBDIVISION IN NEW ZEALAND

A thesis presented in fulfilment of the requirements for the degree of

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ABSTRACT

An eight-lot residential subdivision in central Wairarapa is being developed to demonstrate the principles of sustainable resource management. Local energy sources for low and high grade use, including electricity sourced from proposed grid-integrated, on-site, distributed generation will supplement imported network electricity. A unique component is an internal loop grid for lot connection that interfaces with the local network through a single connection point.

A decision model was designed as a decision-support tool for the development based on the annual supply-demand electrical energy balance, site infrastructure covenants and a range of economic and technology criteria. Solar and wind resources were assessed for potential supply of electricity to the community energy system. Three demand profiles were developed using supplied and estimated electrical demand data; and included assumptions on thermal performance of the houses, the use of low-grade heat, user behaviour, and appliance use. Supply and demand were analysed as daily average profiles by hour for each month of the year.

The decision model outputs were designed to give a graphic view of the system options. The accompanying output datasets also enabled a number of scenarios for connection configurations, load management, and economic sensitivity to be explored for their impact on the communal approach to managing energy.

The viability of the community energy system is significantly influenced by managing demand level in conjunction with system size, capital cost management, and tariffs for electricity import and export. Energy requirements could be best met in the short term by installing a site-wide mixed generation system of sized capacity between 5 and 11kW, supported by metering and information technology to deliver management data to the residents.

Future research opportunities exist to continue monitoring technical, economic and social outcomes from this unique community development. Incentivising private investment in user-focussed energy innovations is an option for New Zealand to consider in the current climate of market-driven large scale electricity developments.

ACKNOWLEDGMENTS

Many people have contributed along the way to completing this work. In particular I would like to thank:

The team at Beacon Pathway Ltd, in particular Vicki Cowan and Verney Ryan for providing data, encouragement, and much useful feedback.

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Andy Duncan, for suggesting I use Totarabank as the subject of my study; and for demonstrating what can be achieved through tenacity and vision.

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Numerous friends, family and fellow tutors from Literacy Wairarapa for being so tolerant.

Lastly and most importantly, I want to acknowledge my husband Steve for his moral, technical, and financial support. It's now my job to do the same for him.

There were a number of unexpected challenges during the course of this work. One source of inspiration that encapsulated these rocky periods came from the late Sir Edmund Hillary's 1952 crossing of the Nup La Pass in a storm:

> *"Often I'd come to an impossible drop or a gaping crevasse and know I was on the wrong route. And then I would climb wearily back to the last piece of track I knew and try again. Many of the crevasses had widened and many of our snow bridges had gone. But we found a way down."*
>
> Excerpt from High Adventure, (Hillary, 1955)

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LIST OF ABBREVIATIONS

BANANA	Build Absolutely Nothing Anywhere Near Anyone
CHP	Combined Heat and Power
DM	Decision Model
EDF	Energy Data File
EECA	Energy Efficiency and Conservation Authority
HEEP	Household Energy End-use Project
ICP	Individual Connection Point (to the electricity network)
kWh	Kilo watt hour
LRMC	Long Run Marginal Cost
MED	Ministry of Economic Development
NIMBY	Not In My Back Yard
NREL	National Renewable Energy Laboratory (US Department of Energy)
NPV	Net Present Value
PCE	Parliamentary Commissioner for the Environment
PV	Photovoltaic
RE	Renewable Energy

1 INTRODUCTION

1.1 Introduction

Household energy use is becoming a familiar topic for residential users in New Zealand, as historic sources of cheap renewable hydro and geothermal electricity are being supplemented with fossil fuels. Health issues arising from damp, cold houses combined with increasing costs for electricity, an increasing expectation of constant supply, new regulations on air quality and significant changes in the structure of the energy market have all created challenges of affordability, health and resilience to loss of electricity supply. The challenges are also impacted by the climate change debate and the subsequent options that exist for managing our energy sustainably at a residential level.

Sustainable energy management can encompass a range of options at the residential scale, from single houses to communities. For the purposes of this report, several of these options are considered in the context of a case study of a multi-lot residential subdivision. The options explored include:

- The use of local renewable resources for generating high-grade electricity and low-grade energy for heating and other services
- The use of grid-integrated distributed generation systems for electricity supply
- The use of technology and systems for managing demand and supply such that residents themselves can consider alternative ways of managing energy without compromising basic needs.
- Promoting energy conservation and energy efficiency in house performance, appliance use and user behaviour as key elements of demand management

Central government has responded slowly in delivering regulations to improve house performance, and incentivise residential energy management options due to a combination of low political will, industry resistance and market signals that incentivise large-scale centralised energy initiatives rather than regional consumer-centric solutions. However, recent changes in regulation for distributed generation now make residential grid-integration a legal option – but implementation is not wide-spread. Skills, knowledge and lessons are still scarce.

Consequently one of the opportunities for change is through education, demonstration and investment by committed individuals and organisations.

Totarabank is a multi-lot development designed to operate under sustainable principles including the use of energy resources. This development is one such project demonstrating the combined approaches of energy conscious house design, localised energy resource use and increased awareness of energy issues in a community setting.

Subdivision is common practice but designing for sustainable energy use is not generally an inherent part of the process; nor is a community approach to managing energy and the provision of electricity. Currently in New Zealand, a few predominantly rural communities taking a communal approach to energy provision tend to have committed individuals with a common vision, issues with receiving affordable electricity services, and access to plentiful local renewable energy. It is still rare for new residential developments to have a 'community' vision for energy management, and to implement the best way of achieving it, including the use of house design that maximises thermal efficiency and solar performance.

This thesis will explore energy management in a grid-integrated system, with a focus on sustainable provision and use of electricity; and indicate what the major factors are in the decision making process.

1.2 Case Study Background

1.2.1 The Totarabank Development

Totarabank is located 8km east of Masterton, central Wairarapa. The development consent was approved under discretionary activity criteria in the District Plan on the basis of environmental impact being less than for a standard, controlled activity subdivision (Duncan, 2005). The site consists of eight residential lots 1200 to 2100m^2, one lot set aside for a communal building, and the remainder of the seven hectare area is common land. Further detail of background and layout for Totarabank is found in Appendix A1 Totarabank Overview.

The key philosophies of Totarabank are:

- to provide a lifestyle option with small building plots, but extensive open common land in a park-like setting,
- to design the development to optimise the use of natural occurring renewable energy, to promote energy efficiency measures,
- to design a more sustainable land development, carried out with respect to the naturally occurring landform, flora and fauna, and
- to design a setting that passively creates a healthy lifestyle.

Totarabank property covenants and Residents Association rules provide the framework for property management, decision-making and activities (Duncan, 2005).

The implications of the covenants around energy use and management are that:

- all lots are designed to make maximum use of solar energy for passive heating, hot water and photovoltaic electricity generation,
- coppicing firewood is provided for heating energy,
- Building Performance Indexes (BPI) are specified by floor area to maximise energy efficient design,
- each lot is limited to maximum current of 30A and 1 switchboard,
- the site is designed with each lot connected to an internal grid, with 1 Individual Connection Point (ICP) connecting Totara Bank to the external electricity network (440V) via a 50kVA transformer at the gate, and
- reconciliation of energy use will be done through Residents Association rules.

The development of this site represented an opportunity to research and model the significant decisions around sustainable energy provision (including electricity export), within the conditions of the covenants. While this research and model cannot pre-determine the eventual decisions of future residents, it will create a detailed basis for better-informed decisions by them. In addition to exploring distributed generation as part of the overall provision of energy, this research provides the opportunity for gaining a better understanding of the contribution building performance and energy use patterns can have in such systems.

1.2.2 Defining Sustainable Energy

Sustainable energy has been defined by Totarabank as being renewable and locally, preferably site-sourced. Other features to consider for sustainable energy include (MED, 2007b), (Boyle, 2004):

- low to no emissions of greenhouse gas or other harmful pollutants,
- promotion of environmentally sustainable energy technology,
- reduced/no dependence on non-renewable fossil fuels, and
- no perpetuation of social inequities or health hazards.

Therefore the approach to sustainable energy management at Totarabank will require a combination of behaviour, resources and technology that is safe for environmental and human health and appropriate to the finances and needs of the residents.

1.2.3 Residential Sustainability Research

A major contributor to national research on sustainability in the residential building context is a research consortium made up of industry, local government and research organisations - Beacon Pathway Ltd[1]. Their work has been aimed at ways of improving New Zealand homes' sustainability in terms of being warmer, healthier, cheaper to run and better for the environment. This project thesis has been initiated independently of Beacon's housing research programme.

At the time of this project initiation (March 2007) there was little available scientific information on the demand profiles from houses specifically designed to be lower in energy consumption that could be used for sizing supply systems for the Totarabank situation. Research at Beacon has included construction of demonstration buildings known as NOW Homes®, where building design and performance along with occupant behaviour are monitored over a period of one to two years.

Beacon energy monitoring data[2] provided an opportunity to use a monitored input in the demand modelling for Totarabank, while recognising the data represents the combination of house performance and user behaviour. Such inputs contribute to testing scenarios for sustainable energy management in the residential context, as long as uncertainty around the impact of user behaviour is acknowledged.

1.3 Problem Statement

Taking a communal approach to grid-integrated renewable energy distributed generation systems used in conjunction with sustainable energy management practices, is not currently well understood in the NZ market. Potential opportunities to improve the technical and economic viability of these systems within pre-set community covenants need to be identified.

This can be done through understanding:

- the electricity connection options within the community while integrated with the local electricity network;
- the various configurations of renewable energy technologies possible within the community; and

[1] Beacon's aspirational goals are: 1. To bring the vast majority (90%) of New Zealand homes to a high standard of sustainability by 2012; and 2. That every new subdivision and any redeveloped subdivision or neighbourhood, from 2008 onwards, will be developed with reference to a nationally recognised sustainability framework. See www.beaconpathway.co.nz.

[2] Monitoring data is collected, and subsequently provided by BRANZ Ltd.

- the impact that energy efficient building design and user behaviour will have on the subsequent load profile, and the effects on the required renewable energy technology configuration.

Looking at these factors in combination will provide valuable insight into the impacts of energy management practices on the financial and technical viability of communal grid-integrated renewable energy systems. Such systems are relatively new at a small scale in New Zealand, and little is understood about the relative benefits of electricity export versus on-site utilisation for multi-lot sites. This information would lead to greater understanding of the best balance between energy management and renewable energy design.

1.4 Aims

The aims of this research are:

- To assess how the Totarabank principles and infrastructure (as set by covenants and rules) may work in the context of including grid-integrated distributed generation in the development.
- To model how a mix of grid-integrated distributed generation will impact the value of energy generated on-site and what the implications could be for taking a communal approach to energy management.
- To identify the key factors that will need to be considered for practical management of energy use relevant to the site and development principles.

1.5 Objectives

The objectives of this study were to:

- Provide a decision-support framework for investment in sustainable distributed generation energy systems for a multi-lot development
- Establish the significant criteria influencing the economic, environmental, technical and social viability of a net-billed, grid integrated system
- Identify the range of energy-use options, including the impact of energy-efficient house design on energy system performance

Understanding and deciding on options for energy management requires a framework demonstrating how energy may be sustainably managed, as an alternative to the standard options for electricity connection and supply on this site.

It is envisaged that detailed system design and specification will be done subsequent to the project outcomes, once the main elements of the energy use options have been identified.

It could be assumed that anything other than standard grid connection will be uneconomic to Totarabank residents; therefore this study adds to the debate around sustainable energy use and the impact of greater consumer involvement in our energy future.

1.6 Project Exclusions

This research does **not** include design for:

- building thermal performance or energy efficiency; but it does assume demand characteristics on the basis that certain features may exist (such as insulation, passive solar design, etc);
- thermal modelling for hot water systems;
- total energy auditing in terms of quantifying potential calorific input from energy sources other than electricity and assumptions made as to when these energy sources are used as alternatives;
- renewable technology sizing or specifications in terms of the final and complete site installations, done subsequent to the conclusion of this research, or
- community-owned energy schemes such as wind farms supplying a large number of houses in an area.

1.7 Report Overview

An overview of the structure of the report and the outline of each chapter is shown in Figure 1.

Chapter Two provides an overview of the NZ market focussing on electricity, distributed generation and sustainable energy. Management of community energy systems is introduced, and insights from a variety of national and international cases studies are reviewed.

Chapter Three introduces the methodology underpinning the Decision Model design with an emphasis on the first stage of the processes managing the supply and demand raw data including demand data benchmarking. These processes lead into the Chapter Four overview of the processes and design features of the Decision Model and an overview of the design of the scenarios that the Decision Model was used to analyse. The validation process for the Decision Model against other energy models is also covered.

Results of the Decision Model application are provided in Chapter Five, along with the results from the scenario analyses introduced earlier. Chapter Six reviews and discusses implications from the outcomes of the results in Chapter Five. Final conclusions and recommendations for future work, and energy management options for Totarabank are proposed in Chapter Seven.

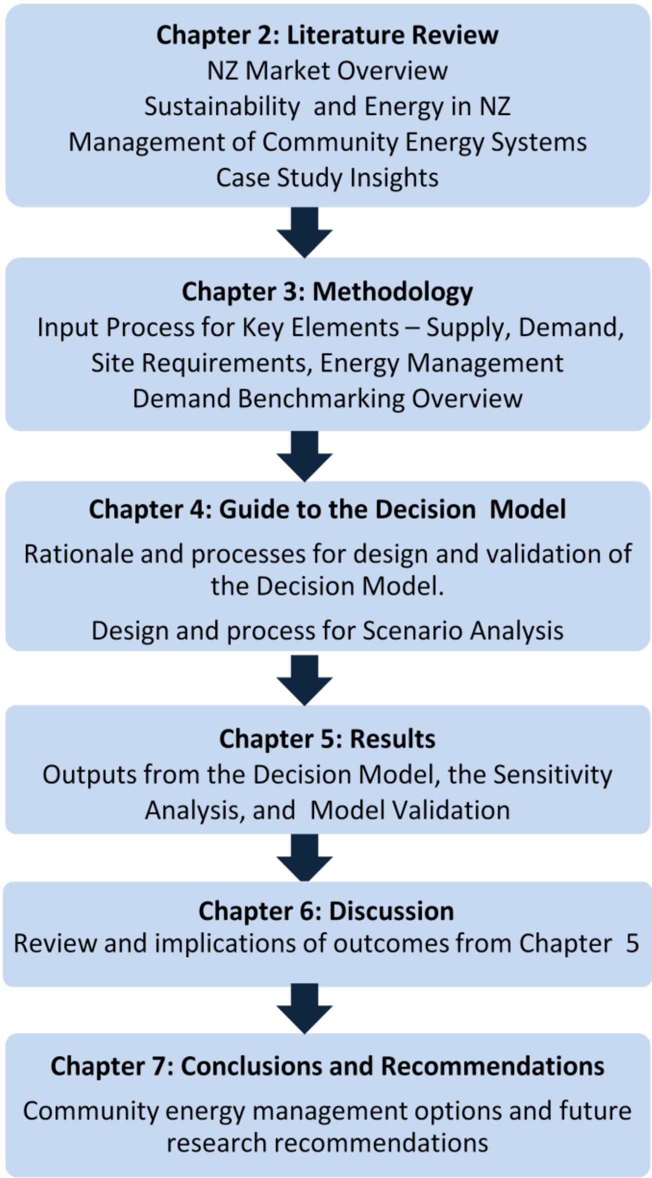

Figure 1: Outline of report structure

2 LITERATURE REVIEW

This literature review explores the implementation of small-scale distributed generation in the New Zealand context of sustainable energy management, with a particular focus on community-scale developments. Although the Totarabank project is a private development, it provides an example for multiple residences in close proximity (much as for any sub-division). There are a number of features being promoted by this project, that may be transferable in future to other multiple-residence situations – these include grid-integration of any on-site generation, managing energy use, and putting sustainability into practice for the long-term benefit of residents.

The findings of the review set up the boundaries and inputs for the decision-support framework model. This framework will provide a practical interface for understanding sustainable energy management options for a group of households in terms of managing electricity supply that includes grid-integrated local renewable resources. This could include apartment block tenants, as well as housing clusters.

Key Definitions

Sustainability:

> "*Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs*." (Brundtland Report, 1987).

This means having a focus on people, a future-based view, considering the effects of decisions; and encouraging a sense of partnership.

Sustainable energy management in this study means taking a long term view of energy provision by ensuring:

- the community's social, economic, environmental and cultural needs are not compromised,
- that they have a means of participating in energy provision and management, and
- that energy sources are reliable, environmentally responsible (as renewable as possible) and resilient to future change

Distributed Generation: According to Electricity Governance (Connection of Distributed Generation) Regulations 2007, distributed generation is defined as:

> *"Equipment used or proposed to be used for generating electricity that is:*

i. *connected, or proposed to be connected, to a distribution network, or to a consumer installation that is connected to a distribution network; and*
ii. *capable of exporting electricity into that distribution network"*

Exporting of electricity may also be referred to as 'grid integration', or 'grid-tie'.

Electricity versus Energy: This study is concerned with the energy requirements for residential living needs (heat, power for high-grade use) not including transport. The energy may be delivered from a variety of on and off-site energy carriers including electricity, biomass, and natural gas. Electricity in turn, may be sourced from the local network (where it could be generated from a variety of sources), or from on-site renewable generation.

The literature is reviewed under the following sections:

- Overview of the New Zealand Electricity Market
    - Market structure; renewable energy in NZ; Distributed generation in NZ
- Sustainability and Energy in NZ
    - Major initiatives; indicators and measures
- Management of Community Energy Systems
    - Defining community energy systems, managing the energy balance, distribution and control systems
- Insights from Case Studies and Research

2.1 Overview of the NZ Electricity Market

<u>2.1.1 Market Structure</u>

The Electricity market in NZ is the result of the development of a large-scale centralised energy system developed since the 1920's (PCE, 2006). Local energy use has evolved to the utilisation of electricity and gas supplied by large generation plants relying on extensive transmission and distribution infrastructure, to deliver energy to where it's needed. The National Grid provides electricity generated from coal, gas, and various renewable sources to local networks as customer demand requires – often thousands of kilometres away from the generator. This situation has evolved from efforts to supply maximum energy for minimum cost; the ongoing challenges of which include the rising costs both financially and environmentally of developing large-scale electricity supply for meeting forecast demand. More detail on the political and regulatory market history is in Appendix A2 NZ Electricity Market History.

The participants of the New Zealand electricity industry are:

- Five generators (two of which are private sector companies) producing electricity from about forty large power plants using a range of resources,
- A National Grid operator to manage the logistics and reliability of the high voltage transmission system (the National Grid), to take high voltage power from the point of generation to the point of local distribution;.
- Twenty-eight network distributors/lines companies[3] operating under a variety of ownership models to distribute power to end-users.
- A market regulator – Electricity Commission of New Zealand (ECNZ). The new Government has signalled a review of ECNZ's function.
- Five major electricity retailers[4] (and a number of smaller ones) who bid through the spot market to purchase wholesale electricity for sale to end-use customers ranging from large industrial users to homeowners.

The majority of the generators, retailers and Transpower are operated as State Owned Enterprises (SOE's). This has created a dichotomy between returning maximum profits to the shareholder (the Government and ultimately the taxpayer) and incentivising efficiency and conservation of electricity use.

As of March 2008, electricity represents around 30% of total energy consumption, shown in Figure 2 (MED, 2008).

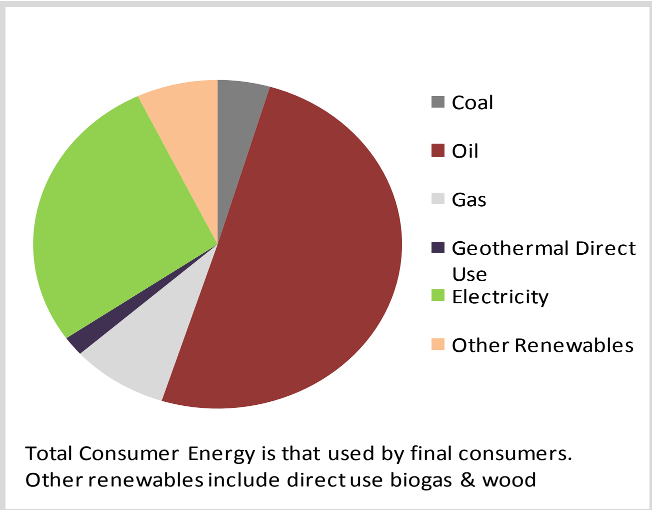

Figure 2: Total consumer energy (PJ),to meet New Zealand's total demand in 2007

[3] These were initially separated from generation business but recent regulation changes allow lines companies to participate in some sales of their own generation.
[4] Most of the retail sector is facilitated by generators, known as 'gentailers', with the result that end-user charges integrate costs for electricity transmission, distribution and purchase.

In the last 10 years, consumption of electricity, and combined non-electrical fuels (oil, gas, coal, biogas, wood and geothermal) have all grown by over 20%.

Electricity is generated across NZ, predominantly from generation sites greater than 10MW capacity. Only 2.3% (982,085 MWh) of electricity came from plants smaller than 10MW in 2007 (MED, 2008), the main contributors being hydro, gas and biogas. This does not include electricity from cogeneration which can provide useful injections of energy from a variety of sites located alongside industrial operations maximising the use of local plant and resources.

Generation capacity for renewable electricity in 2007 was 6,253 MW, being 67% of total generation capacity (EDF, 2008). Investment in new generation such as wind, biogas and wood added 3% of capacity.

Consumption by Sector

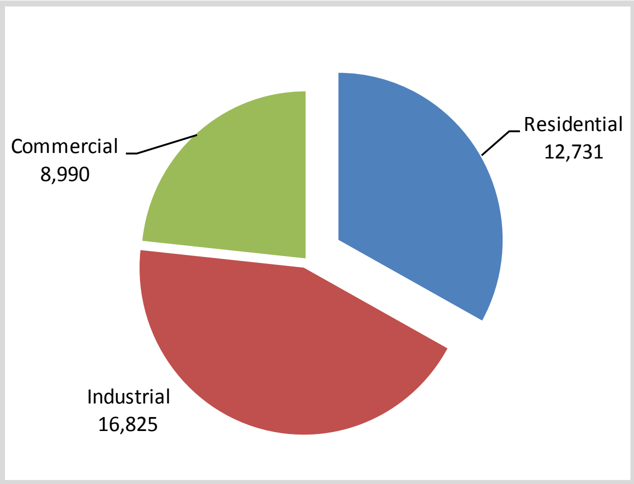

Figure 3: Electricity consumption (GWh) by Sector, 2007

Considering the residential sector represents a third of consumption (Figure 3; MED, 2008), it has had the most significant increase in price since 1995. Figure 4 compares how prices have changed over a period of 10 years[5] – the residential increase of 32% is significant compared to minimal increases for the other sectors (MED, 2008).

[5] At the time of writing, further revelations were made (Small, 2009) regarding electricity prices increases after the release of the Energy Data File (from which this data is taken). The Commerce Commission released a report indicating that the four major electricity generators used their market power to maximise profits, including withholding power at peak times. The report claimed prices rose 72% from 2000 to 2008 – thus supporting the view that pricing is about maximising profit.

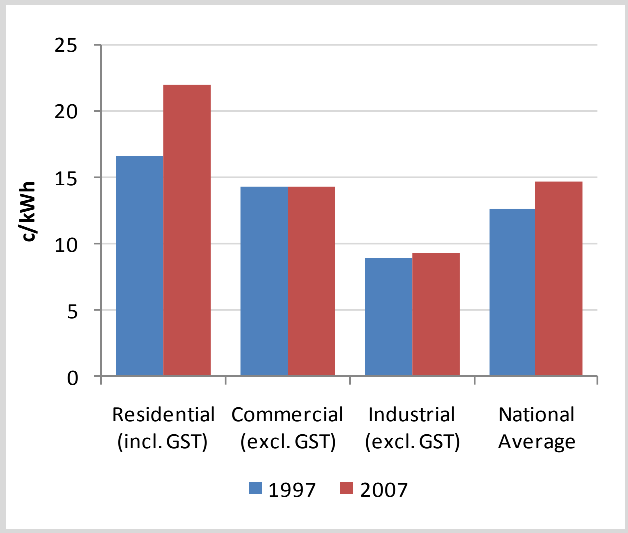

Figure 4: Sector Electricity Price Comparison over 10 years (2007 values)

Sector consumption patterns over time, (Figure 5) indicate residential consumption is not growing as fast as the other sectors (MED, 2008). Average residential consumption stayed relatively constant over the period whereas average consumption in the non-residential sector increased by over 10%. This suggests that increasing consumption in this sector is not underpinned by increased efficiencies and may reflect consumption becoming more energy inefficient or is being driven by increased production levels (large industrial users), or a growth in new demand such as agricultural irrigation. Whatever the contributing factors are, increased electricity revenues are being extracted from the sector of the market that has no power to negotiate price, only the ability to change suppliers.

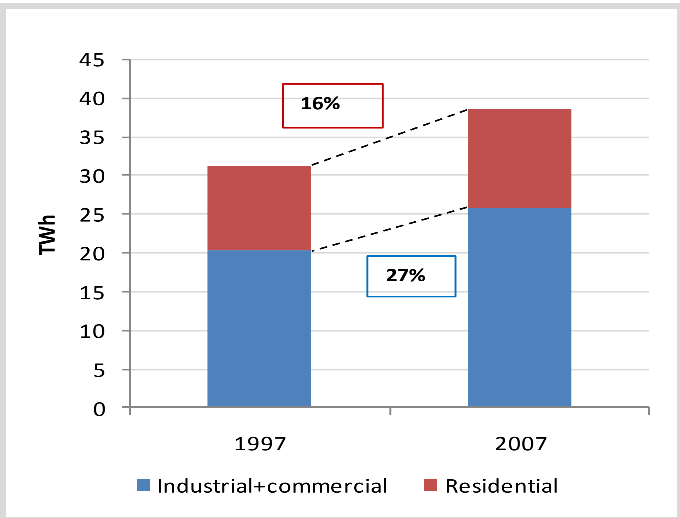

Figure 5: Sector Consumption Growth over 10 years

Residential Consumption Patterns

Space heating is the largest end-use, followed by hot water (Isaacs, et al., 2006). Electricity is the most common fuel source in NZ houses, but there is a trend to greater use of gas for hot water and solid fuel use for space heating. Developments in appliance efficiency, along with appliance use are a forecast of reduced energy consumption by appliance, but offset by a greater number used per household – potentially leading to increased electricity use over all.

HEEP estimates the top 20% of households use over 14,450 kWh of energy per year, of which over 10,000 kWh is electricity (the remainder is gas, wood or LPG) and account for 36% of total household energy use.

2.1.2 Renewable Energy in New Zealand

Renewable energy in NZ is used at all levels (passively and actively), as direct energy for heat (from sources such as geothermal, wood and biogas), or to generate electricity. Uses include (EECA, 2006):

- household level low grade energy for passive heating and cooling; powering small appliances, and high grade electricity generation using micro-generation such as PV and wind;
- commercial/industrial DG installations for local area supply; and
- large-scale centralised installations of wind, geothermal and hydro supporting the National Grid.

In 2007, 29% of total energy used was derived from renewable resources, including electricity. Non-renewable energy still has a major part to play in NZ due to transport needs, with oil representing around half of total energy.

In terms of electricity, Figure 6 shows energy derived from renewable resources represents about 67% of energy used (MED, 2008). This reduced as a result of the dry winter of 2008 – highlighting the vulnerability of our reliance on large hydro for renewable supply.

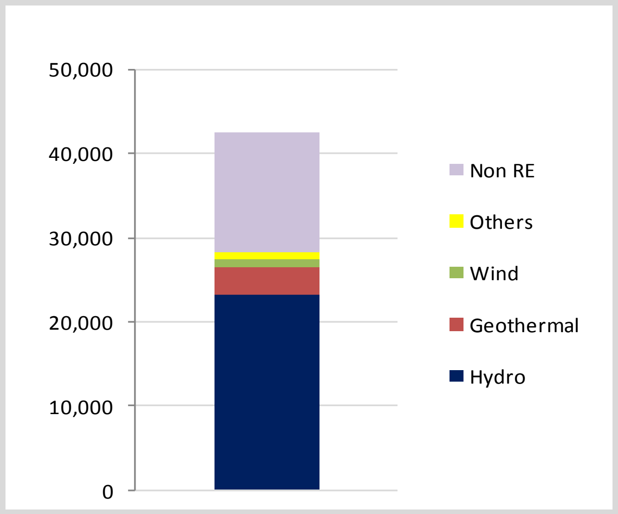

Figure 6: Electricity Generation GWh, by Fuel Type, 2007

Electricity is generated predominantly by generation plants sized over 100MW (Figure 7). Generation plants less than 10MW (including cogeneration) mostly utilise renewable resources, or gas (MED, 2008). Smaller plants are located closer to the point of use where energy sources such as waste heat can be utilised.

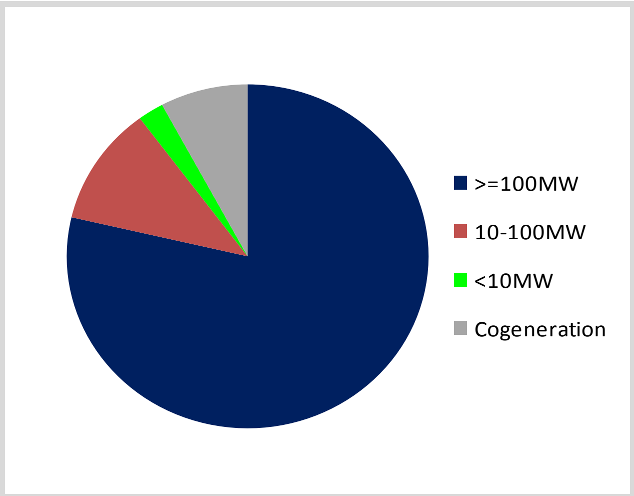

Figure 7: Electricity Generation by plant size, 2007

Issues for Large-scale Variable Renewable Generation

Wind generation capacity is now around 300MW and is expected to continue making an increased contribution to NZ's future energy needs. Wind represents a further dichotomy between the value of renewables and the tyranny of harnessing natural resources on a large-scale – with a growing rate of resistance over the amenity effects for communities and landscape (Barry, 2007). Ongoing development of wind generation (and most likely large hydro and solar) will have to manage the following issues:

- grid integration of large scale variable supply especially at high penetration levels – to maintain supply/demand balance;
- rethinking the ownership models to increase community participation;
- accurate resource assessment based on long-term data (wind speed is the major economic driver);
- location effect on resource quality, infrastructure access, connection quality and proximity to transmission;
- environmental effects and consenting barriers, including community opposition;
- relationship between materials cost, number of turbines (or dam size) and access costs for particular locations; and
- environmental and community impact of ongoing maintenance and operation.

2.1.3 Distributed Generation in New Zealand

Distributed Generation (DG) includes a wide range of system capacity (Figure 8) with applications ranging from micro and small-scale domestic systems delivering electricity and low grade heat; to commercial/industrial sized installations that include combined heat and power plants (CHP), cogeneration, and generation plants fuelled by renewable or fossil fuels (CAENZ, 2007). Renewable fuels for DG include wind, PV, biomass, hydro and geothermal.

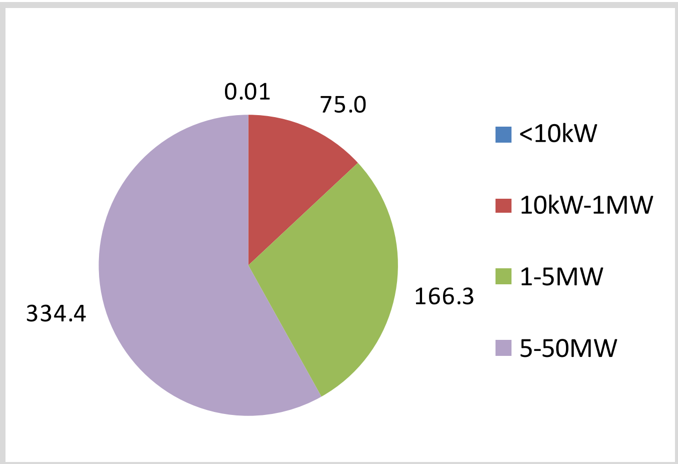

Figure 8: DG Capacity in MW, by system size, 2006

DG can be installed by private individuals, businesses, large generators and lines companies. DG systems based on diesel generator sets are common– they can be operated on demand, and are used by commercial businesses for peak load lopping or peak load supply. The total capacity of current DG systems installed (Figure 8) represents approximately 6% of the total electricity capacity of 9,100MW reported in the 2008 Energy Data File.

It should be noted that systems of less than 1MW capacity make a very small contribution to this total. However, as system size decreases, the data is less accurate. Hydro energy is the most common renewable energy source, and along with fossil fuels (petrol, LPG, diesel, gas, coal) is used at all scales. It is important to recognise fuel type can have a significant bearing on the functionality of a DG system where it is installed; and that DG systems are not necessarily based on renewable fuels.

Microgeneration Potential

An assessment of microgeneration potential (PCE, 2007) provides an insight into how small systems can provide a greater contribution than they do currently (Figure 8). The increased contribution is predicted to come from building performance[6], heat, and electricity over a period of 30 years (Figure 9).

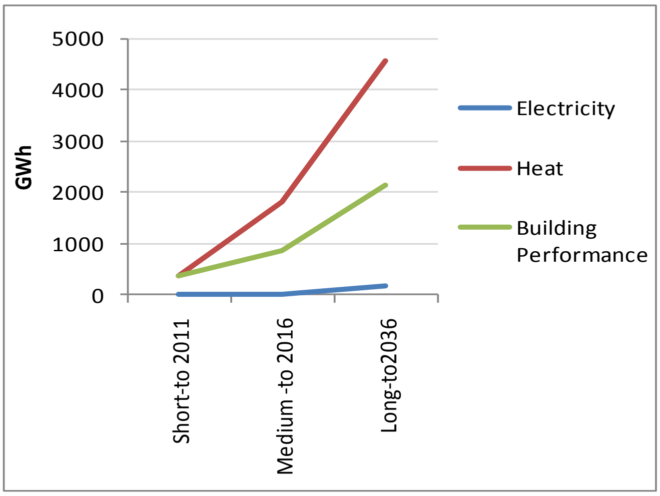

Figure 9: Generation potential (GWh) for microgeneration systems

This corresponds with predictions that installed capacity from small grid-integrated electricity generation systems of mini (<10kW) and micro (<100kW) hydro, biogas and wind could triple by 2030 to nearly 100MW (HydroTasmania, 2007), (PCE, 2007). However, technologies such as PV have the potential to increase significantly off a very small base yet overall contribution to capacity will be small because of the barriers of high capital cost, and planning constraints.

Increasing interest in small or micro-scale systems is claimed (EECA, 2006) but quantification is not available, suggesting volumes are still too small to be of interest. This is the case for

[6] Building performance technologies were defined as passive solar design, insulation and double glazing. These make a direct difference to house thermal performance. Details can be found in East Harbour Management Services (2006)

photovoltaic and micro-wind systems - in NZ little data is available. Most are small scale stand-alone systems associated with farming, road and weather services, and domestic use.

Regulatory and Policy Environment for Small-Scale DG

Although the Totarabank project fits in the micro scale for DG systems, the regulatory environment must be considered. Based on a review of the policies and regulations relating to this project, a list of the relevance and potential future implications has been developed (Table 1). Although the Government strategic initiatives are under review, their outcomes are continuing to inform the energy debate.

Table 1: Policy and Regulatory Summary relevant to Distributed Generation

Document	Relevance	Future Implications
Electricity Governance (Connection of Distributed Generation) Regulations 2007 (MED, 2007a)	Specification of processes for generators to apply to distributors for approval to connect DG systems; regulated terms applying to the connection of distributed generation in the absence of contractually agreed terms; pricing principles to be applied; and a default dispute resolution process. It specifies two system classes: less than 10kW and greater than 10kW.	The regulations need to be applied in order to see what barriers they provide. There may be negotiation around the 10kW size boundary for systems that use small/ micro technology – this will be dependent on regional strategies of distributors.
Electricity Industry Reform Amendment Bill Amendments (2007): to facilitate investment in generation and retailing.	Specific changes to the act: • Raising the threshold for corporate separation and arm's-length rules from 5MW or 2% of peak load to 10MW. • Exempting Lines companies from generation quantity restrictions, retailing restrictions, corporate separation and arm's-length rules (except accounting separation) where their investments are outside their own lines areas. These changes are designed to free up the ability of lines companies to participate in generation and retail of their own electricity, with an emphasis on renewables as the basis for new generation.	Likely to be an increase in generation investment for schemes smaller than for traditional grid supply. However disputes around river and amenity values will still continue. The danger of bundling through integration of generation, distribution and retail costs will need monitoring. Lines companies may discourage investment in small DG projects that could compete directly with them.
Continuance of Electricity Supply (MED, 2007c)	The obligation to supply electricity would continue to be protected beyond 2013. The obligation to supply would be able to be met by using lines or, where local consumers agree, alternative local generation.	Rural communities will still need to find alternative supply for areas needing costly upgrades or maintenance.

Document	Relevance	Future Implications
Government Policy Statements (GPS) Electricity governance; RE Generation Renewable Preference Amendment Act (2008)	These GPS's encompass policy development for the Climate Change (Emissions Trading and Renewables Preference) Bill that was introduced to Parliament on 4 December 2007, and repealed in December 2008. Part of this GPS was the target of 90% renewable electricity by 2025.	The ongoing debate around the Climate Change bill means continuing uncertainty about carbon values for non-RE systems, and options for emissions trading .
New Zealand Energy Strategy to 2050 (NZES) (MED, 2007b)	The NZES was a Labour Government vision for a sustainable, low emission energy system. Strategic issues relevant to this project included: • Security of electricity supply, • Low emissions power and heat, • Increasing energy efficiency, • Sustainable technology and innovation, and • Affordability and well-being. Distributed generation and sustainable energy options are presented as options.	The NZES and NZEECS provided an integrated view for strategy and action that had been missing in NZ. Both strategy documents produced after significant consultation are now under review by the 2008 National Government. Actions at the time of writing have been to remove the emphasis on sustainability, and revoke the target for renewables. It will be important not to lose the targets and action plans as they could do much to address future energy concerns.
New Zealand Energy Efficiency and Conservation Strategy (NZEECS), (EECA, 2007)	This is the Government action plan for the NZES, for increasing the uptake of energy efficiency, conservation and renewable energy programmes. It contains high level targets to address climate change and sustainability objectives that included: • Initiatives to promote healthy homes with reduced energy costs. • 90% of electricity generated from renewable sources by 2025. The strategy programmes were to deliver: • 30PJ savings of non-transport energy by 2025. • 9.5PJ new direct use renewable energy/year by 2025.	

Sources: (PCE, 2007)*;* (CAENZ, 2007)*;* (EECA, 2007) *;* (MED, 2007b)*;* (MED, 2008)

The 2007 Electricity Governance (Connection of Distributed Generation) Regulations specify two system size bands – below 10kW, and above 10kW. The fees, application detail requirements, contracts and timeframes differ for each system capacity level. Because the regulations are relatively recent, systems that are just over 10kW and less than 100kW do not have many precedents. Most systems over 10kW are in excess of 1MW, and have numerous system performance and safety requirements to ensure no adverse impact on the local network they are connected to. This has ramifications for systems between 10kW and 1MW as without any precedent, these small scale systems may well be required to fulfil the same requirements. Operation strategies for DG systems less than 1MW ultimately depend on the system size, location, and complexity of the commercial contracts (CAENZ, 2007).

Therefore part of the analysis required for Totarabank will be to establish the optimum system size for the project, and the impact of regulatory requirements should the total system size exceeds 10kW. To date, there has been no clear explanation for the origin of the 10kW band boundary (Gardiner, 2006a) and most projects of the size of Totarabank could exceed it. Factors that could affect regulatory approval of the system include the impact of the type of technology, system size impact on network management, and purpose of the system (e.g mitigation of demand rather than a focus on export).

Key Stakeholders

Small-scale DG implementation in New Zealand is influenced by a number of key stakeholders, as described in Table 2. If uptake of small-scale DG is to increase there are a number of issues that need to be understood, to ensure DG will deliver financially and technically. The structure, economics and size of the NZ market underpin the stakeholder influence and mean any change in facilitating small-scale DG will be driven in the short-term by desire to increase Government profit rather than by user benefit.

Table 2: Distributed Generation Stakeholder Summary

Stakeholder	Role in DG Facilitation	Current Issues
Transpower	Manage operation and investment into grid infrastructure, including the ability of the grid to manage increased use of DG.	A strategy for managing an increase in localised and intermittent DG within grid infrastructure is underway.
Gentailers (through retail business)	Control buying and selling of electricity to end-users, including tariffs. Own and lease electricity smart meters; involved in supply and installation of microgeneration technology. Electricity purchased from privately owned grid-tied DG competes directly with retail electricity sales, so no desire to incentivise it.	Assessing the potential of local DG to contribute to national security of supply. Encouraging community /private investment as a source of capital, and alternative ownership models. Valuation of energy delivered by DG against the wholesale market does not reflect other benefits.
Line Companies	Invest in, manage and maintain distribution infrastructure assets. Approve system design and connection of grid-tied generation to local distribution networks, against AS/NZ standards, and local network needs and constraints. Increasing ownership of renewable DG (up to 10MW), and smart meter development.	Complex decisions between maximising return on distribution assets vs. increased generation by end-users vs. investing in own generation vs. service delivery can create barriers for small DG. These could be mitigated if there are benefits for avoiding network upgrades, network strengthening; or creating other opportunities.
Individual generators	Individuals or businesses that invest their own capital in generation systems from single house to community to commercial/industrial scale.	A growing community awareness of the environmental and social impact of building large scale generation. A lack of awareness by end-users of benefits of using small-scale DG systems, especially around building performance and heat.
Industry Suppliers of DG systems.	Industry sets price, availability, and quality of relevant technology and installation. Some units manufactured locally (solar thermal, micro-hydro); PV and wind is predominantly imported.	Performance standards and service are inconsistently applied. Costs and standards are a barrier to increasing uptake.

Sources: (PCE, 2007), (Gardiner, 2007), (CAENZ, 2007), (Barry, 2007), (Transpower, 2007)

Pricing Influences for Small Generators

The following points should be considered in the context of the residential price trends shown in Figure 4, page 24.

Market Structure

The NZ electricity market has become reliant on a centralised grid system, which through its scale creates expectations for ongoing investment and system performance. However, recent issues around transmission infrastructure, security of supply, and market uncertainties mean Distributed Generation systems are becoming more attractive for some networks under pressure. Gentailers such as Meridian Energy will continue to consider viable new generation projects that are 'consentable', and meet financial criteria, while ensuring a diversity of supply sources (Meridian Energy, 2006).

Land access, ownership and resource consents are having an increasing effect on the viability of new large generation projects, particularly new renewable generation involving wind, hydro and geothermal, and the extension of existing schemes. In time, carbon charges and availability of transmission infrastructure will add further complexity and cost, especially for projects requiring connection to the National Grid to be effective.

Currently, large scale grid-supporting generation is valued as part of the wholesale market. As the scale drops, renewable systems used as distributed generation can displace costs of supporting or replacing infrastructure such as rural spur line replacement, lines upgrades for increased load, or contributing to local network load management at peak times (CAENZ, 2007). In such cases costs greater than commercial tariffs may be the economic alternative, and other non-economic criteria may be significant in terms of valuing these systems (e.g significant landscape value; community issues).

Hydro Tasmania, (2007) suggests "To compete with the wholesale electricity price on an economic basis, grid-connected renewables must generate electricity at less than 15c/kWh by 2030" – providing an indicative benchmark for assessing future investments.

Network Costs

Lines Company pricing varies due to factors such as customer demographics, infrastructure upgrade needs, geography, and load reliability. The cost of the load drawn by the network at the Grid Exit Point (GXP) during critical peak periods where capacity shortages exist may be included in pricing for all customers. Therefore a Lines Company facing a peak capacity problem can incentivise a DG system owner supplying the right amount of power at the right time to the network from commercial systems that use a variety of fuels. DG system owners are paid based on avoided cost of capacity expansion, for the capacity provided at the right time (Jayamaha, 2003), (CAENZ, 2007). The challenge for a small DG system to participate in such a way, is supplying power at a consistent rate and time – not easy with a variable renewable system. In general, lines companies have a continuous challenge balancing investment costs with reliability needs, infrastructure renewal and regulatory constraints which is ultimately reflected in pricing (Powerco, 2009).

Retailer Pricing Issues

Pricing to small generators putting electricity back into the network is based around being either a market participant[7], or selling directly to the retailer. A market participant sells into the main electricity wholesale market and requires financial and half-hour metering infrastructure that is very expensive (Whitlow, 2008). Consequently most small generators will have a contract with their retailer at a set export rate.

If the uptake and use of small-scale DG technologies were to increase on a large scale, the structure of electricity tariffs would probably be altered so that fixed costs were recouped; the avoidable, variable tariff component would be lower and the fixed charge would be higher (Meridian Energy, 2006). This implies the structure of retail import tariffs may change such that the economics may be less attractive as the variable tariff value drops; against which savings (or avoided costs) from distributed technologies are assessed. If the technology is providing a net input back to the network, the economics could move closer to being valued at the wholesale (energy only) delivered price, which is significantly lower than the variable tariff.

Therefore it is likely NZ export tariffs will move closer to wholesale prices[8]. From a retailer perspective, pricing reflects the wholesale clearing price of electricity purchased from the closest GXP node for that customer location (CAENZ, 2007) – so that their captured retail margin remains the same. The anomaly here is pricing locally generated electricity equivalent to the GXP price when no further distribution and selling activity is required. Because of the small amounts of electricity involved, this situation is unlikely to change in the short-term unless there are other more strategic reasons to encourage small-scale DG. This is reviewed further in section 2.3.2.

Feed-in Tariffs

Feed-in tariffs (FiT's) are of interest as an economic incentive mechanism used internationally to drive renewable energy uptake. FiT's are an alternative 'premium' pricing mechanism for grid-integrated renewable energy, used in up to forty countries and states across Asia, Eastern and Western Europe; and the Americas (Alternative Technology Association, 2007), (Sovacool,

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[7] The Electricity Commission (ECNZ) currently oversees these functions, and all detail for the market infrastructure on pricing and participation can be found on website www.electricitycommission.govt.nz.

[8] Ad hoc phone conversations (16/12/2008, & 22/01/2009) with two retailers noted that current export tariff rates (equal or close to standard variable tariffs) were expected to reduce over time if uptake increased. The aim would be reduction to at least 50% of standard tariff if not down to wholesale levels. Any surplus over a 'zero' annual bill would be paid at wholesale rates. No detail would be provided in writing.

2008). They are designed to recognise the direct economic and environmental benefits of distributed generation to national electricity supply such as:

- reducing fossil fuel consumption and consequently emissions,
- increasing network supply security and avoiding network investment by matching supply to network peaks (i.e. PV matched against afternoon demand), and
- creation of jobs and businesses associated with technology supply and installation.

The tariffs are paid in the form of 'Net' export to the grid – where a system owner is paid for excess electricity exported after own use (equivalent to the net-billed export tariff used in NZ); or as 'Gross' – where all electricity generated by the system is paid for. Tariff level adjustment over time will vary by country, length, and technology according to long term strategy and eventual replacement of other incentives. For example, Australia has a range of FiT schemes by state, with the most recent being the ACT (Australian Capital Territory) instituting a gross feed-in tariff of 3.88x the customer tariff with the aim to deliver a PV system payback in 10 years (Passey & Watt, 2008).

Detail on how FiT s work in the market are discussed in Passey & Watt (2008), Klein et al (2008) and Sovacool (2008 & 2009). Barry (2007) explores how such tariff structures could be applied in the New Zealand context. Although incentives such as FiT's are unlikely to exist in NZ in the near future the option to explore the economic impact on a community energy system is of interest to this research.

2.1.4 NZ Market Structure Insights

Based on the information reviewed in Section 2.1, a number of potential implications for the structure and performance of the New Zealand electricity market are presented below.

- The integration of retail and generation has vested significant power in the hands of a few predominantly Government owned companies. This creates tension between the need to maximise profit through increased consumption versus the need to improve conservation and efficiency of use in order to avoid generation expansion. This is a barrier against incentivising private generation.
- Increased electricity revenues are being extracted from the residential sector- which has no power to negotiate price, only the ability to change suppliers.
- Public investment through SOEs is skewed towards large scale centralised generation systems despite the increasing resistance to the long-term environmental and community effects.

- Factors such as strict economic criteria for ensuring security of short-term supply, resource consent approval, transmission infrastructure and potential carbon pricing means some renewable generation is seen as too expensive. These also affect cost allocation throughout the electricity supply chain, and export rates offered to small generators.
- Internationally non-economic criteria, strategic vision and regulation around climate change and peak oil are used to invest in future energy options and explore uptake incentives like feed-in tariffs. New Zealand's narrow non-strategic vision for security of supply presents an inadequate set of solutions for the future.
- There is an opportunity to better balance economic, social and environmental criteria to find the best mix of technology, efficiency and conservation options that will ensure a secure energy future.

2.2 Sustainability and Energy in NZ

The concept of sustainability and residential development involves choices and decisions to enhance sustainable outcomes, while also understanding potential compromises needed to achieve them. According to the PCE Report "Creating Our Future" (PCE, 2002), sustainable development recognises:

- the finite reserves of non-renewable resources,
- the limits of natural life-supporting systems (ecosystems),
- the interactions between environmental, social, and economic outcomes, and
- the well-being of both current and future generations.

The PCE report also presents the concept of "strong sustainability" – where neither the economy, society nor the environment alone can determine if our systems function sustainably. For growth to be sustainable, it must have regard to physical and ecological limitations as well as to society's expectations and values.

New Zealand has historically enjoyed relatively affordable energy, however now terms like 'fuel poverty', and 'rising electricity prices' are having a real impact on how people live. Therefore, a sustainable approach to energy use is becoming more important with the increasing price of residential energy, the debate on climate change mitigation, and the growing awareness of the relationship between home living environments and health.

Sustainable residential energy use can encompass being more energy efficient, conserving energy by reducing the overall amount that's required, and using renewable energy resources.

For the Totarabank project locally generated renewable electricity is a part of this approach, along with the use of energy efficient house design, and a holistic view of resource use in general.

Central and local government frameworks for guiding and implementing specific standards for sustainable developments are few in NZ, converse to international trends. Central government is currently stepping back from driving any change in this area, leaving local and regional councils to create their own policies, and for motivated communities to create change for themselves.

2.2.1 Policy and Regulation

There is no regulation in New Zealand governing standards for sustainability in a holistic sense for residential developments. The application of specific outcomes rests with individuals, and local bodies. The only major resource for land development is the Subdivision for People and the Environment Handbook, from Standards New Zealand (Standards New Zealand, 2001), and the New Zealand Standard NZS 4404:2004:Land development and subdivision engineering.

Regulations and standards for sustainable housing and house performance are not available in New Zealand, as they are internationally – for example the United Kingdom has introduced codes aimed at sustainable housing (Communities and Local Government, 2008), and zero carbon legislation (UK Green Building Council, 2008). The NZ Building Code sets minimum standards for elements such as thermal energy efficiency performance based on a number of areas such as insulation and airtightness – to achieve a high-performing building these standards need to be exceeded.

Central Government through the Ministry for the Environment implemented a range of sustainability initiatives up to 2008, including policy in the form of the Energy Strategy and Climate Change Bill. The Bill is now under review by the current National Government.

2.2.2 Innovation for Residential Sustainability

Sustainable Housing

Beacon Pathway Ltd have been researching options for improving the sustainable performance and standards of NZ housing, for the purposes of supporting long term change in public policy and practise. A set of sustainability benchmarks has been proposed to raise the performance of new and existing housing, and to raise the awareness of changing user behaviour as part of improving house performance (Beacon Pathway, 2008). Performance benchmarks are set with the ultimate intent of delivering social, environmental, health and economic benefits. They are referred to as Beacon's High Standards for Sustainability (HSS™).

The value case for HSS™ benchmarks for energy was set in the context of Beacon's strategic energy targets:

1. 90% of New Zealand homes to use energy efficient systems for water heating, space heating, lighting and appliances, and have a high standard of insulation (to maintain a minimum temperature of 18°C), by 2012, aiming to reduce the demand on reticulated energy from homes by 40%.
2. All homes to have a minimum net 50% of their energy supplied from local renewable sources and have a minimum temperature 18°C by 2020; AND all energy into all homes/neighbourhoods will be supplied by renewable sources by year 2040.
3. All new homes and consented renovations will be designed to reduce total energy requirements through active management of the passive solar and thermal performance by 2012.

The value case (Beacon Pathway, 2007) recommended options to achieve the HSS™ outcomes such as using energy efficient appliances, lighting, space heating (pellet/wood burners, heat pumps) and water heating (solar, heat pump, instant gas); and high levels of insulation. Use of local renewables for high and low grade energy delivery are recommended where feasible. All options will vary in feasibility depending on whether a house is new or it is retrofitted – the options (technical and economic) are greater when building a new house.

The benchmarks for new houses in Table 3 for climate zone 2[9] , are relevant to Totarabank.

Table 3: Proposed HSS™ Energy Benchmarks

	Potential HSS™ benchmarks for new houses kWh/year/house				
HSS™	All electric (hp = heat pump)			Electric and renewable	
Climate zone	No hp or solar	Hp space and no hp water	Hp space and hp water	Hp space and solar water	Renewable space and solar
1	8,600	7,300	5,800	5,100	4,400
2	10,000	7,800	6,300	5,600	4,400
3	11,900	8,800	7,300	6,600	4,400

Source: (Armstrong & Ryan, 2009).

[9] Climate zone 1: Northland, Auckland, Coromandel Peninsula
Climate zone 2: Rest of the North Island (not including Central Plateau)
Climate zone 3: South Island and NI Central Plateau.

Solar Design for Residential Land Development

In addition to housing performance, is the potential for innovation in the approach to residential land development to achieve sustainable outcomes. Design tools have been developed to optimise land use for the purposes of increasing renewable energy use and energy efficiency gains, predominantly by optimising solar resources (Duncan, 2005). The approach included specifying thermal energy demand for buildings and assessing that against site thermal energy potential. This work is the basis of the Totarabank development.

The main requirement from such an approach is early stage consideration of available resources which can be included in building and site design. The long term benefits for resource efficiency are clear if enough land developments considered them.

Sustainability and DG System Design

Post market deregulation, challenges for rural communities making decisions around ongoing electricity provision were made more complex by the pending changes to industry supply obligations – as identified by Murray (2005). The requirement for secure and sustainable rural supply created the need for a decision-analysis framework that could combine resource measurement and load analysis with community concerns and needs around environmental, social, technical and economic aspects. This project worked to develop a methodology and framework that could take a more holistic view of the issues pertinent to a rural community while reducing the time and cost in gathering the resource and load data needed for system design.

The DG systems of interest were grid-connected, and although the project outcomes were based on the use of complex decision-analysis software, there are aspects of this work of relevance to the Decision Model being developed here. Detail of relevant criteria and measures are explored further in the next section; and in Table A1: Energy Sustainability criteria and measures, .

2.2.2 Indicators and Measures

Four sustainability goals (economic, social, environmental and technical) were identified to support the investigation of sustainable rural power (Murray, 2005). Beacon Pathway have researched sustainability criteria for housing innovations (Beacon Pathway, 2007), and decision frameworks for the use of residential renewable energy options (Armstrong & Ryan, 2009). The New Zealand Department of Statistics have also initiated the measuring of national progress using sustainable development indicators, including a set for energy. These are based on how well we meet energy needs across society and economy while limiting environmental impact. Appendix A3 Sustainability Indicators contains the details of relevant criteria from these reports.

Indicators of interest to this project for energy and sustainability are summarised in Table 4 to provide a perspective on the value of sustainable energy systems beyond economic payback. A measure such as payback is commonly used as the only indicator to describe long term benefits of non-standard energy systems. It is important to progress beyond this to also consider technical, social, and environmental indicators in assessing future benefits of these systems.

Table 4: Summary of Key Sustainability Indicators

Economic	Environmental	Social	Technical
Investment value over time, of system	Contribution to pollution reduction	Ability to manage system complexity	Reduction in peak loads
Internal vs. external electricity costs (c/kWh)	Reduction in imported electricity (grid displacement).	Security of supply and resilience to changes.	Energy and electricity fraction delivered by renewables.
Energy expenditure by household and community	Efficiency of resource provision and use	Comfort and health of owners	Average hourly kWh delivered
Investment in local economy	Total energy supply per person	Positive community spirit	Reliability and standards of systems

2.3 Management of Community Energy Systems

A community energy system has an intrinsic local focus on resources and systems, and implies a collective approach as to how energy is sourced and managed.

For this research, renewable Distributed Generation is considered as part of a total energy system integrated with the external electricity network. For the Totarabank community, this means having to consider multiple residences, not just a single house. It provides the opportunity to examine the supply, use and control of energy, where a mix of energy sources has to be balanced against collective community demand within a microgrid, while operating as part of the local electricity network. .

2.3.1 Defining the Community Energy System

Microgrids

A microgrid is a way of managing multiple end-users as a linked 'grid' to share energy generation and management, and any subsequent downstream benefits. A microgrid can use a range of generation technologies; network interface management systems (including antiislanding and electricity import); load monitoring; metering; and low grade energy for services. A grid-connected microgrid can operate as a single load, and either store energy, or export surplus back to the network (PCE, 2007).

Gardiner (2007) has defined microgrids as:

> *"a power network that operates at the community level, including the integration of small electricity sources, energy storage and controllable loads."*

This concept assumes the microgrid is connected to the network, but can automatically transfer to islanded mode if storage is available. Power flow can occur in and out of the microgrid to the local network – with the option of having a microgrid delivering variable (network dependent), or firm supply (network independent). It promotes improved energy efficiency from the use of on-site renewables reducing losses associated with the transmission and distribution of reticulated electricity on the regional network.

In similar research, Abu-Sharkh (2005) proposed microgrids in the UK as a concept for better integrating clusters or networks of local demand with small-scale local supply of heat and power such that the demand is met and controlled. A mix of supply sources is assumed including fossil fuel generators, and heat and power co-generation.

In the UK research, the microgrid intention was to be self-sufficient in terms of meeting load, but still have a connection with the commercial network if there are benefits to supporting it through electricity export. The particular need in the UK for heat means that combined heat and power (CHP) technology can be well-utilised.

Therefore, key features of a microgrid would be:

- demand/load management strategies;
- delivered power at the right quality for use by the microgrid, from on-site generation and network import;
- use of on-site low grade energy sources;
- metering and control systems to manage the network interface, electricity export, power balancing and quality (import/export);
- storage for non grid-connected systems, or to ensure no spikes of exported power for grid-connected systems; and
- metering and internal charging to reflect internal price of delivered power in the microgrid.

Figure 10 illustrates how these features interrelate as part of a community energy system.

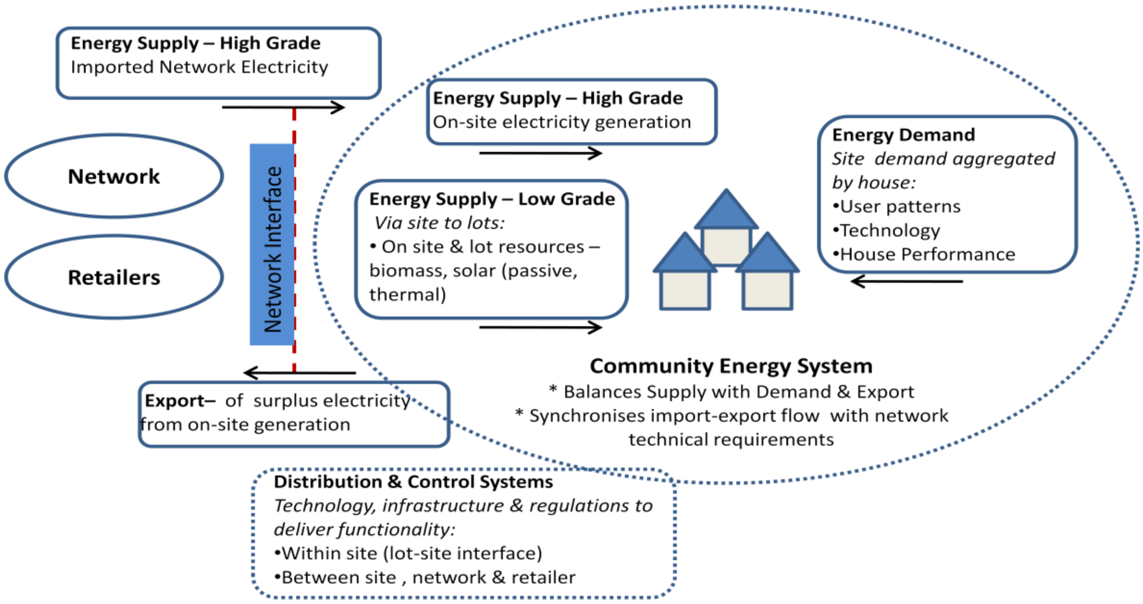

Figure 10: Features of a Community Energy System

The challenge for a microgrid powered from renewable energy resources is managing variable supply. The key question would be – does the micro grid have the facility for firm supply for both its users, and the local network; or will the micro grid essentially deliver variable supply only, with the network providing the firm supply back up? It must be noted that using the network for storage and firm supply means the lines companies must still take the risk on infrastructure investment to ensure capacity is maintained – even if the impact of a micro grid is to significantly reduce peak demand and general load. If the microgrid has to have capacity for firm supply if the network shuts down, storage and the ability to island have to be considered.

The functionality of the microgrid will be determined by available technology, the community's intention and requirements for their energy system, and management of the interfaces with lines company and retailer.

Smart Grids – The Future

'Smart Grid' is a term used to describe the next development of the microgrid concept. It is based on using small DG generation systems actively with load management using communication systems to manipulate specific loads or circuits (PCE, 2007). Although not used in New Zealand yet, such systems could combine technology for active load management in conjunction with local network requirements, local DG, energy storage, smart appliances, user preferences, dynamic price signals and remote communication. The intent of smart grid systems is to enable better microgrid response to demand changes, electricity generation and distribution; and reduce the need for large spinning reserve (Galvin Electricity Initiative, 2007).

New Zealand Network Definitions

The Electricity Commission has guidelines on secondary networks (ECNZ, 2008a) that include definitions around network set-ups and regulations relevant to a subdivision like Totarabank. A secondary network is generally one connected to a local distribution network, which is in turn connected to the National Grid. The local network (owned by a Lines Company) distributes grid electricity to anyone who needs it, including secondary networks defined as follows:

Embedded Network

An embedded network is defined as

> *"... an electricity distribution network that is owned by someone other than the parent network owner, where consumers have ICPs allocated and managed by the embedded network owner (or another distributor appointed for that purpose), and the electricity traded is reconciled at the point of connection between the embedded network and the parent network".*

Consumers with their own ICP's can switch retailers in this system. Generally, the embedded network owner has to set up facility for trading and reconciliation as well as half-hourly metering. Embedded networks are found in airports, large malls, and apartment blocks.

Customer Network

A Customer Network is defined as:

> *"...an electricity distribution network that is owned by someone other than the parent network owner, where consumers connected to it are not switchable and therefore have no choice of retailer. A customer network is no different from a standard ICP for the purpose of the Rules, and from the perspective of a parent network."*

Customer networks have one ICP only for local network connection, and all billing occurs through the ICP owner. Individual consumers in the network don't have their own ICP and cannot switch. Billing occurs under an arrangement between the customer network owner, and the individual consumers – a common arrangement in shopping malls.

Network Extension

A Network extension is defined as:

> *"...an electricity distribution network that is owned by someone other than the parent network owner, where consumers have ICPs allocated and managed by the parent network owner, and the electricity traded is reconciled at the NSP (Network Supply Point) for the parent network at the grid exit point (GXP). Consumers connected to them are switchable and therefore have a choice of retailer."*

Such set ups have to satisfy network losses and line service needs for the local network, and these charges are passed on to the individual ICP owners.

Subdivision Connection Options

In general, a subdivision of a size such as Totarabank would be connected as an embedded network. Each house, on its own lot would have a standard radial individual connection point (ICP) to the network, with a relationship with a Lines Company and a retailer independent of their neighbours (Figure 11). Each lot would be free to install any microgeneration technology within the regulations for residential grid connection such that demand and supply is managed individually.

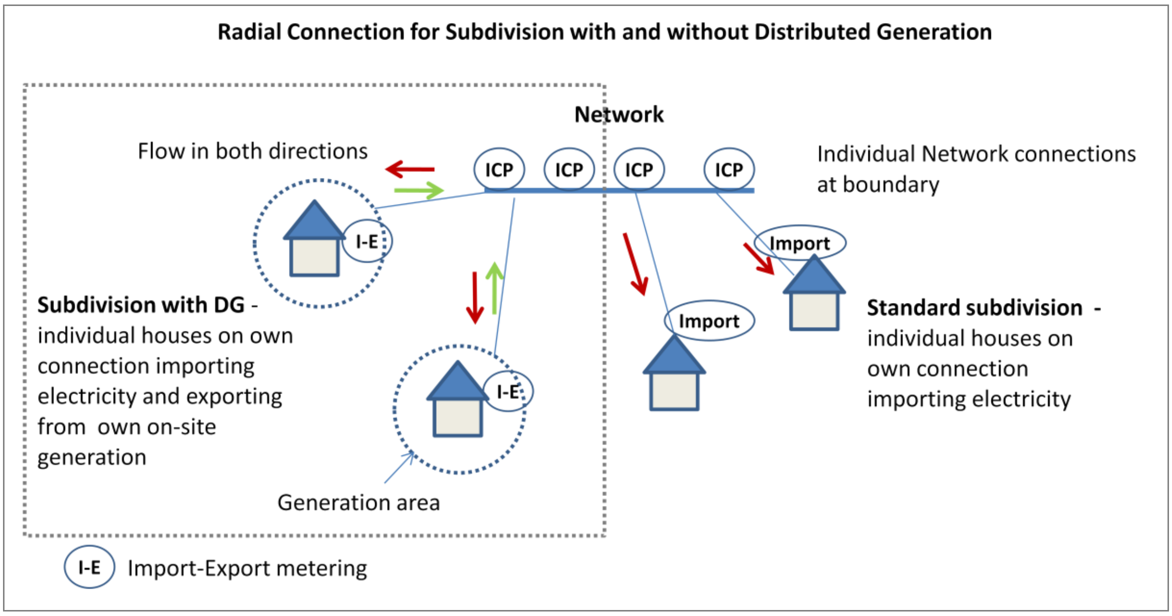

Figure 11: Standard Connection System for New ICP

In contrast to these standard connection systems (Figure 11), Totarabank has been designed with each lot connected to an internal 'loop' grid to a specified current limit, with one ICP connecting the site grid to the network (Figure 12). The lots are linked together in terms of their demand impact on the ICP capacity, and in terms of best use of generating electricity on-site. As there is a single ICP connection, this system fits the definition of a customer network; or it can be seen as a single large residential customer. The schematic below is illustrative of the system concept, which is applied to eight lots on the actual site.

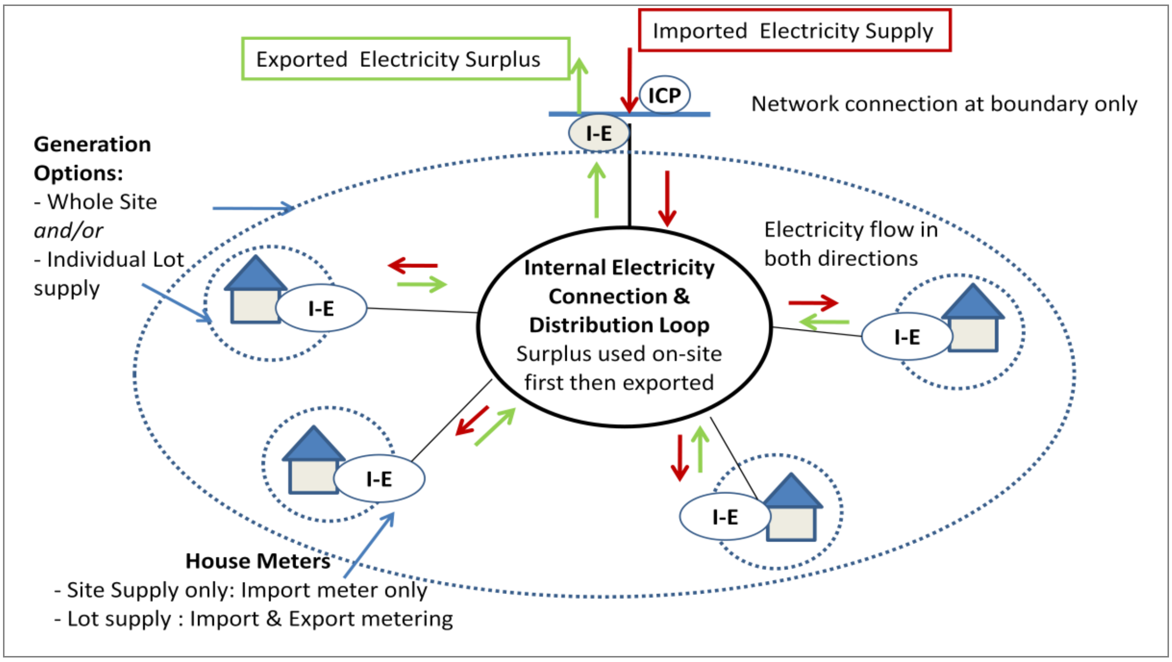

Figure 12: Totarabank Internal Loop Connection System

There are still options for each lot to have their own microgeneration, while all lots can benefit from a communal system. Metering systems for distribution and control will depend on the generation system configuration.

2.3.2 Managing the Energy Balance

In order for the microgrid to function effectively to service residents, as well as interface with the local network, the energy balance across the site needs to be understood and managed. This requires managing energy supply options for low and high grade energy, understanding demand/load profiles and how they change and how these features are continually balanced to meet community needs (Figure 13).

For a grid-integrated system, understanding the options for managing the electricity balance is important for assessing the overall benefits of import versus investment into on-site generation and any benefits from export of surplus energy.

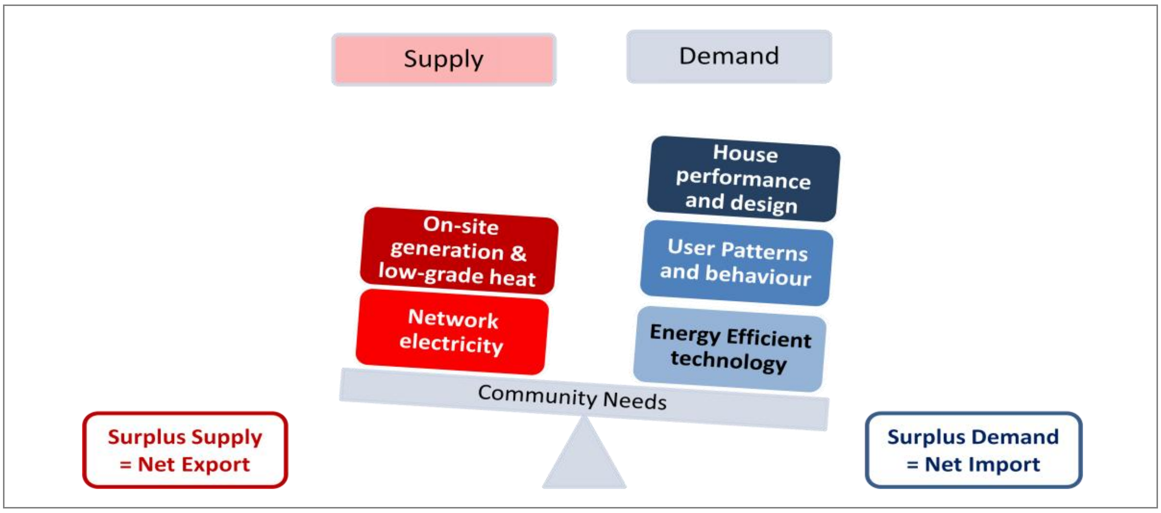

Figure 13: Energy Balance Relationships

Supply

The available energy resources of a site set the options for energy supply. For a standard residential site, occupants will generally assume that grid-supplied electricity is the main energy source, with some supplementary energy gained from a woodburner, or maybe gas for cooking and water-heating. A site where a community energy system is planned can have external electricity delivered through the local network, supplementing this with varying levels of on-site electricity generation. Use of other supply options for heat such as solar or biomass can complement the energy grade balance thereby reducing the amount of electricity required for the site.

Therefore, the available energy resources must be identified, and quantified where possible if grid-supplied electricity is to be supplemented or replaced. Resource data for the local conditions are matched with appropriate equipment performance data, to estimate the potential high-grade energy generation (in this case electricity). Climate and resource data also contribute to assessing low-grade energy options (non-electrical), and for deciding how house design can be optimised to make best use of them. Maximising the use of low grade energy (passive and active) where appropriate is fundamental to reduce the use of electricity for space heating, lighting, cooling and water heating (Table 5).

How much supply is needed is finalised once the likely demand is known – what is the energy to be used for, at what time of the day, for each season?

The combination of generation technology options is important in renewable energy dependent systems to ensure supply in a variety of conditions. Systems are more resilient to shortages if a number of resources can be used, especially if a reduction of imported electricity is required, and still be able to meet baseload requirements if the network fails.

Some form of storage is often required to 'smooth' the ability for supply to meet demand. Supply and storage technology options for microgeneration are described in detail in PCE (2007), Redman (2002), Irving (2000), Jayamaha (2003), Murray (2005) and Masters (2004).

Renewable generation can be intermittent (not available all of the time), so a storage facility ensures that when on-site generation cannot meet demand, electricity supply is still available via the stored energy. A grid-connected system like Totarabank uses the network as the storage facility rather than having chemical (batteries, hydrogen-based fuel cells) or mechanical storage (flywheels, compressed air). However, some amount of storage may be useful for improving the resilience of a community system during network outages – this is discussed further in Section 2.3.3 Distribution and Control Systems.

The microgeneration options most relevant to Totarabank are summarised in Table 5. Options such as micro-hydro or biogas from waste for electricity are not included.

Table 5: High and Low Grade Energy Supply Options

Supply Option	Technology	Description
High Grade Electricity	Solar PV	Rooftop and ground mounted flat plate arrays
	Wind	Micro (up to 20kW): rooftop and tower-mounted to small communal
	Network	Grid-supplied electricity delivered through the local distribution network.
Low Grade Heat	Biomass Burners	Wood, pellet, chip burners for space and water heating (wetback).
	Solar Thermal	Flat-plate and evacuated tubes; for hot water. Boost powered by electricity or gas.
	Boilers	Fed by biomass or biofuel; for whole-house space (radiators) and water heating
	Passive Solar	Combining energy efficient design features for solar gain to store and distribute space heat. Done properly, will deliver space cooling by excluding summer sun.
Future Options (System retrofit)	Combined Heat & Power	Up to 5.5kW heat: 1 kW power from a Stirling engine fuelled by gas or LPG, with possibilities for biodiesel
	Biofuel Generators	Diesel gen-sets adapted for biofuel, for stand-by and possibly peak load.
	Heat Pumps	Ground-source and air-water heat pumps may offer efficient heat provision options, although they are powered by electricity.

Some biomass burners such as pellet fires may have a delivery mechanism powered by electricity.

Diversity of Supply

Matching load requirements with a range of supply options for heating and electricity provision (Table 6) requires careful analysis if the reliance on the grid to supply base load is to be minimised.

Identifying suitable supply technologies has to consider the range of loads, and the range of resources that must be utilised to meet them if the grid is to be supplemented (Armstrong & Ryan, 2009). A degree of base load needs to be available to ensure basic energy needs can be met all year round – supplied in this case by the network. Heating options are considered according to whether space and/or water heating are provided, and the relative convenience of heat provision.

Table 6: Criteria for Managing Supply Diversity

	Criteria	Technology Implications
Generation Mix	Proportion of baseload provided by the grid	Greater grid dependence means less need for diverse supply technology
	Site suitability for various renewable options	Consider requirements for consents, neighbours, and set-up space.
	Availability and consistency (variability) of renewable resources, including seasonal variation	Solar is plentiful in summer but low in winter. Wind's regional diurnal and seasonal patterns need to be assessed.
	Specific energy needs, and pattern of energy demand	Understand load profiles and nature of peak demand for resource matching.
Space/Water Heating	Availability and variability of renewable fuel source	Solar is more available in summer; biomass is available year round. Solar thermal requires a winter boost.
	Seasonal severity and climate zone	Heat technology must deliver to climate extremes and desired comfort levels.
	Ability of energy efficient house design features to utilise technology	Insulation, double glazing and passive solar design should maximise heat capture and retention; and utilisation of low-grade heat options.
	Convenience of use for technology for individuals (a preference for on- demand or continuous?)	Decisions for switching on/off versus loading fuel versus using year round passive options are user and resource dependent.
	Regional regulations such as emissions standards and consenting processes	Biomass fuels can be restricted in some regions.

Demand

Key factors of demand include:

- Residential Demand Contributors
- Profiling Demand
- Demand Profile Management
- Network Demand Management

Residential Demand Contributors

Understanding the contributors to user demand, or load placed on the energy system is a core part of managing the site energy system. The ultimate aim is to deliver maximum benefit from available energy services for as few energy units as possible (Masters, 2004) especially if those units have an associated cost.

Main contributors to user demand relevant to a community system in New Zealand include (PCE, 2007):

- house performance and design – houses based on resource efficient design and materials are healthy, comfortable and cost less to heat and cool year round;
- user patterns – based on end-uses, occupancy, household size, and behaviour; and
- energy efficient technologies and appliances especially in conjunction with appropriate house design.

A holistic view of how energy supply options are connected to demand is illustrated in Figure 14 (Armstrong & Ryan, 2009); (Redman, 2002). An aggregated community approach to alternative ways of sourcing and using energy has the ultimate intention of reducing the use of network electricity and increasing resilience. Increasing the focus on energy efficiency is dependent on house performance, and user behaviour (a variable that can make a significant impact on demand profile, yet is rarely quantified).

These principles are also explored in a report (Isaacs, 2007) where data from the Household Energy End-use Project (HEEP) is used to compare household fuel use with energy end-use. It proposes better matching of the energy source (fuel) with services such that large end-uses like space and water heating make better use of direct-heating fuels to increase efficiency and reduce the peak load effect of electricity use in winter. The point is made that substituting some high-grade electricity with low-grade energy will maximise electricity availability for end-uses where it cannot be replaced – a 'fit for purpose' approach.

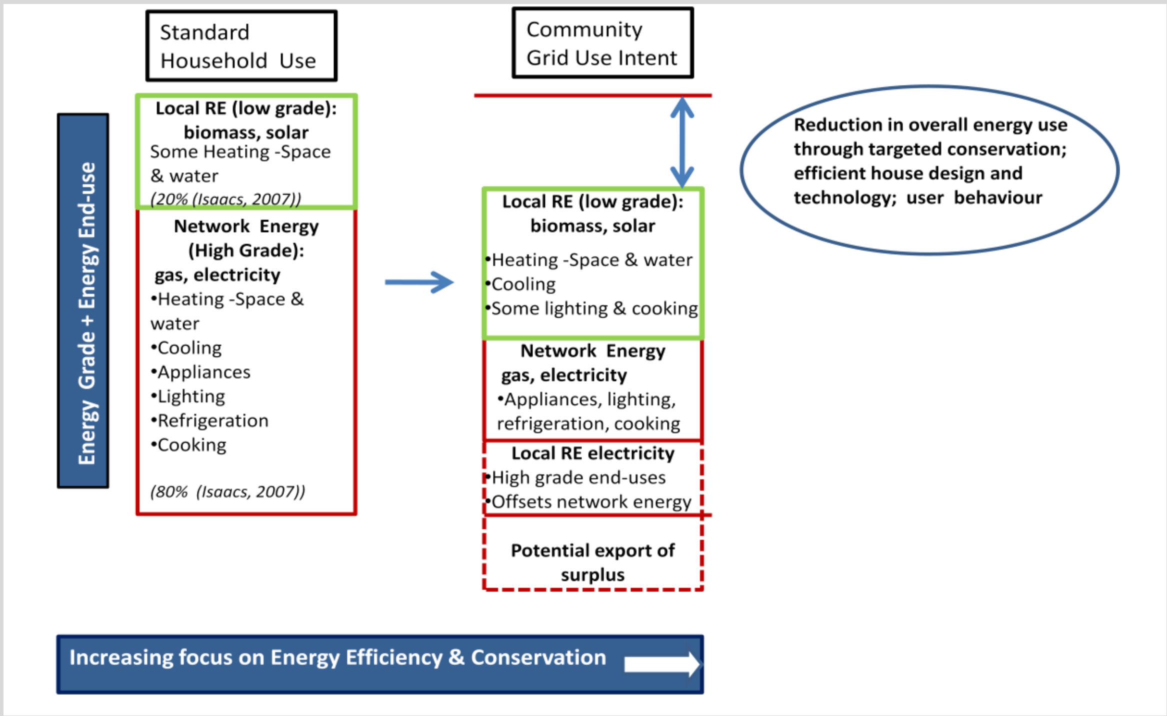

Figure 14: Energy grade and end-use concept for a community grid
(Note: the diagrams are not quantitative)

Examples of the technologies underpinning the concept in Figure 14 are summarised in Table 7, for grid-connected houses. The principles are to understand energy consumption patterns and use sustainable energy resources for low grade use before taking steps to generate electricity on-site (Bernhardt, 2008). Reducing and replacing are cheaper than generation and will also better utilise network electricity for essential high grade end-uses.

Consider that in the UK, heat pumps are not promoted as carbon-neutral unless they are powered by renewable electricity (UK Green Building Council, 2008). Convenience rapidly supersedes efficiency, especially if the user perceives they are getting something for nothing (or more for the same price).

Table 7: Technologies for Managing and Reducing Energy Demand

Demand Contributor	Technology	Description
House design for energy efficient performance	Passive solar design	Combining orientation for solar gain with thermal mass, insulation and glazing to store and distribute space heat. Done properly, it will deliver space cooling by excluding summer sun.
	Passive ventilation design	Solar chimneys; vents to shift warm air out of the house/circulate cool air in summer and shift cool air out/circulate warm air around the house in winter
	High performing thermal envelope	Above Building Code insulation levels, and glazing
	Natural lighting	Deliver natural light into areas that will benefit, to reduce use of electric lighting
Building Performance Index (BPI) and Home Energy Rating Schemes (HERS) can quantify the impact of design features		
Energy efficient technology	Energy efficient appliances	Performance –rated low energy white/brown/ wet ware (refrigerators/freezers, washing machines, cook tops, dishwashers, vacuum cleaners, entertainment, office equipment etc) LED/CFL light bulbs Sheltered clothes drying and drying racks (no clothes driers)
	Heat delivery	Heat pumps – ground-source, air-water, air-air *(still require electricity as fuel)* Heat recovery – ceiling/roof-space air; hot waste-water
User behaviour	Conservation vs. take-back	Education and attitude combined to make best use of available energy, and reduce where possible, as opposed to substituting gains made with new loads due to perception of free energy (known as 'take-back').

Sources: (Abu-Sharkh, et al., 2005), (Armstrong & Ryan, 2009), (Redman, 2002), (Bernhardt, 2008)

Profiling Demand

Developing a 'profile' over a time period is a fundamental part of system design. The factors discussed above together with the energy supply mix all contribute to developing a load profile for a particular situation.

Load profiles can be constructed for all energy sources aggregated over time, however the quantified profiles of interest in this project will only consider electricity. Demand, or load profiles represent the cumulative electricity consumption over a period of time, usually 24 hours (Jayamaha, 2003). It is derived by measuring power flow in an instant of time, which is cumulated over a particular time period (say an hour) to result in energy usage for that hour.

According to Masters (2004):

- Power (P) is the rate at which electricity or heat is generated or used, measured in Watts (joules/second). It is expressed as the product of voltage(*V*) and current (*I)*,

$$\boldsymbol{P = VI} \qquad \textbf{Equation 1}$$

- Energy is the total work done (or power used/generated) over time, usually measured in kilowatt-hours (kWh) or megawatt hours (MWh).

Potential power output is important for sizing of energy supply systems, and understanding the impact of instantaneous loads that the system must be able to meet. Energy is important for assessing costs, as the basis of electricity price tariffs is kilowatt hours (kWh).

Electricity load profiles can be sourced from:

1. On-site meter measurements; or 'dynamic' load profiling of actual users. The best-known example is the HEEP database (Isaacs, et al., 2006) – monitoring 400 houses from around NZ monitored for energy use over ten years by the Building Research Association of NZ (BRANZ).
2. Modelling of historical, aggregated load profiles representing a 'typical' user. Power companies measure total electricity use for groups of users to derive load profiles by user type –these are not generally available outside the companies.
3. Ground-up profiles based on estimates of appliance use by time and end-use over a typical day, month and year.

An example of a load profile extracted from a HEEP database for the Lower North Island is shown in Figure 15. Power (Watts) was measured every ten minutes, over a 24 hour period. Energy use can then be calculated from the ten minute data.

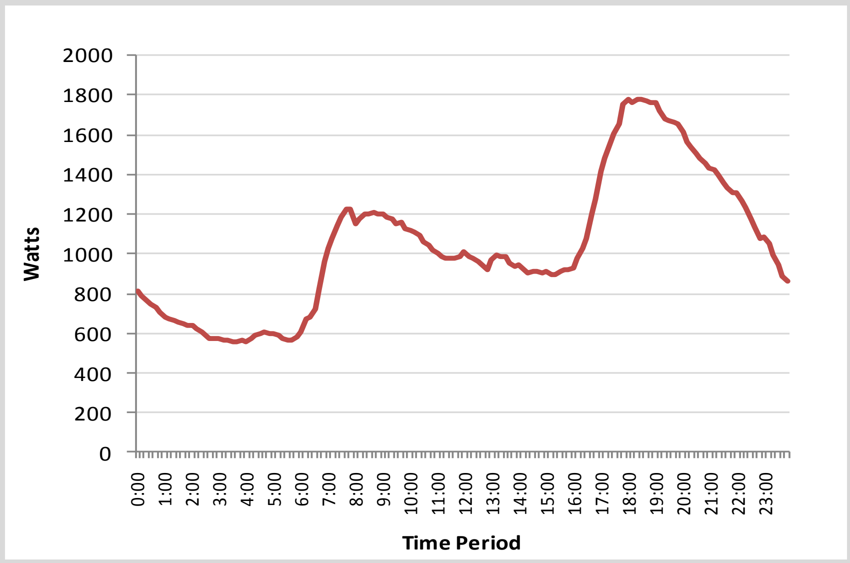

Figure 15: Load profile example of typical lower North Island family dwelling on an average winter day

Managing the Balance - Export

In the context of managing a grid-integrated energy system, the balance of energy supply with community demand (Figure 13) will determine any 'exported' surplus. Such exported energy can be variable, or planned depending on how the system was designed and how it is managed (Table 8).

Energy value, network impact, and economic benefits to the system owner will vary according to the relative amount of export the system delivers. In some cases export quantity can be a primary driver, or it can be a consequence of the balance between supply and demand. The subsequent benefit, or otherwise, on the network will be a result of the amount of export, time period it occurs, the capacity of the receiving network infrastructure, and the regularity of export such that any negative impact can be managed. Network benefits from export can be incentivised by the lines company if they require 'packets' of exported electricity at peak use periods (usually delivered under contract).

Table 8: Export System Functionality

System Function	Output Energy Value	Network Impact	System Benefit
1. No export: System generates less than site load requires. *("Behind the meter" generation)*	Net retail price of 'saved electricity. Internal generation valued separately (usually a higher price due to capital cost)	Reduced load peaks seen by the network if generation peaks match them. Good for avoiding new capacity investment, but can reduce investment value if no capacity issues in the network.	Reduced peaks and reduced costs with lower load. Simple retail contracts if technical standards are met.
2. Intermittent export: Variations in load and generation require capability for import or export. *("Behind the meter" generation with intermittent surplus)*	Depends on contract tariff for export. If higher than retail tariff, export will be promoted. If lower, on-site use will be valued over export. Time of Use (TOU) tariff structures incentivise export at peak times, increasing the value of export, and of import savings.	Import and export metered separately. Depending on system size and load profile, the owner can manage system to generate at peak to access premiums if available. Network may need to manage export if likely to exceed line capacity. Manage islanding if network fails/needs maintenance.	Infrastructure costs and flexibility can be improved with load management. The system can provide resilience to network power failure. Connection and retail contracts required for safety and export.
3. Export only: All generation goes to network	Wholesale price or at agreed export tariff. (Despite the potential benefits of such systems for supplementing the grid there is little financial incentive for private investors)	Supply can deliver network benefits to increase capacity, and supply specific locations or loads thereby avoiding investment in grid generation capacity. Intermittent export can be harder to manage.	Easier to manage and can fulfil local needs using local resources. Retail and connection contracts will depend on ability to manage networks benefits.
4. Back-up and peak lopping: used to support intermittent systems or for network support.	Wholesale price or at agreed export tariff – which may equate to peak tariff.	Network support on demand or at specified times when network is under stress.	Can reduce/lop peaks to support network and reduce load cost.

Sources: (CAENZ, 2007); (Gardiner, 2006a)

Where any export is variable, especially from a small system, it is difficult for the network to accurately predict supply or demand – thus the network still needs to have peak capacity available at the same cost as if there was no behind-the-meter generation. Variability of supply can be seen by the receiving network operator as a cost rather than a benefit (Gardiner, 2006a), therefore import-export systems need to have an overall aim to reduce network load in order to have a network benefit.

A number of factors have to be balanced to get benefits for both the network and microgrid (Table 8). These include:

- tariffs that reward investment yet reflect network costs to provide infrastructure. Currently, residential customers do not have access to the TOU metering and pricing options that would go some way towards this;
- network signals to clearly indicate system needs (i.e. time to export, or reduce load);
- technology that can manage the microgrid/network interfaces, including safety requirements; and
- active generator engagement with their system – to manage network interface and extract maximum value for their investment.

Export and Network Management

The NZ electricity market structure is not geared to accept smaller 'packets' of variable energy to support load, either from an infrastructure, or from an incentive perspective. Variability makes it hard to deliver the set amounts at a set time which are advantageous for network management and to the retailers at peak demand times. Value to the network is largely based on managing network constraints at peak times. 'Firm' energy supply is that guaranteed to be delivered under contract, for a set amount at a set period, usually at peak times. It could use controllable generation sources such as gensets; or externally controlled generation (utility uses ripple controllers to free up capacity in the system).

For a DG generator, it is of value to supply/export at these times as well as during wholesale spot price peaks or if Grid Exit Point (GXP) constraints signal an opportunity (Redman, 2002). However as DG system size and technical capability decreases, it becomes too difficult to access value opportunities at peak times, unless generation is designed specifically to deal with these situations.

Lines companies such as Orion have set up systems and incentives to do this where they have drawn a direct link to the benefits of DG, of delaying network capacity upgrade investments and adding security to the energy system (Orion, 2009). Reliable provision of export from a variety of energy sources (mostly diesel gensets) at peak periods is financially incentivised to drive the benefits to Orion.

Conversely, Powerco has a widely dispersed network, with significant regional differences in growth rates and upgrade needs. Due to the prevalence of remote rural lines, stand-alone energy systems are becoming of interest– it is cheaper for the company to install dedicated systems for isolated communities than to maintain lines for import, and export. Pricing signals in Powerco's DG contracts include a location rebate by substation that increases as substation spare capacity decreases (CAENZ, 2007).

Revenue from lines charges to end users cover investments made in distribution to maintain service and supply. Therefore, if demand drops, revenue from consumption drops. The issue then becomes covering the provision of network services against income. In particular for grid-integrated DG if the bulk of load is met on site, and there is surplus to export, there is little opportunity for the retailer to access margin on sales

The need to ensure maximum return on investment by ensuring assets deliver service and performance in the most cost-effective way is common to all stakeholders, whether they are lines companies or DG system owners. Current market conditions mean that DG system owners will be compromised in meeting this need.

2.3.3 Distribution and Control Systems

The level of interaction of the community energy system with the local network is underpinned by the functions of energy distribution, power connections, and overall control of energy and power flow (Figure 10). These functions occur within the site, between the site and the network; and between the site, network and contracted retailer. Implementing these functions will be dependent on current regulations, technology, and infrastructure – all of which are reviewed below.

Regulations

The regulations (MED, 2007a) for DG outline conditions for network connection, including pricing, contracts, and the resolution of disputes. Two system size bands are specified – below 10kW, and above 10kW. The costs for testing, inspection and metering can vary significantly between the two size bands, as systems over 10kW generally deliver significant levels of export energy, and so are of a size that can have an impact on network function.

Used in conjunction with the MED regulations are the company policies (Powerco , 2008a) and technical procedures set by each Lines Company to ensure appropriate standards are met. Procedures for each size band will differ according to the specific safety and operating standards that must be followed (Powerco, 2007), (Powerco , 2008b). Procedures will vary between companies depending on regional differences for issues such as number and frequency of DG installations, infrastructure investment strategy, and customer requirements.

Orion NZ is an example of a lines company that has been encouraging DG integration for about seven years and the procedures reflect this (Orion , 2009).

Implications for Distribution and Control

Systems that are just over 10kW and less than 100kW do not have many precedents; therefore the optimum system size for the site relative to the impact of regulatory requirements should the total system size exceeds 10kW has yet to be established. The relative amount of export from the site and the subsequent impact on the network may also have an influence on how the regulations will be applied, particularly if export amounts are small. These issues will be examined with the local Lines Company when the final system design for Totarabank is decided.

Technology

Technology requirements for addressing distribution, connection and control are reviewed under the following headings:

- Metering – a grid-integrated community system will require meters to monitor electricity flow in/out of the network as well as metering at each house switchboard.
- Internal monitoring and management - in conjunction with metering, internal site energy balance has to be managed to ensure smooth functioning of the network interface, that on-site generation and import meets demand, and that internal pricing and billing can be done.
- Network interface management – Communications between site, retailer and network are dependent on the export contracts, meters, and the internal monitoring systems. It is also important for identifying technical issues relating to the impact of the community system on network distribution performance.

Metering

The regulations for DG Connection (MED, 2007a) state in Schedule 2, that electricity meters are required to separately record electricity flow into the site system, and electricity exported to the network from the site. These are located at the ICP – for a community system such as Totarabank these would be gate meters. To get an indication of the feasibility of a grid-integrated system, activity through both import and export meters must be modelled.

The relevant technical requirements of the types of meters installed are contained in the Lines Company procedures and in Electricity Commission guidelines (ECNZ, 2008a), but generally require a separate kWh meter for import and export. Any data recorded by the meters must be made available to the Lines Company on demand. Residential meters are rented from the electricity retailer (who bills for service), and owned by a metering company who installs them on behalf of the retailer (SEANZ, 2008). Details of meter types are found in Appendix A4 Metering.

Meters at the ICP enable retailers to invoice for imported electricity use and reconcile the exported electricity value against the cost of imported electricity (this varies by retailer). Lines companies also charge for network services, which are partly based on kWh of use. For a multi-lot site, meters are also required at the switchboards of each house. Import and export functions happening to and from each residence each require meters, with import meters needed as a minimum. This enables monthly invoices to be apportioned by lot use.

Advanced Metering Systems (AMS) or 'smart' meters include attributes of TOU meters plus more advanced communications capabilities. Such systems have been used internationally for some years. However, their use in New Zealand is small, but growing[10]. Their use was originally implemented to reduce the cost of meter reading by enabling remote monitoring of electricity use. AMS are now increasingly being used internationally for demand management by encouraging electricity usage away from peak times. To do this, time of day pricing, usage data and pricing incentives are needed to better manage peak demand and to get the appropriate demand response. Australian studies suggest customer savings of $200 to $700 per year are possible (Sustainable Energy Forum, 2007). The use of AMS would mitigate the findings of a Consumer NZ report highlighting the issue of punitive tariffs at peak times when many consumers had no choice to switch their usage to another period (Whitley, 2008).

The Electricity Commission initiated policy in 2008 for the development of technology and infrastructure around AMS to ensure open access to the technology developments and to drive strategic benefits, especially for load management (ECNZ, 2008b). Benefits of advanced metering, as listed in the policy, are contained in Appendix A4.1 Benefits of Advanced Metering – they represent potential for changing the way electricity is managed and consumed in the future. Ultimately, the meters used will be based on the type of network the site microgrid is deemed to be (refer to Section 2.3.1 Defining the Community Energy System), the best available technology and the nature of the pricing and connection contracts agreed to between the Lines Company, the retailer and the microgrid owner.

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[10] At the time of writing significant work was being done by industry stakeholders, and the Parliamentary Commission for the Environment on smart meter development in NZ, the timing of which precluded the use of outcomes in this thesis.

Internal Monitoring and Management

Discussions with industry experts (Whitlow, 2008); (Brown, 2008); (Beatty, 2008) identified additional features of metering systems for internal monitoring and management of energy within a multi-lot site (Table 9). These features are concerned with industry rules compliance as well as ensuring a functional infrastructure for a multi-lot site. They may be negotiated on a case by case basis with stakeholders (system owner, retailer, and lines company).

Table 9: Internal Monitoring and Management System Features

System Feature	Key Points
Meter configuration	• Meters must be industry compliant • TOU metering capability is recommended, or an agreement to get usage data from the retailer. • Smart meter capability does not guarantee data will be supplied to the site! • Meters (house and gate) should deliver an electronic pulse, and have the capability to log these via a data logger.
Infrastructure	• Cable or cellular network can be used to connect all meters to a central data logger. • Energy management systems that meter, log and control water, gas and electricity use (including ripple control) are available for customer networks such as lifestyle villages. • There is a range of available systems, with cost and capability dependent on site requirements and compliance issues.
Pricing	• Maximum of 2.5 million kWh/yr can be sold through a customer network; no limit for embedded networks (Brown, 2008). • Contract negotiation possible for purchase at the gate if site has the capability of managing demand and peak avoidance. o Export back at peak times could deliver a cost advantage, but it has to be **consistent** (set minimum amount at a set time)**.**

Future Options	• 'Smart'/Home Area Network[11] (HAN) capability, based on:
	    o Smart meters,
	    o Effective 2 way communication (house: retailer),
	    o Internal ripple control based on price signals, and
	    o Customer specified load management protocols.
	• Load Management options based on households having better access to TOU-type information.

The ability to generate and access information to manage the energy flows around the site is critical. The challenge will be establishing the best system to do this within investment and compliance constraints.

[11] A Home Area Network has been defined as "two or more computers interconnected to form a Local Area Network within the home" (ECNZ, 2009). It uses a communication medium to link with electricity consumption or generation devices so consumers can directly participate in the electricity market. Industry can use price signals to encourage export; consumers use price signals to manage demand.

Network Interface Management

Managing the interface with the external electricity network is important for ensuring a grid-integrated system can deliver consistent supply to the internal consumers, while not disrupting network operations. One of the key advantages of a community energy system is the ability to manage site demand to minimise load on the network. The benefit of such management is based on load shifting out of peak periods and when done on a scale relative to existing network loading can reduce or delay the requirement for new generation infrastructure.

Strategies for demand management include the following (CAENZ, 2007), (Jayamaha, 2003), (Beatty, 2007).

- Peak Lopping – where energy generated at low-use times is stored for release during peaks; or is released from stand-by generation during the peak. Charging/discharging of storage devices, or generators to meet load at the appropriate times is the mechanism for peak lopping.
- Peak Shaving – removing energy demand by switching off/controlling load at the peak. Flattening the demand profile reduces infrastructure needed to meet maximum peak demand. Ripple control is one such mechanism of control.
- Peak Shifting – transferring load demand from one period of the day to another when supply is available, and/or less expensive. This is a common strategy for stand-alone renewable systems, where supply abundance results in discretionary end-uses being done when supply allows.
- Delivering price signals and usage information to consumers so that decisions can be made on an informed basis. Technology is the mechanism for a better consumer interface (described in the earlier section under Technology, page 57).
- Storage – storage options such as batteries or hydrogen can be used for surplus supply from on-site generation, rather than export. The subsequent releasing of the stored surplus into the network at peak demand periods can benefit the network but can be similarly used to offset on-site demand peaks to avoid importing from the network. Storage can add self-reliance to the microgrid during loss of network service, providing the right back-up technology is also available. Investing in storage options for a grid-integrated system does require a cost-benefit tradeoff in economics and technology selection.

Meeting industry standards and regulations requires a DG system owner to ensuring that system performance quality is maintained and the network is not compromised. A number of technical issues can arise that may cause a disruption to the connected network (Table 10) and this should be mitigated at the design stage, or tested for and corrected once the system is in place.

Table 10: Network Distribution Technical Issues

Issue	Description
Voltage Flicker	Caused by variations of input voltage. Some distribution lines and rural feeder set-ups, even when lightly loaded, are not able to deal with variations in loads created by variations in drawn current (e.g. start-up needs of motors). These are considered 'weak lines', less able to deal with switching loads. Voltage compensation or regulation devices can help manage this, and should be part of newer network set-ups.
Power factor correction	PFC adjusts the power factor of a system to near 1.0. to increase network capacity and reduce transmission loss. A load with low power factor draws more current than a load with a high power factor, for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system.
Power Quality	Acceptable power quality relies on voltage maintaining a steady sinusoidal waveform. Power quality can be affected by voltage spikes, where supply voltage reduces to <90% of its nominal value; or increase unexpectedly. On the customer-side of the meter these can be caused by poor grounding or harmonic distortion from certain appliance loads. Stored energy can be released to maintain voltage levels; or regulation devices may be installed.
Load factor (asset usage)	Load factor is a measure of efficiency and of cost to provide power. It is the ratio of average load over a period to peak load in that period. Low load factor indicates poor capacity utilisation. It can be increased by releasing stored energy, or by shifting peak loads to even out demand patterns. Lines companies can charge for low load factor at peak times.

Sources: (CAENZ, 2007), (Jayamaha, 2003), (Masters, 2004)

Technology Implications for Distribution, Connection and Control

Technology is developing rapidly in this area. The biggest complication currently is the retention of value from new metering technology by retailers and distributors, preventing the consumer demand-side from taking action to manage their own costs and efficiencies. The benefits to be gained from such metering and logging technology must also be accessible to the operators of microgrid systems to ensure the economic benefits are available and to ensure the technical design features of such systems are realised.

2.4 Insights from Previous Case Studies and Research

There are a number of previous case studies on a residential approach to energy management in New Zealand, (Easton, Pollard, & Jacques, 2008), (Saville-Smith, 2008), (Vale & Eason, 2006), (Bernhardt, 2008), and internationally (Gies, 2008), (UK Green Building Council, 2008), that review energy-efficient design and performance of a house. The outcomes from the Zero and Low-Energy House project (ZALEH)[12] (Stocklein, Zhao, Christie, & Skumatz, 2005) although of interest for individual house design features, does not offer insights for communal energy management. This has been a common theme for the NZ-based studies.

There are comparatively fewer examples available for review, of multiple dwelling developments (such as Totarabank) where grid-integrated communal energy provision was part of the focus. No example could be found through the available channels, in New Zealand or internationally of any actual development where individual residences were connected to a common grid with a single meter to the distribution network – although apartment developments are documented in international case studies.

2.4.1 New Zealand Case Studies and Research

New Zealand based case studies of direct interest were few. They consist of examples of broad approaches to community sustainability or where energy developments are off-grid (Table 11); and several research reports on a community approach to distributed generation.

Table 11: Summary of NZ Community Energy Case Studies

Case Study	Development Focus	Features
Waitati Energy Project (a Transition Towns initiative)[1]	An existing community looking to improve energy resilience, security, and awareness of energy issues.	Exploring demand reduction options. Renewable resource assessment for installing grid-integrated community generation. Aiming for a collective ownership model for the generation system. The community is working with technology suppliers, Otago University Energy Research Centre, Dunedin City Council and EECA to ensure wide advisory support.
Co-housing Communities: Earthsong[2], Kohatu Toa[3], Awaawaroa Bay Eco Village[4]	Holistic focus on sustainable living as part of a community with shared decision and management structures.	Resource-efficient non-toxic buildings including energy efficient technology. Individual not communal electricity. Renewable or alternative generation is off-grid.

[12] ZALEH was conducted by BRANZ and explored the effects of energy technologies in new and retrofitted houses in terms of economic and non-economic benefits.

Case Study	Development Focus	Features
NIWA-FRST 'Energy for Maori' Project (De Vos & Hamm, 2008)	Long-term improvement of living conditions in remote Maori communities, using renewable energy.	Development of a consultative process to identify needs, resources and solutions. Energy efficiency options first priority. Generation options dependent on ease of installation and maintenance.

Note: These community initiatives have no official published documents other than material posted onto the following websites: [1]www.transitiontowns.org.nz, www.earthsong.org.nz[2], http://users.actrix.co.nz/kohatutoa[3], www.awaawaroa.org.nz[4]

Research: Community Distributed Generation

The best-documented example of a grid integrated communal approach to energy management is that of the Totara Valley Rural Energy Project, coordinated by Massey University. The long term research site (since 1999) has had a focus on exploring the impact of renewable DG technology on supplying a grid-connected rural community of three families and associated farm buildings. The community has a range of heat and power technologies, consisting of:

- Three export meters.
- Generation systems connected by residence rather than for the whole community (micro hydro, biodiesel generator, photovoltaics, hot-water heat pump and solar thermal hot water) providing approximately 7 kW power capacity and 5kW heat.
- Novel energy storage technology based on wind generated hydrogen piped to a fuel cell.

Export of surplus electricity has reduced power bills and is not disrupting network power quality; with the bulk of the surplus coming from the micro-hydro plant. The opportunity exists to optimise the system for network support, and increase energy supply. This could subsequently provide more integrated communal benefits to all residents in terms of cost reductions – currently these are accessed according to individual generation systems.

Research associated with Totara Valley is included in the following summaries:

Community Owned and Operated Renewable Energy Schemes in Rural New Zealand (Irving, 2000)

This project evaluated viability of community owned and operated renewable energy schemes, based on two rural community case studies by developing a computer model. This used data for consumption (peak load, number of properties and use of electric water heating), connection infrastructure, available resources and technology to find the optimum combination of wind and solar to meet community demand. The optimisation was based on Excel Solver function, and outputs included:

- annual cost of grid connection
- annual cost of supplying renewable electricity,
- The value of the renewable energy in c/kWh.

These were used to make decisions about the viability of community owned renewable energy and the technology combinations to do this as stand-alone versus retaining grid connection. For both communities, it was significantly more expensive to install a stand-alone scheme than to integrate a community scheme with the grid.

Residential Distributed Generation (Redman, 2002)

This project developed a decision support tool to assist Meridian Energy to identify residential market opportunities for Distributed Generation (DG) applications, not necessarily based on renewables. The model consisted of load profile development, DG technology, operation control, costing, and a calculation engine. Emphasis was on technology evaluation in terms of energy delivery and network impact. A network analysis showed the technologies could reduce peak loading. The project noted a future critical issue for DG was the price of export electricity.

Distributed Generation on Rural Electricity Networks – A lines company perspective (Jayamaha, 2003)

The viability of rural distributed generation was assessed from the Lines Company, and investor perspectives. A detailed computer model was developed to explore scenarios for metering, pricing, peak management and incentives. Resource and demand data was sourced from the Totara Valley community, due to their location, and the impending threat of loss of supply post 2013. Centralised systems were economically viable than for individual properties, and generators offered opportunities to provide network capacity at peak periods. The biggest influences on future action were lack of technical knowledge, lack of incentives for DG installation, and loss of revenue by the Lines Company.

Designing Sustainable Distributed Generation Systems for Rural Communities (Murray, 2005)

Selecting sustainable electricity alternatives to rural supply led to a model that combined resource analysis, energy system optimisation and decision-analysis software to create a decision analysis framework. The model was tested using load and resource data from Totara Valley and the results ranked by stakeholder preference between sustainability aspects of the recommended systems.

Distributed small-scale wind in New Zealand: Advantages, barriers and policy support instruments (Barry, 2007)

The increase in wind-generation has been driven by the need to increase electricity from renewable sources. In New Zealand there is increasing resistance to large-scale developments, and fewer investors who will fund them. A survey was completed in Masterton and New Plymouth to determine the level of interest in community ownership of wind. It determined that small wind developments with some community ownership would be more attractive than large-scale wind farms. Policy changes were recommended to facilitate smaller, community owned developments.

Industrial Research Limited (IRL): Integrated Distributed Energy Systems

IRL has completed a number of studies in the energy field, including small scale distributed systems (Gardiner, 2007), (Gardiner, 2006a), (Gardiner, 2006b). An Integrated Distributed Energy System is a distributed electrical energy system connected to a local energy load, also connected to the network. These have been studied at Totara Valley, along with novel generation and storage technology based on hydrogen.

Energy Management Insights from New Zealand Case Studies and Research

Common themes from the case studies in Table 11, and the research summaries indicate that:

- Off-grid systems are common for rural communities, but they are sized for individual houses rather than for the whole community. The common drivers are environmental action and the need to maintain services.
- Communal grid-integrated systems are not common in New Zealand. Totara Valley is the only reported net-billed example of community energy, but is not fully optimised in terms of maximising site resource potential and consistent benefits to the whole community.
- Initiatives rely on grass-roots motivation, and input from a range of sources to access knowledge and technology at a reduced cost. Developers do not seem to be prominent leaders of forward-looking energy options.
- Energy efficiency and reducing demand are common approaches for managing energy.
- Technology is predominantly solar thermal, micro-hydro, wind and photovoltaic.

There is little evidence of urban housing developments implementing sustainability features, and assessing the effectiveness. The initiatives above, and individual housing projects such as the Beacon NOW Homes®, are the major documented examples – few developments have a specific strategy for managing energy including use of local renewables. This remains a large opportunity for action in New Zealand and a topic for further research and monitoring.

2.4.2 International Case Studies

The international case studies (Table 12) ranged from modelling impacts for existing communities through to assessing technology performance post installation. Compared to New Zealand there are more international examples of large urban developments, where the impact on a range of stakeholders from networks to consumers is assessed (Johnson & Dignard-Bailey, 2008). There were many variations of what constitutes a community system, so the examples given are broadly focussed on systems associated with residential housing clusters including apartments. The concept of 'Solar' neighbourhoods, streets and cities has been applied in several countries – wind technology is less common in urban installations due to the lower efficiencies of micro systems.

Table 12: International Case Study Summary

Case Study	Development Focus	Features
Renewable – energy clusters for Remote communities (Underwood et al, 2007)	Modelling the impact of supporting energy supply of a Northumbrian village, with building- integrated solar and wind turbines. Demand based on existing patterns, and with energy efficiency measures.	Model developed combining supply - side model with domestic electricity demand. 40% of demand could be met if export mechanisms were available; 8% of demand would be met if system is off-grid.
Merri Solar Community, Melbourne (Cunnington & Pockley, 2009)	13 households in a Melbourne suburb each installed grid-connected PV systems (1-2kW) and monitored performance.	Differences in tilt angle and system size did not affect per-panel performance, but dust, heat and shading did. Energy consumption didn't change significantly over 12 months but consciousness was raised. Residents became more aware of weather, tariffs, and bill formats.
International study of community-scale solar systems (IEA-PVPS Task 10, 2008)	Improving building efficiency, load diversity, energy efficiency, and grid infrastructure by increasing the uptake of solar technologies in urban developments. (38 solar communities across 12 countries in Europe, Asia-Pacific and USA)	Range of PV, thermal and passive solar combinations. Individual connections (up to 500) in housing clusters or on apartments. Some shared inverters (1 for 4 houses) but otherwise energy systems were individually managed by users; or exported directly to grid (managed by utility). PV systems range 1kWp to 8.5kWp, with average 3-4kWp/house. Display systems linked to all meters. Export tariffs ranged from encouraging in-house use, to export of all energy.

Case Study	Development Focus	Features
Dockside Green Development, BC Canada (Dockside Green, 2008)	Mixed-use (residential to industrial) 16 acre site based on Triple Bottom Line sustainable development in Victoria, Canada.	Buildings rated using LEED[1]. Passive design features and energy efficient appliances reduce demand. Meters with displays to show water, heat and electricity use data. PV, solar hot water, small wind and communal heating schemes installed for site benefit.
Canada: Solar Neighbourhood (www.cleanenergy.gc.ca)	Government funded portal with case studies on a range of energy projects including 'Canada's First Solar Neighbourhood'	Building-integrated PV of 3kW per home, on 14 homes. Aiming for reduction in emissions of 4 tonne CO_2/yr per home.
Australian Government Solar Cities Initiative (Solar Cities, 2009)	Energy efficiency measures, pricing trials, access to solar technology and community education for residential and commercial users in several cities across Australia	Consumer cost and energy savings. Industry testing of sustainable energy option . Cost savings potential for electricity providers for peak demand periods. Government development of energy and greenhouse policy.
Beddington Zero Energy Development , UK (BedZED): Peabody Trust (Pipkorn, 2008)	BEdZED is an independent residential 'prototype' sustainable development of 100 homes and 100 workspaces. Completed in 2001 with monitoring ongoing.	Design and construction of buildings for maximum energy efficiency, including: Orientation for the sun, super insulation, thermal mass, high performance glazing , natural ventilation, efficient appliances . Renewable energy power technologies: Biomass CHP (combined heat and power) system; and PV panels. Results: CHP operation has been problematic leading to inefficiencies. Residents needed education on use of passive design features and energy meter use. However, there is significant contribution to carbon reduction.
Lochiel Park Housing Development, South Australia (Bishop, 2008)	Lochiel Park is a medium density (<100 lot) brownfield development underway now. It's a State Government initiative to demonstrate some extensive sustainability principles. Monitoring is to be done over 9 years. Energy objectives: reduce consumption by 66% and GHG by 74%.	Housing designed to have a 7.5 star performance rating with AccuRate. Load management devices installed to reduce peak loads by switching off circuits in-house (with air-con first). Extensive heating, cooling, lighting and power input sizing standards. Minimum 1kW PV per $100m^2$ per house. The utilities were reluctant to accept the peak load reduction steps will result in reduced infrastructure, so standard levels were installed.

[1]: LEED® rating system administered by the Canada Green Building Council and United States Green Building Council is a green building rating tool that assesses the environmental impact of buildings.

The design and technology requirements for houses in Lochiel Park are shown in Appendix A5 Energy Efficient Housing Example, to show current options for energy efficient housing. Although these are for a warm climate, they represent an approach that could be adapted for New Zealand.

Energy Management Insights from International Studies

The key insights to be drawn from the international case studies of community scale energy management (Table 12) differ significantly from New Zealand in terms of the drivers for energy development; and the reported outcomes.

Although there are a range of initiatives in a number of countries, common themes emerged as drivers for community energy developments:

- Attempting to establish a collaborative process amongst a range of stakeholders who all have different needs (government, industry, consumers).
- State support and investment to implement practical demonstrations of social, technological and economic options for sustainability including energy.
- Demonstration of sustainable energy technology in a residential setting, including meters, displays and the impact of energy efficiency.
- Desire to explore impact on grid stability.
- Trialling options for demand reduction, including daytime peak matching in countries where air conditioning loads in summer are increasing.
- Raising education and awareness among all stakeholders.
- Developing a community sense of 'green' identity, purpose and appearance.
- Long term strategic desire to create policies and tools for reducing fossil fuel use, and managing climate change.

The outcomes from the case studies included:

- Reduced demand (ranging from 5% to 60%), that led to reduced energy costs
- No network stability issues from grid-connected PV particularly if the utilities were involved in developments from the start.
- Urban community systems could smooth load profiles due to closer matching with commercial load and provide opportunities for enhanced grid design.
- Residential demand patterns altered – influenced by tariff type, and in-home displays showing supply and demand information.
- Property values increased in some communities (USA).
- Energy awareness increased alongside changes in the sense of community identity.

The success of solar community projects is underpinned by enabling policy, leadership, and support from public and private sector – especially in managing upfront technology cost (IEA-PVPS Task 10, 2008), (Johnson & Dignard-Bailey, 2008), (Bishop, 2008). Benefits such as cost reductions through demand reduction, from managing peak profiles, from selling turn-key systems or from selling housing developments with solar features must be valued by the stakeholders who receive them.

New Zealand, in contrast, appears isolated from international influences, as government and industry value profit from increasing electricity demand more than the long-term benefits of reduction. Consumers are not incentivised to change demand pattern; industry remains fragmented in the absence of appropriate policy, and the consumption of fossil fuels for energy generation is being promoted.

To identify insights of specific interest to Totarabank required a level of detail that was rarely reported – in that the post-implementation monitoring was sporadic and usually anecdotal. This represents a huge future opportunity in energy research, where the effort involved in implementation should be matched by rigorous monitoring and reporting to ensure lessons are learnt and transferred. It can only be hoped that stakeholders in industry and government along with end-users identify the value of post-implementation monitoring, and expect it as part of future projects.

2.5 Review Summary

The rationale for undertaking this research is based on exploring options for managing communally operated grid-integrated renewable energy distributed generation systems. There are few examples in NZ of multi-lot developments utilising sustainable energy management as a core part of the development approach. Researching the technical and economic viability of these systems within pre-set covenants for house performance and energy use is required to better understand the balance between these factors. Consequently, the development of a decision-support tool is of value to land developers and future residents involved in new approaches for community energy.

Chapter Two has reviewed the New Zealand electricity market, sustainability in the context of energy, the management of community energy systems, and insights from previous case studies and research. The findings of the literature review as they relate to the research rationale are discussed below:

- The electricity market review indicates national energy consumption is growing, placing increasing pressure on network infrastructure and generation capacity to meet demand. Small-scale renewables have the potential to contribute to this if recent regulatory changes enable an increase in distributed generation installations. The regulatory environment, and the stakeholders involved are geared to large scale supply developments (renewable or not) and the retention of profit by the Government, creating an incentive for end-users to explore alternatives.
    - These insights support the potential role community energy systems have in contributing to local networks by utilising distributed generation options for demand management, delaying capacity investment and improving resilience of end-users to increasing electricity costs.
- The review of sustainability and energy management concluded support for this approach is inconsistent nationally. Research based on implementing residential sustainability based on better building performance, rural electricity and use of local renewables provides options for a more holistic approach to resource management.
    - A set of sustainability indicators based on previous research, is suggested for assessing the benefits of sustainable energy systems in achieving social, economic, technical and environmental goals.
- Reviewing community energy systems demonstrated the complexity of the technical, regulatory and management features involved. These features impact management of the energy balance between supply and demand, the choice of network connections; and options for electricity export. There are few precedents in NZ.
    - Clarifying the relationships between, and functions of, the features of a community energy system is fundamental to designing an effective decision support tool to model energy system performance.
- Insights collated from previous cases studies and research, indicated a greater incidence of grid-integrated community electricity systems internationally compared to NZ – where only one well-documented example exists. Internationally, projects ranged in size and used a range of technologies for sustainable supply (predominantly solar), monitoring and display, house design and energy efficiency. The drivers were often a state-supported aim to increase sustainability awareness, reduce fossil fuel use, and manage network performance through practical demonstration. NZ currently has no incentives for similar investment.

- The Totarabank approach appears to be unique, in that no examples could be found, of individual residences in a development connected to a common grid with a single meter to the distribution network. This supports the development of decision support tools to better understand the possibilities of grid-integrated community systems based on sustainable energy principles.

3 METHODOLOGY - STAGE ONE

3.1 Introduction and Overview

The first stage of the design and development of the Decision Model, as a decision support tool for Totarabank required sourcing and analysis of a range of data prior to the tool development. Data acquisition and analysis is described as the Key Element Input Process. This approach was based on elements of microgrid design (Abu-Sharkh, et al., 2005) also common to systems aiming to balance renewable energy (RE) supply, with an estimated demand.

The key elements are the foundation of the Decision Model. The rationale for the translation and analysis of the data associated with each element is introduced below:

Site Requirements: Estimated the site system capacity set by the covenanted limits for the site electricity infrastructure against capacity requirements to meet the site energy balance.

Supply: Estimated the energy available from distributed on-site wind and solar generation, to be used to supplement imported network electricity. The potential supply data was then analysed against estimated demand to deliver an electrical energy balance for the site.

Demand: Estimated the likely electricity demand (or load) from eight houses operating individually, but having an aggregated effect on the site microgrid infrastructure. The impact of non-electrical energy and house performance was taken into account.

Energy Management: Estimated the impact of economic criteria of pricing, forecasts, payback periods, retailers, technology costs and other factors contributing to supporting the decision process.

In the first stage, raw data was gathered from a range of sources for transformation, initial analysis and formatting into datasets that became the key inputs to the Decision Model (Figure 16). The second stage (The Decision Model Process) saw the model designed in Excel around these inputs to create the desired outputs and datasets used for further analysis and decision making.

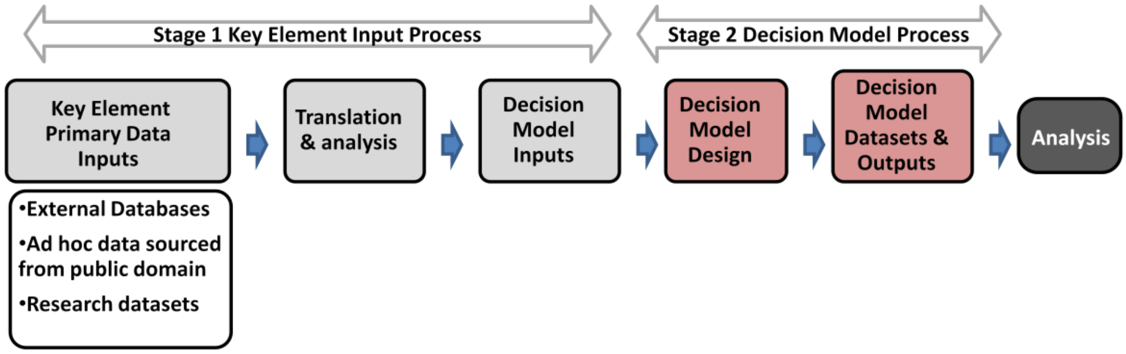

Figure 16: Process Overview

<u>3.1.1 Assumptions for the Energy Balance</u>

The decision model function is based on calculating electrical energy balances. Estimation of the site electrical energy balance assumed the contribution of appropriate grades of energy sources other than electricity for certain end-uses. The emphasis of the model on electricity was due to the requirement to assess the viability of electricity export in a grid-integrated system. If a full energy balance was to be done over the Totarabank site, the energy contribution from biomass, passive solar, solar thermal, and bottled gas would need to be quantified – this exercise is at the discretion of the Totarabank developer.

The availability of the appropriate resources on Totarabank to meet the thermal energy requirements through the use of biomass combined with building performance standards was addressed in an earlier thesis (Duncan, 2005). Lamige (2008) explored thermal analysis of building design at Totarabank and assumptions were made (Figure 14) regarding the effect on electricity demand from other energy sources and of building performance based on this report.

3.2 Key Element Input Process – Stage 1

The overview of the first data management stage is shown in Figure 17. It demonstrates the link between the rationale (blue boxes) for each of the key elements, and the type of data that was sourced for the initial transformation and analysis (white boxes).

The data translation processes had to convert a year's worth of raw climate and energy monitoring data into user-friendly hourly formats before any further analysis could take place. Subsequent analysis then took reformatted climate and energy data, along with the data for pricing, equipment performance, capital costs, infrastructure limits to create Decision Model inputs in the appropriate format.

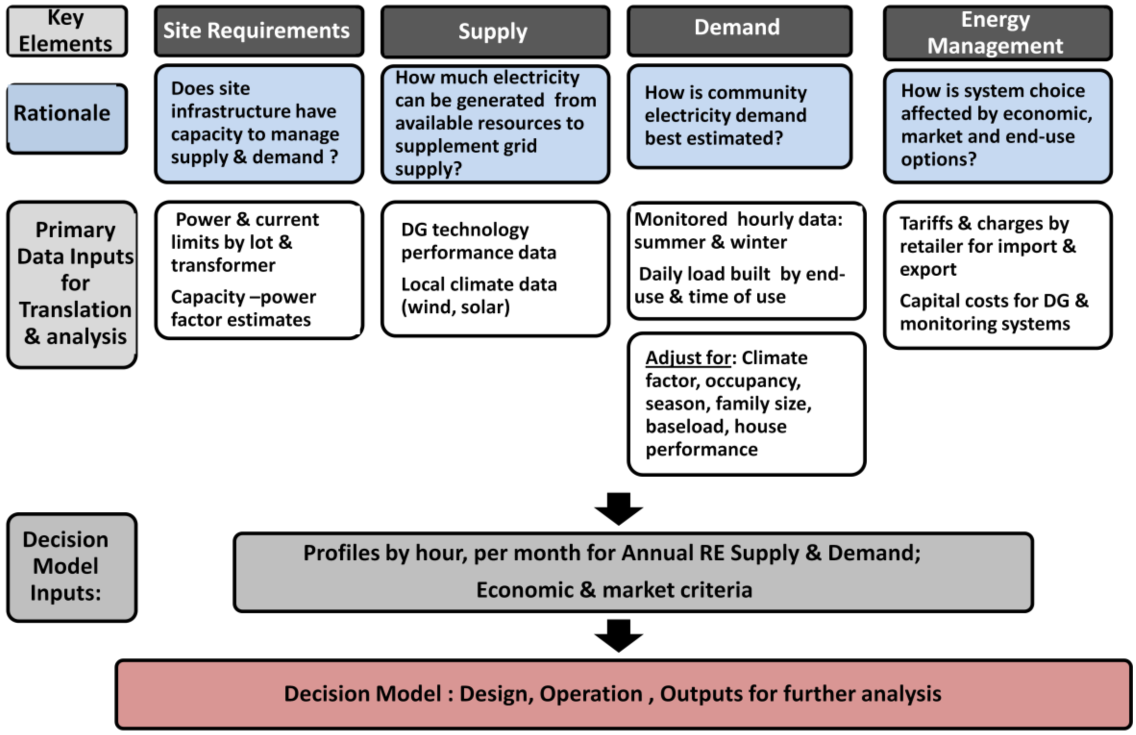

Figure 17: Overview of Stage 1 Key Element Input Process

3.2.1 Site Requirements

Site requirements were modelled by estimating the site system capacity to meet the requirements of the site energy balance, based on the electricity infrastructure covenants. These are:

- Maximum 30amp current limit per lot.
- A 50 kVA transformer for the site.

Site requirements were re-estimated as demand and supply combinations were changed, to highlight transformer and lot capacity shortfalls as part of the decision process.

1. Estimates for peak power (kW) derived from the demand profiles, were used as the basis for assessing lot and site system capacity. The following equations were used:

   Estimating lot current draw, to satisfy the 30amp restriction

   Based on Equation 1, (as described in section 2.3.2 Managing the Energy Balance) the equation for Peak current draw (amps) A_{Peak} is:

   $$\boldsymbol{A_{Peak} = \frac{kW_{Peak}}{240Volts}} \quad \textbf{Equation 2}$$

   Current needed to be < 30 amps to satisfy the covenant.

Estimating transformer capacity

Transformer capacity assessment is based on peak power, and assumptions for power factor. Power factor is an expression of how much work the network has to do to deliver power, as a result of current and voltage synchronisation (Masters, 2004). As current and voltage move out of phase, losses increase in the lines, the power factor drops, and more current is required to deliver the same amount of power. The power factor should be as close to 1.0 as possible for minimising capacity shortfalls in the network and in the transformer used to deliver power efficiently to the site.

Power factor (p.f) = real power (kW)/ apparent power (kVA)[13] **Equation 3**

2. In order to account for the effect of appliance choices[14] on each lot that could negatively impact power factor, a lower limit of 0.65 and an upper limit of 0.95[15] were chosen for assessing the transformer performance. Equation 3 was used to estimate the transformer apparent power (kVA), as the peak power varied for each demand profile.
3. The apparent power estimates for each power factor were assessed against the transformer capacity of 50kVA. This enables a site scenario to be assessed against how the site infrastructure can manage a particular supply-demand combination, and how much capacity there is in the system to manage low power factors.

3.2.2 Demand Datasets

The processes and rationale for developing the demand profiles as key inputs for the Decision Model are outlined here.

Demand Profile Rationale

Low, medium and high demand profiles were created as inputs to the Decision Model. Three profiles were created so a demand range could be established for decision-making, to enable developers and residents to get a broader perspective on the impact of demand on energy outcomes.

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[13] : Apparent power kVA is the vector sum of real power in kW that does the actual work, and reactive power in kVAr that is an expression of synchronisation of current and voltage waveforms.

[14] : Motorised appliances with high inductive loads reduce power factor and increase current draw. These include CFL light bulbs, fans, dishwashers, heat pumps, vacuum cleaners, refrigerators etc. Conversely, incandescent bulbs are reactive loads with low current draw so that power factor stays high.

[15] This was based on HEEP 10 project monitoring (Isaacs, et al., 2006) where three houses were monitored for power factor fluctuations. The mean power factor varied from 0.76 to 0.97, influenced by season and appliance type.

The low demand dataset and base profile was created using a "ground-up" approach (Figure 18). This allowed more flexibility by way of assumptions on major end-uses scenarios, and also considered the use of non-electric fuels. This includes developing profiles for occupancy, pre-schoolers and household size.

The medium and high demand datasets and base profiles were created (Figure 19 and Figure 20) using BRANZ HEEP data sourced from on site monitoring of residents living in a house designed with resource efficient principles (French, et al., 2007).

The base profiles were translated into full annual profiles by month, using a seasonal adjustment process (Figure 21).

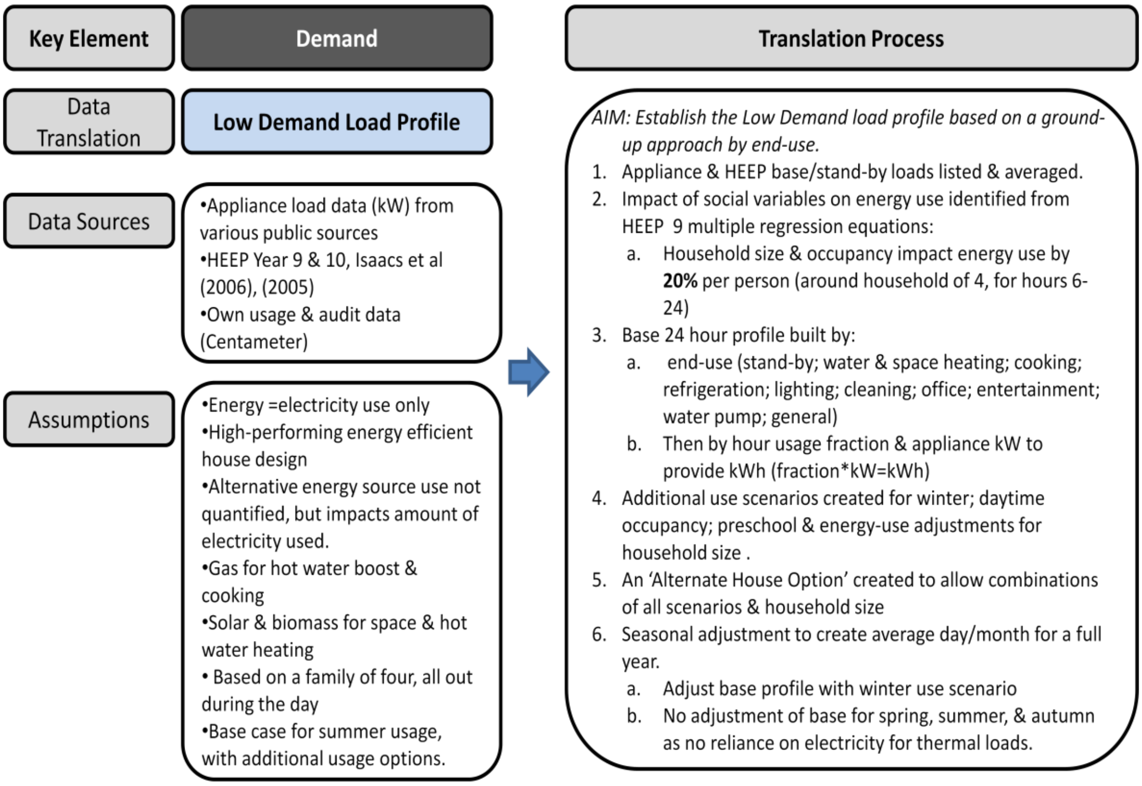

Figure 18: Low Demand Load Profile Overview

Energy use data for use in compiling the medium and high demand profiles (Figure 19) was provided by Beacon Pathway, and analysed by BRANZ[16] (Appendix B2 BRANZ Data Request for Raw Demand Data) from data extracted from NOW Home® research. This data set was used because it was the only available data from a family living in a house designed to be energy efficient. A summary of key data based on the draft research report by French et al (2007) is contained in Appendix B1 Beacon Monitoring Data .

[16] Note only two months worth of data was used (a typical summer and winter month) as this is all that would be provided by BRANZ. The remaining months were estimated using seasonal adjustment ratios.

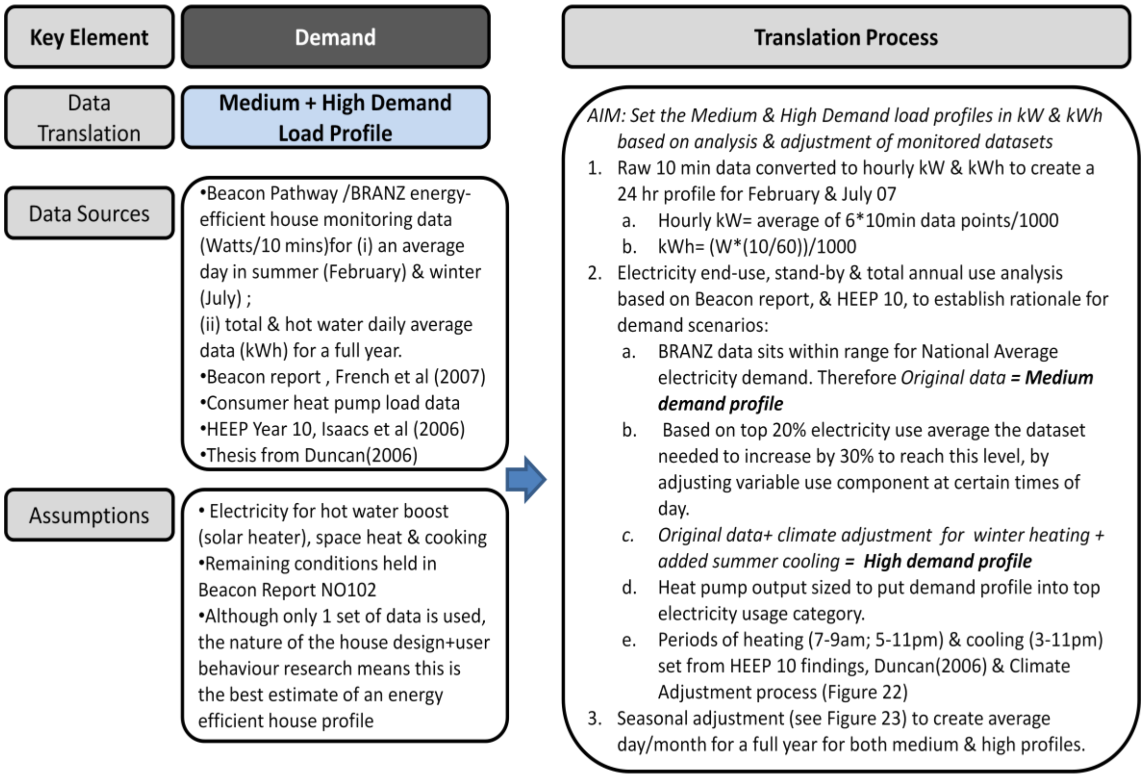

Figure 19: Medium and High Demand Load Profile Overview

Climate adjustment[17] of the raw data was required to consider the climate differences over the heating season, between Auckland (NOW Home®) and Masterton (Totarabank) (Figure 20). This was done using the interim model for ALF 3.1.1 (BRANZ thermal modelling software).

[17] It is important to note that the climate adjustment process was conducted early in the timeline of the model development, and subsequent model construction and analysis was based on this early work. Although it was delayed for as long as possible to allow for the new version of ALF to be released, the interim version had to be used.

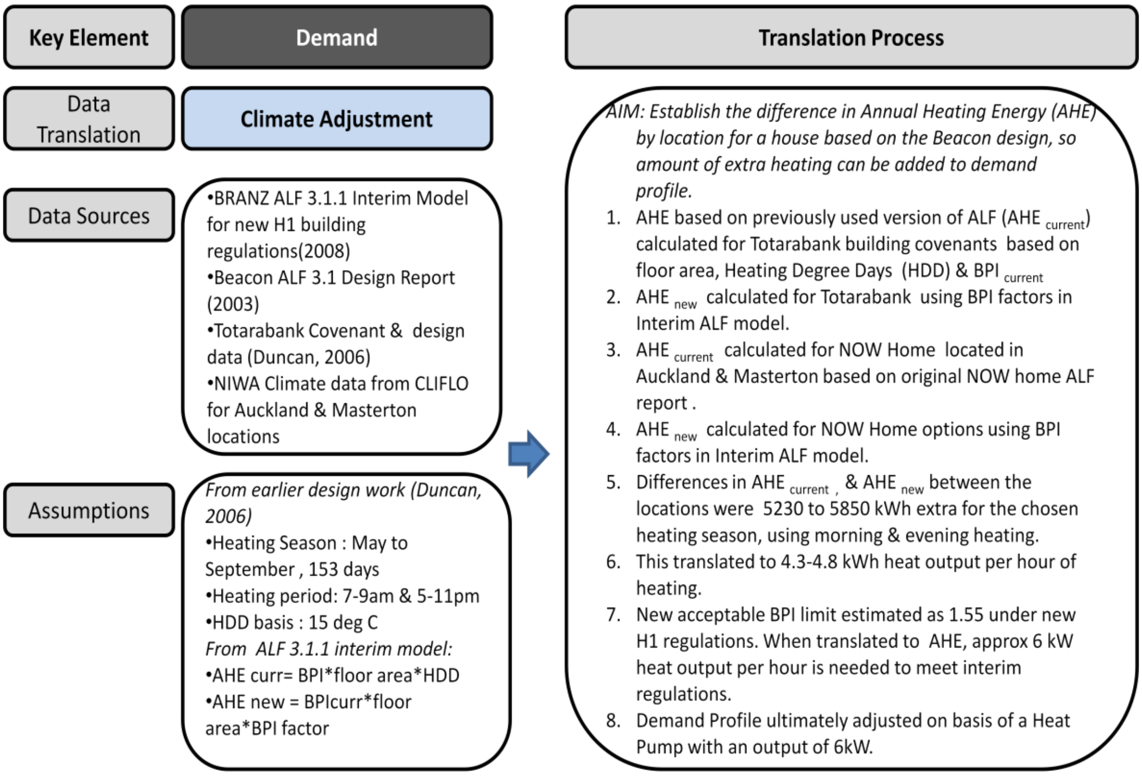

Figure 20: Climate Adjustment Overview

The base demand datasets had to be adjusted (Figure 21) using ratios (Appendix B3 Seasonal Data Adjustment) to create average day/month datasets for the remaining months.

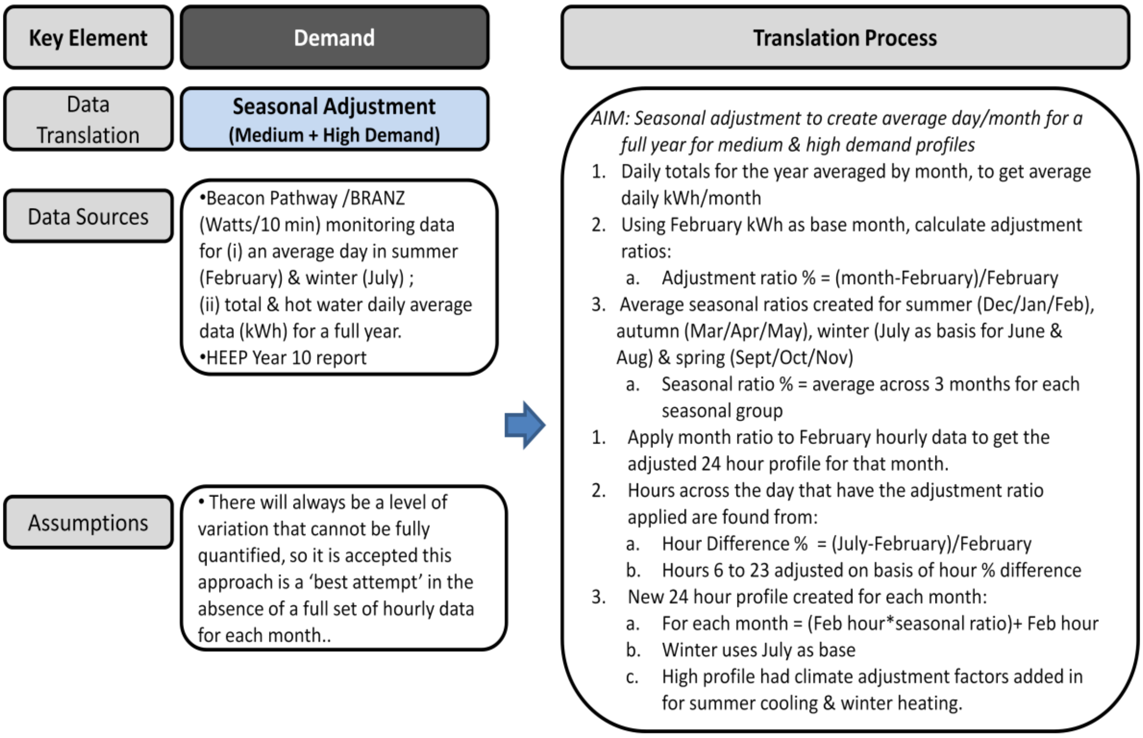

Figure 21: Seasonal Adjustment Overview

Decision Model Inputs - Demand

The demand profiles created (Figure 22) as the result of the processes outlined in the previous sections, become the key inputs for the Decision Model.

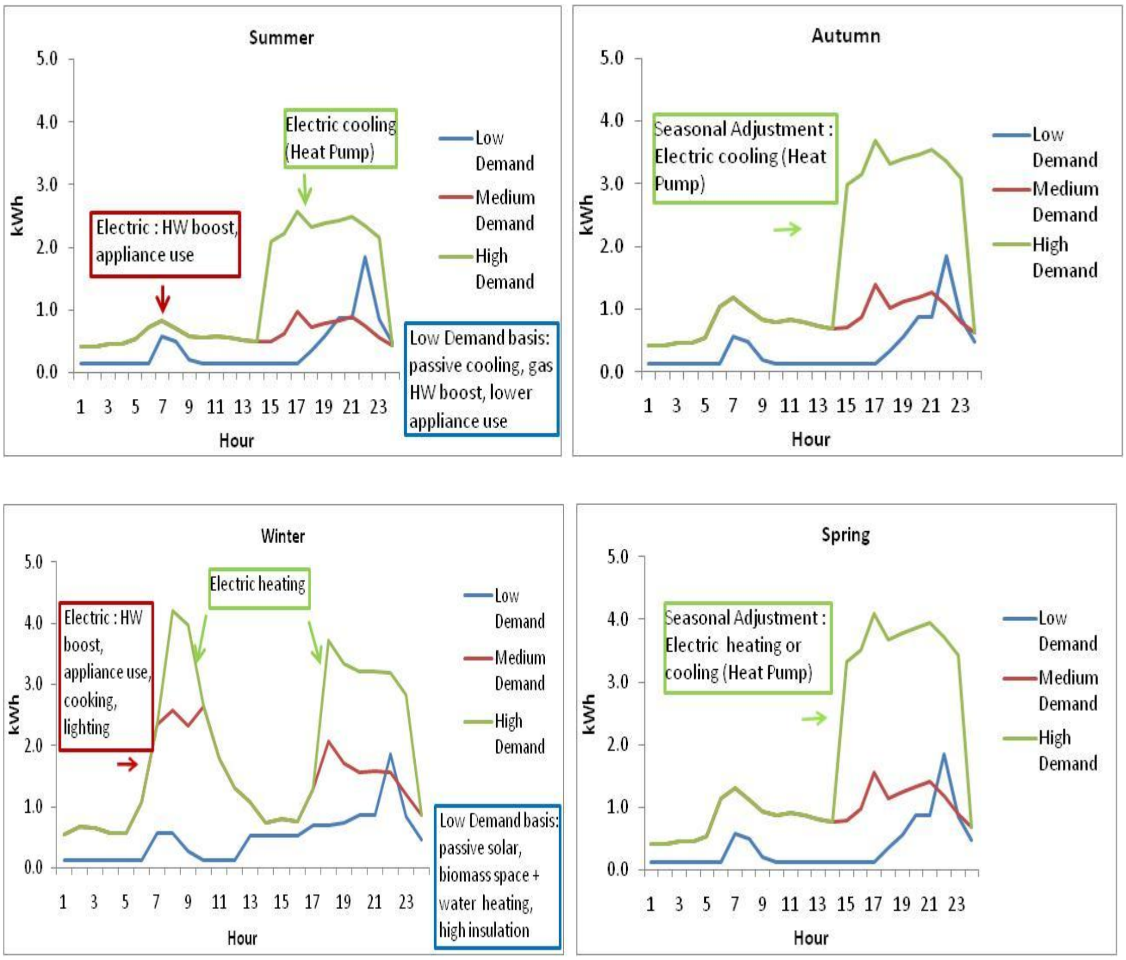

Figure 22: Demand Profile Comparison by Season

The differences in each of the profiles (Figure 22) are based largely on the assumptions of user behaviour for heating and cooling, and the use of non-electric alternatives for space and water heating, as listed in Figure 18 and Figure 19. Cooking is largely based on gas for the low profile, and all-electric for the other profiles. These profiles are designed to demonstrate a demand range that allows for human nature as well as house performance.

The household is assumed to be aware of conservation benefits in the low demand profile. The high profile in contrast, has assumed that the household will use a heat pump to supplement heating requirements in winter and to cool in summer. Although the house performance is designed to be energy efficient, this is exploring the demand effect of a household ensuring comfort is never compromised throughout the year (hence heating or cooling loads in shoulder seasons). In reality, the Totarabank developer is aiming to educate residents to ensure both house design, and behaviour will keep demand as low as possible without being completely prescriptive.

Average daily demand for each profile is shown by season, in Figure 23. The total annual demand calculated on a per house basis is shown as well, to provide context of the relative differences between the profiles in a commonly used measure for electricity use.

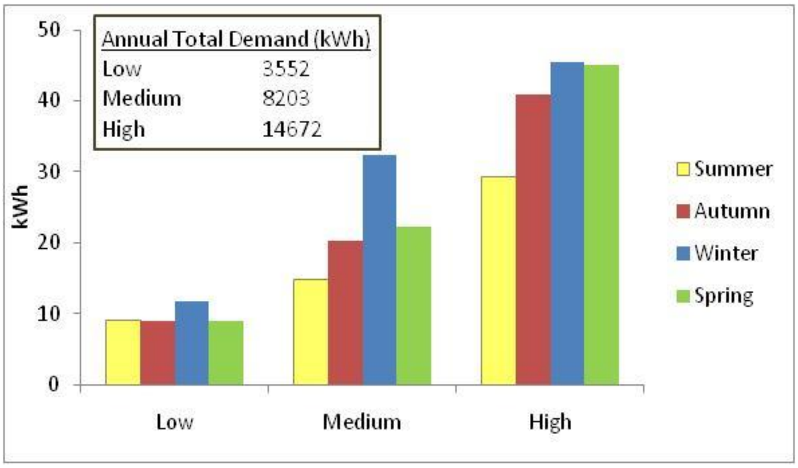

Figure 23: Comparison of Average Daily Demand, by Season

End use comparisons are shown in Figure 24, including data from HEEP 10 (Isaacs, et al., 2006) for average electricity end-use.

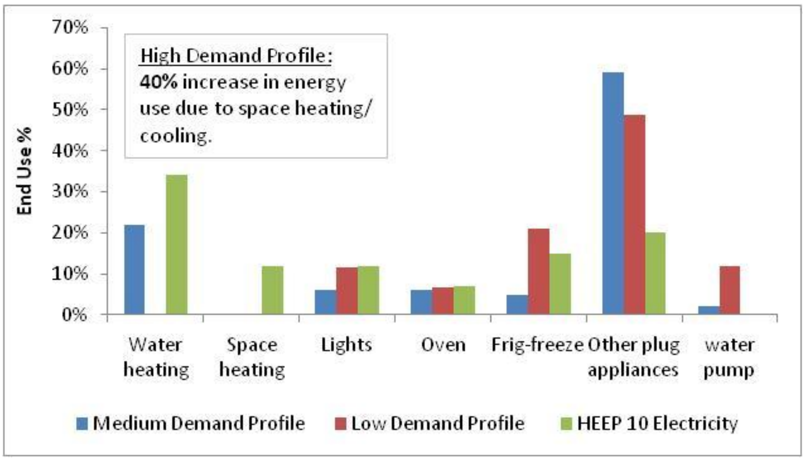

Figure 24: End Use Comparison

3.2.3 Supply Datasets

Raw climate hourly data was sourced from the NIWA National Climate Database (CLIFLO[18]) for wind speed and insolation, from the East Taratahi weather station[19] (closest to Totarabank).

Following the translation of raw climate data into the appropriate units and format, average daily profiles by month for solar and wind resources were created based on averaging hourly data across each day in the month. The data sources, assumptions and translation processes for resource data is shown in Figure 25.

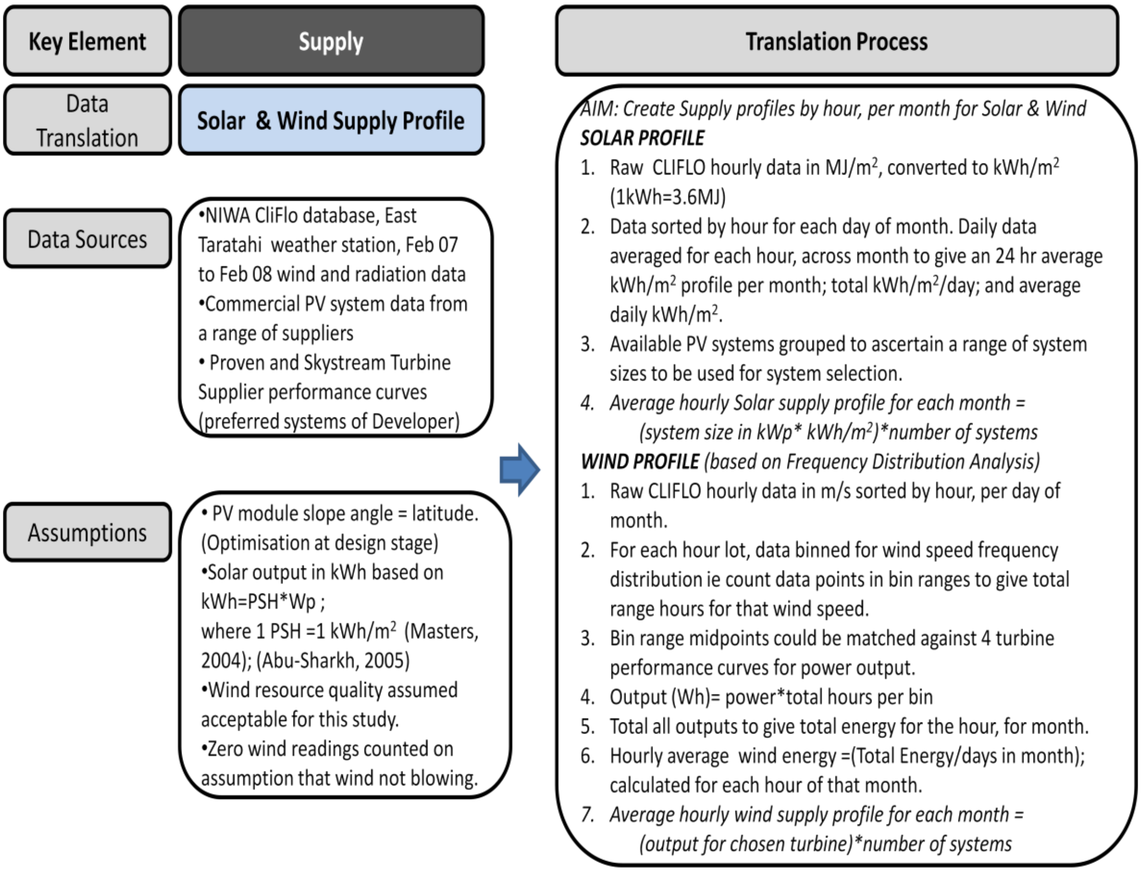

Figure 25: Supply Profile Overview

Weibull assessments done by Sigot (2008) as part of a site resource assessment study, showed wind resource quality is marginal based on East Taratahi CLIFLO data – average wind speed was estimated as 3.2m/s. The developer had alternative wind map data indicating increased wind speeds specifically in the Totarabank area (average annual wind speeds in the range 4 to 5m/s); and wished to pursue modelling wind turbines for site electricity supply. Therefore the wind resource was included in assessment for this study.

[18] This database can be accessed via http://cliflo.niwa.co.nz. Access is free for a range of raw data and statistics from about 6500 climate stations.

[19] Located at East Taratahi, station number 2612, Latitude (dec.deg) -41.016; Longitude 175.622

System Sizing Rationale

The design of the Decision Model was to allow flexibility of choice in selection of supply options, rather than designing the supply system to meet peak demand.

Photovoltaic panel systems from three suppliers[20] were compared by the size range (Watts peak, Wp) to get a picture of the broad size categories[21] offered. Those size categories were used as the inputs for selecting system size. The rationale for this approach was to enable quick, easy comparison[22] of the relative effect of sizing of solar supply, on the assumption that the final system design would sit somewhere within the range.

The wind system sizing was done on the basis of pre-selected systems preferred by the Totarabank developer. The performance curves from Proven, and Skystream turbines were used to determine the final wind supply output options. Therefore, the system size choice was done on the basis of turbine type. Additional turbines can be readily added to the decision support model for quick assessment and review.

The final wind and solar PV supply profiles were generated in kWh by hour, by month over a year (Figure 26), and are then used to form the basis of the supply portion of the site energy balance.

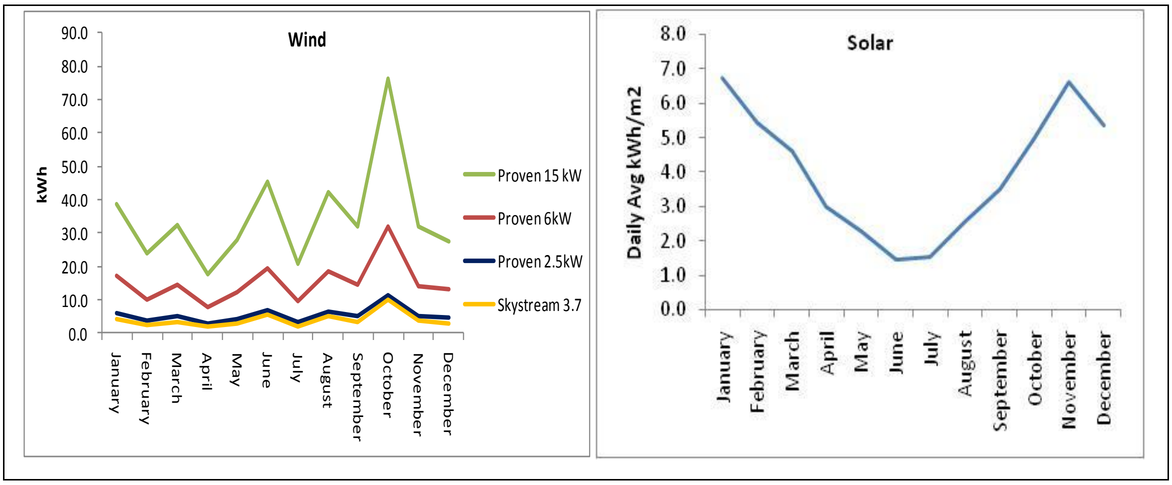

Figure 26: Annual Supply Profiles for Wind and Solar

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[20] Online and hard copy catalogues from Powersmart, EcoInnovation, Alphatron. These suppliers offered full systems in a range of sizes.

[21] Size categories chosen were (Wp) 1.2, 1.7, 2.6, 3.6, 5.1, 10.8. The intent is to demonstrate a range.

[22] The alternative approach is to allow the user to input any PV system size of their choice; deemed less convenient for users who have no understanding of system size possibilities.

3.2.4 Energy Management

The Energy Management element is designed to support the economic and financial decisions for a community system, using a range of data inputs (Figure 27) for:

- electricity tariffs (retail import, export, wholesale, and fixed lines charges);
- retailer choice;
- capital costs according to supply system selections, overall system size, and maintenance estimates;
- analysis based on payback time, forecast price changes, and interest rates; and
- alternative options for Feed-in tariffs and incentives, to test the impact these could have if available in the New Zealand market.

Part of the data translation process required automatic generation of some data inputs within the model, on the basis of initial selections. For example, retailer selection automatically generated tariffs, and supply system size generated additional capital costs for approvals and testing if the system exceeded 10kW.

The data sources, assumptions and translation processes to manage the raw data inputs for energy management are shown in Figure 27.

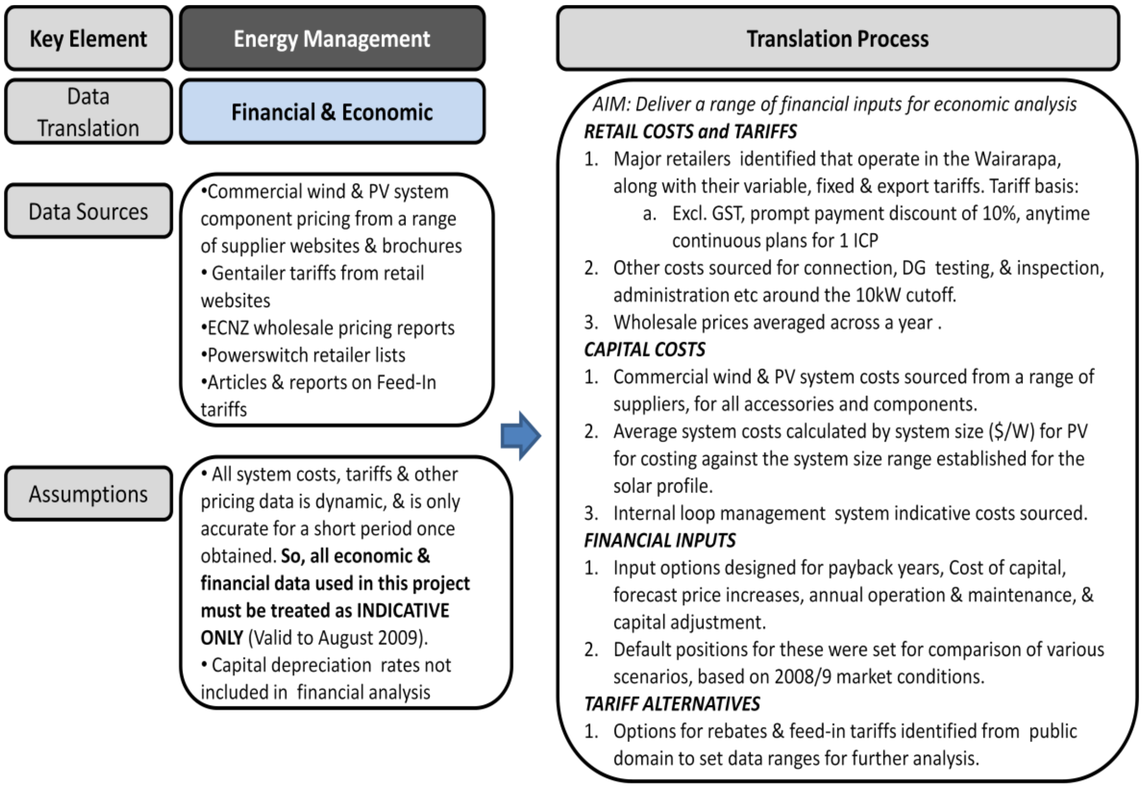


Figure 27: Energy Management Overview

Details of the retail costs, financial inputs and capital cost data work up can be found in Appendix B4 Energy Management Inputs.

3.2.5 Demand Data Benchmarking

Due to the initial data used to create the demand profiles coming only from the NOW Home®, data from the HEEP database (Appendix B5 Demand Data Benchmarking- HEEP) for the lower North Island was used as a benchmark. The rationale was to benchmark the demand profiles created for the Decision Model, against 'standard' HEEP houses – predominantly to ensure the three profiles represented a range within which the HEEP data would sit.

Four datasets were constructed from the HEEP supplied data:

- Electric fuel use (Tot. Electric) – to understand the average electricity consumption
- All Fuels (Tot. All Fuels) – to benchmark the comparison between multiple fuel use and the datasets that used all electricity for all end-uses
- All Fuels less Solid Fuels (Tot. All Fuels-Solid Fuel) – to break out the effect of woodburners on winter demand profiles
- Electric fuel use less solid fuel (Tot. Electric-Solid Fuel) – to explore how the profile changed with the removal of woodburners in winter, and benchmarked against the Low demand profile.

Benchmarking Outputs

HEEP data is compared against low and high demand datasets, as the clearest way to see the benchmarking against the demand range. The datasets are represented on a *per house* basis. The summer and winter profiles are shown in Figure 28.

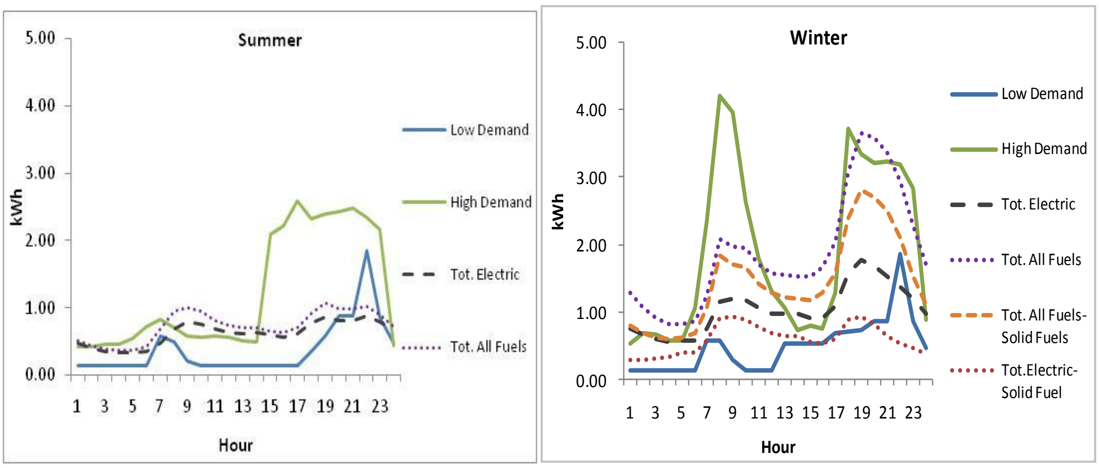


Figure 28: Typical Daily Demand profile benchmarked against HEEP Lower North Island profiles (Dotted lines are HEEP datasets; solid lines are Model Demand sets)

The HEEP datasets sit within the demand range chosen for this study. There is variation during the day in terms of the higher relative energy consumption of the HEEP houses in winter – most likely a function of the passive solar effect built into the original demand profiles leading to lower heating need.

The seasonal comparison of average daily demand (Figure 29) between low and high demand, and two HEEP datasets indicates the HEEP datasets sit within the chosen demand range for the Decision Model.

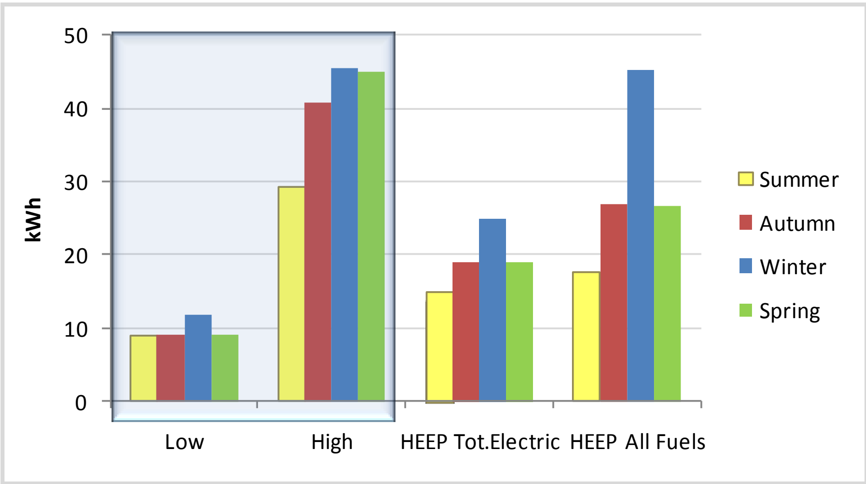


Figure 29: Average daily demand, by season - HEEP benchmark

A more detailed set of seasonal comparison data is contained in Appendix B5 Demand Data Benchmarking- HEEP.

4 GUIDE TO THE DECISION MODEL

4.1 Introduction

The Decision Model is designed as a series of linked Excel worksheets. A user-interface allows the input of key variables for demand, supply and economics, from which a range of datasets and graphs are produced.

The Decision Model aims to:

- model a grid-integrated distributed generation system for this site, based on electrical energy balances; so that the features of electricity export versus on-site utilisation for multi-lot sites can be identified and understood;
- estimate the value of energy generated on-site in the context of the Totarabank system;
- deliver a range of outputs as datasets and ready reference 'snapshots' to support energy management decisions and/or further analysis; and
- provide a platform for developing tools for analysis of scenarios and alternative datasets such as HEEP.

A functional Decision Model should enable the developer and residents to assess the differing scenarios and key factors for managing energy use relevant to the site and development covenants; and understand potential implications for taking a communal approach to energy management.

It has not been designed to optimise a renewable energy system sized to meet peak demand, as a stand-alone system would be.

4.1.1 Core Functions of the Model

The core functions of the Decision Model allow the flexibility to explore a variety of options for supply and demand. Modelling a community had to allow for variation in demand, as well as the likelihood of individualised ideas about participating in renewable generation. The Decision Model allows for this while also modelling the complexities of grid-integration.

The following points outline the core Decision Model functions:

- demonstrate import and export meter activity;
- deliver energy balance outputs (kW, kWh) by hour, month and year;
- flexibility to assess :

- Combinations of demand profiles, and alternative use scenarios that could impact demand,
- Individual house outputs as well as aggregated community outputs,
- Various end-use and occupancy options on an individual house basis (as well as for the site),
- Various supply system configurations,
- Various site and lot system connection options, and
- A range of economic conditions including retailer choice; and

- provide a framework for a separate 'calculator' model to process multiple inputs based on data arrays for the purpose of scenario analysis.

The model has been structured around hourly averaged daily profiles as residential metering in New Zealand is not half-hourly. The approach taken here reflects the tariffs and contract conditions relevant to residential customers, and will assist decisions to be made accordingly.

4.1.2 Model Overview

The main components of the Decision Model and the process overview to develop it are shown in Figure 30. The process detail for each stage is covered from Section 4.2.

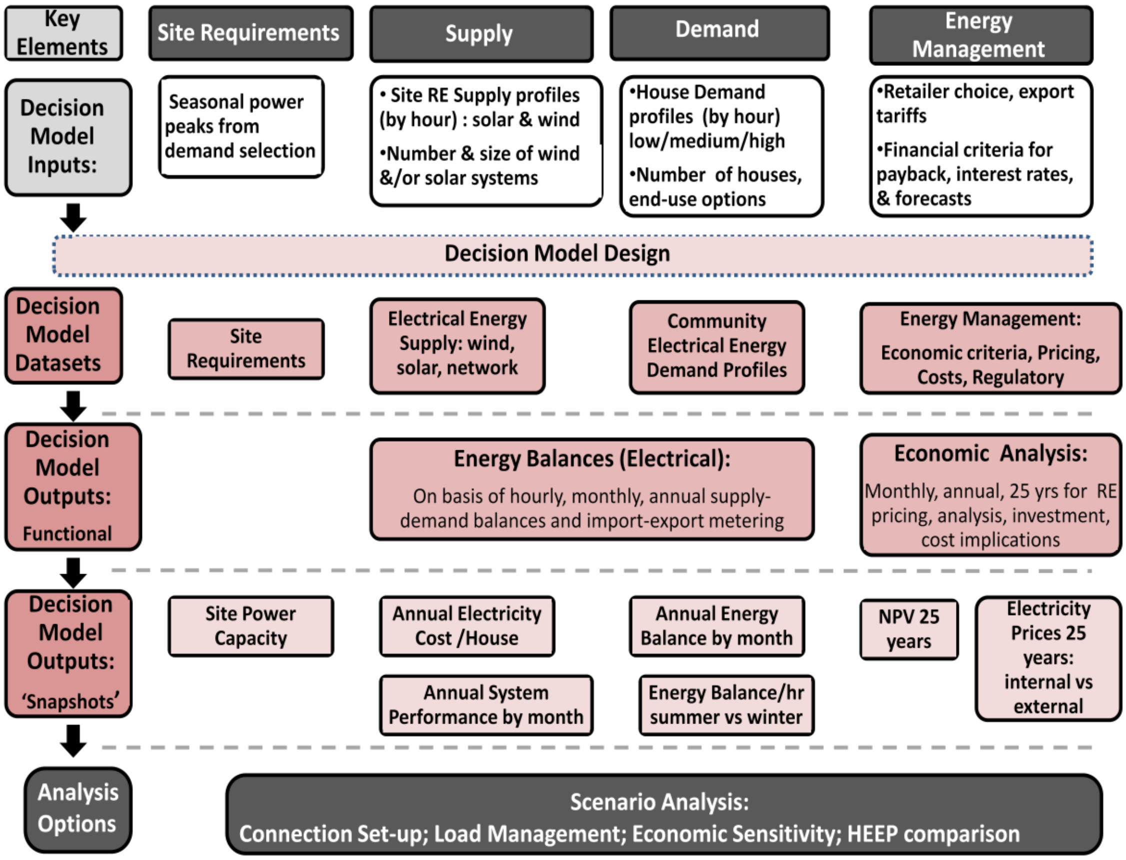


Figure 30: Overview for Stage 2 Decision Model Process

The Decision Model structure is based around the key elements listed along the top of Figure 30, and the respective Model inputs. The calculation processes in the Model deliver a series of aggregated Datasets from these inputs, forming the basis of the analysis outputs. These are represented in the diagram as 'Functional' outputs (tabulated data that can be used for decision-making as they are or for further analysis); and as 'Snapshots' (output data presented instantaneously as summary graphs for each of the seven boxes shown in the 'Snapshots' line). Desired analysis options can then be explored using appropriate output data.

4.2 Process Detail

The Decision Model inputs (Section 3.2 Key Element Input Process – Stage 1) are firstly aggregated to create site profiles and economic conditions for supply and demand based on selections at the Model interface. The aggregated profiles are then manipulated by the Decision Model to deliver the main outputs of the Electrical Energy Balances, and the corresponding Economic analyses.

Detail of the data input section of the Decision Model, is shown in Appendix C1. This interface is the basis of the process descriptions in Figure 31 to Figure 34.

4.2.1 Community Demand Profile

Data (based on individual house demand) is aggregated to create a community profile (Figure 31). This community demand profile becomes a key input for the site electrical energy balance.

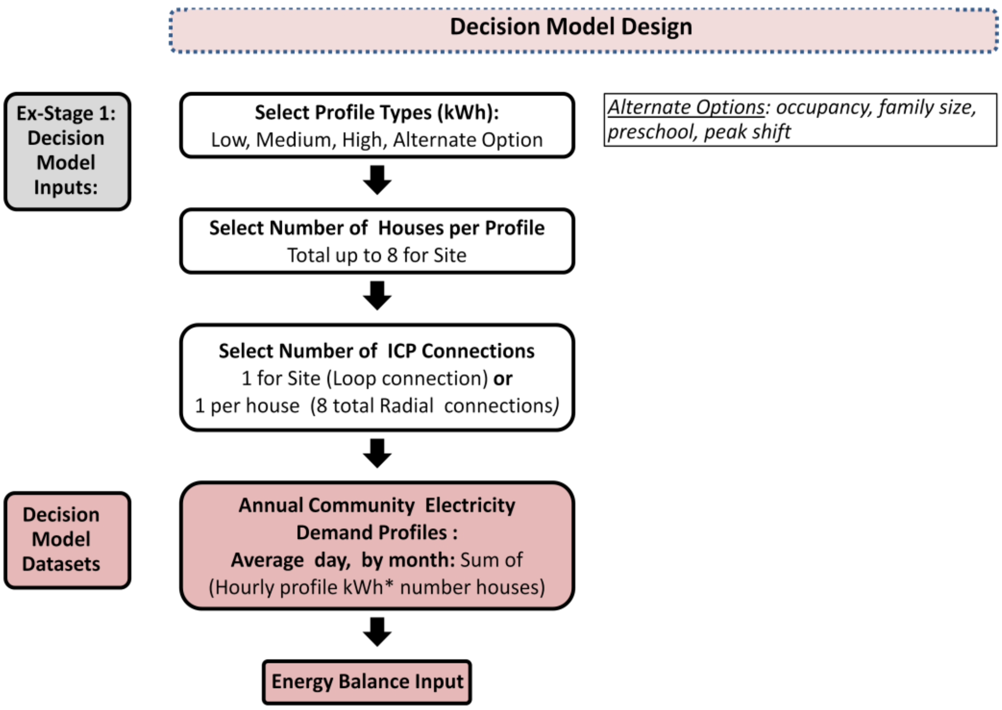


Figure 31: Community Demand Aggregation

4.2.2 Community Supply Profile

Aggregating the supply profiles for wind and solar creates a site supply profile (Figure 32). This then becomes a key input for the site electrical energy balance, with imported network electricity supply as the other key input for site supply.

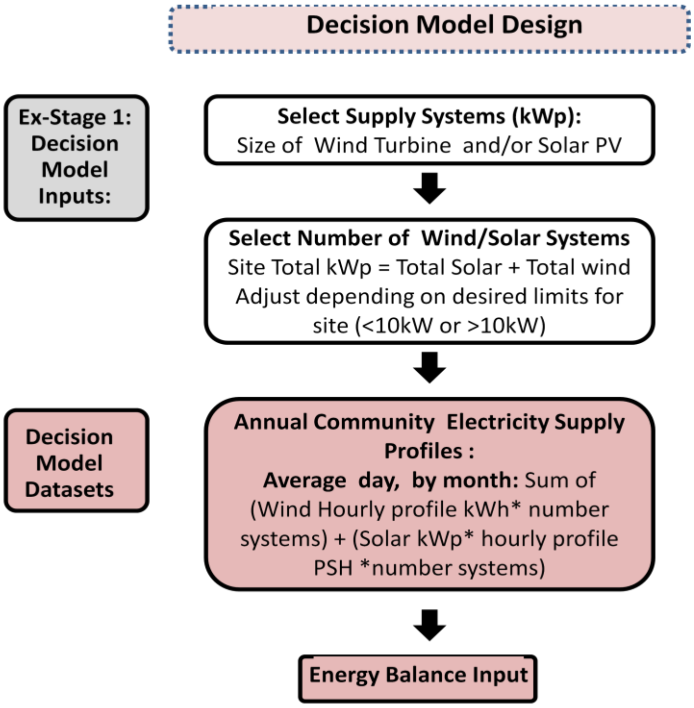


Figure 32: Site Supply Aggregation

4.2.3 Electrical Energy Balance

The Energy Balance aggregation process (Figure 33) brings together on-site supply, network supply and community demand to establish the overall electricity balance by hour, average day, month and year. Load, supply, import and export[23] are also reported on the same basis.

An example of the energy balance and meter aggregation is shown in Appendix C3 Electrical Energy Balance and Meter log.

The energy balance forms the basis of subsequent economic analysis, and calculation of system performance criteria.

[23] Export was calculated only if positive balance exceeded 100W, to allow for small fluctuations in energy flow that may not register on the meter.

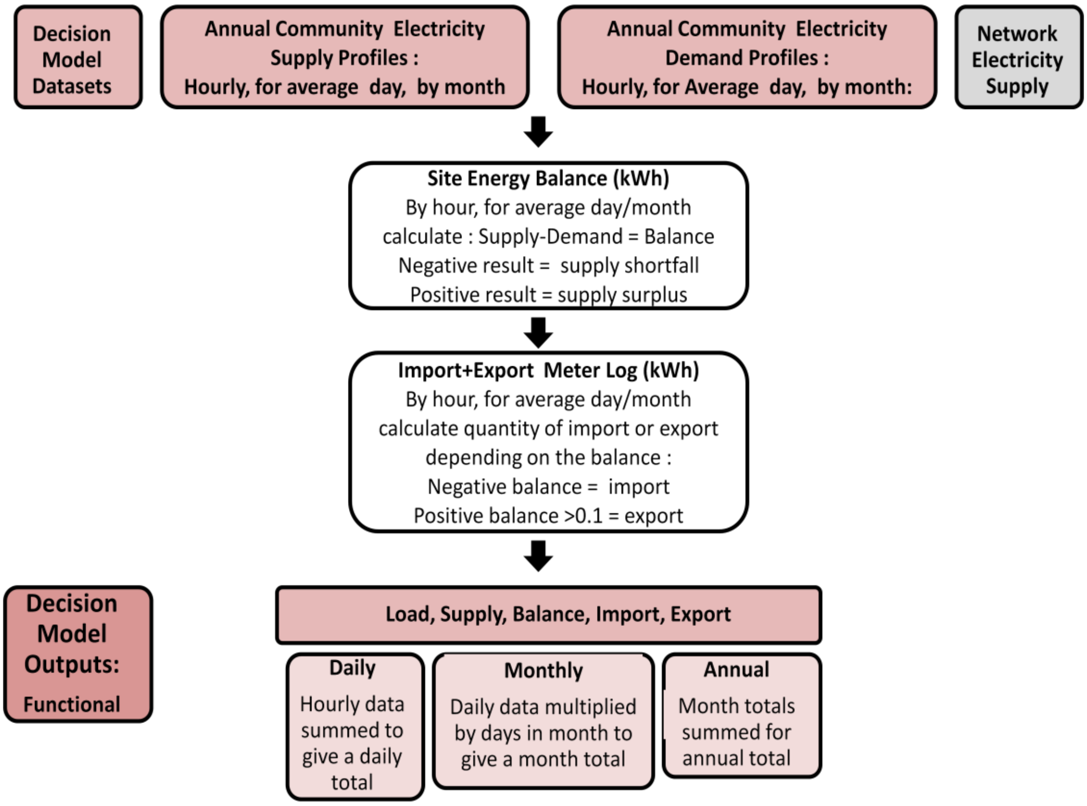


Figure 33: Electrical Energy Balance Process

The system performance criteria (Table 13) were calculated from the energy balance outputs. They provide greater insight as to how efficiently and effectively the site supply could be used to meet demand, and how much imported electricity may still be required. Consideration of these criteria in conjunction with the outputs from the energy balance process provides a comprehensive range of information for decision making.

Table 13: System Performance Criteria

Criteria	Rationale	Calculation
Renewable Energy (RE) Contribution to Load %	Proportion of load met by on-site renewable supply. If RE % drops it means supply is not being used when it's generated. (Also known as "power matching effectiveness")	(supply-export) load *Or:* *(load-import)* *load*
Supply Utilisation %	Proportion of on-site supply that is used on-site, rather than being exported.	(supply-export) supply
Offset Load kWh	Offset load is saved load, or reduced import, from the network. Offset load is less than supply when there is excess of supply.	(Total supply – total export) for the month.
Load Factor (Summer & winter only)	Indicator of capacity utilisation, based on ratio of average to peak load.	(daily load kWh) Peak load*24

An example of the Model summary outputs of daily and monthly data is contained in Appendix C3.1 Summary Outputs for Monthly Energy Balance. This summary forms the basis of the energy balance inputs required for the economic analysis sections of the Model.

4.2.4 Economic Analysis

The economic analysis sections of the Decision Model follow a similar process to constructing the energy balance, in that data is generated on a monthly and annual basis. In addition, a long term economic analysis section has been developed to provide a 25 year perspective. This is linked to a cashflow analysis which provides an opportunity to review criteria such as NPV. It must be noted that for simplicity depreciation has not been included, and it is assumed the equipment has a lifetime[24] of 25 years for the purposes of this Model.

Pricing, capital cost, financial criteria and price alternatives are combined with outputs from the energy balance calculations to provide a range of economic analyses (Figure 34). There is an automatic comparison of costs based on 'standard' load using all imported electricity, against all on-site supply selections.

Appendix C1 details the master inputs and calculations for economic data. An example of the tabulated functional outputs for short and long term economic analysis is shown in Appendix C4 Economic Analysis.

[24] Management of depreciation and supposed lifetime of renewable generation equipment are areas that can be included in an evolution of the model. It was deemed in discussion with the Totarabank developer that an overview of long term financials was of interest, but would be analysed more fully outside of this tool.

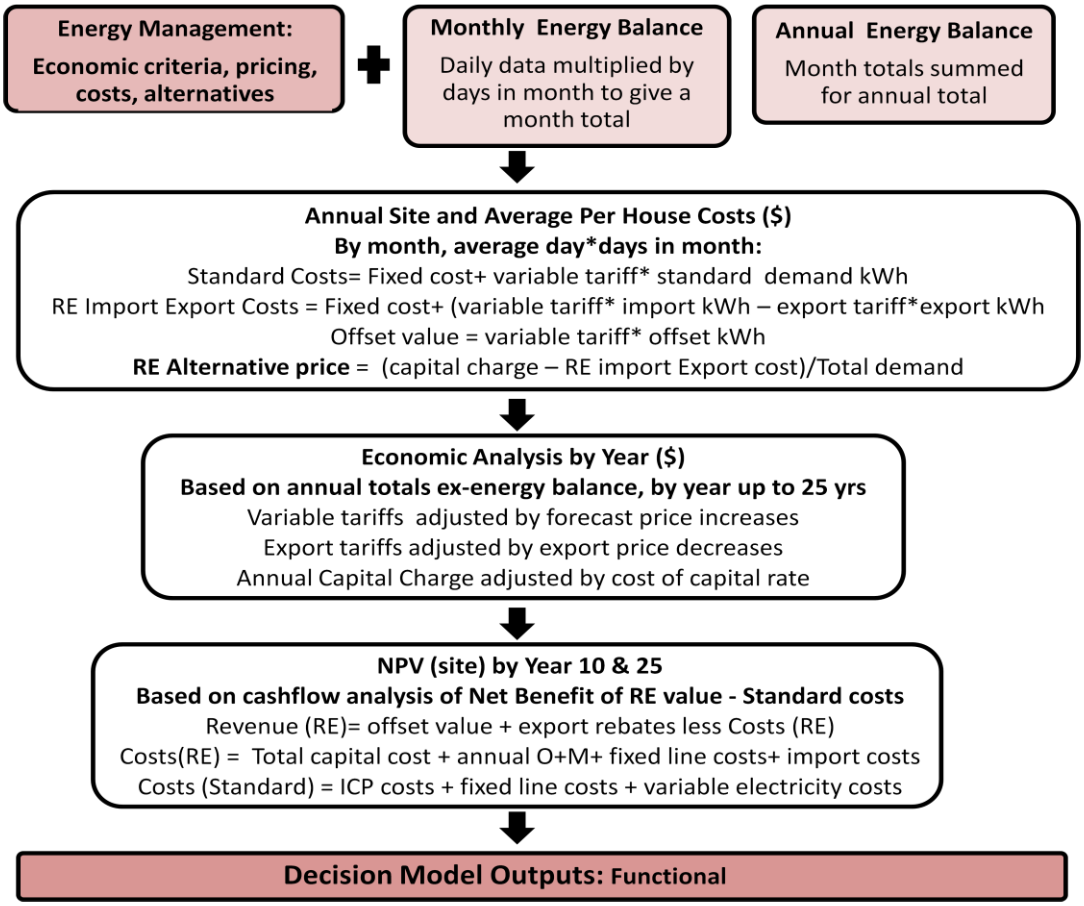


Figure 34: Economic Analysis Process

The rationale and use of the 'RE Alternative price' and 'NPV site' criteria are described in more detail in Appendix C4.1 Economic Analysis: Key Criteria Description.

4.3 Scenario Analysis

The facility to explore scenarios requiring the analysis of data arrays with multiple input variables was developed using a duplicate Decision Model.

4.3.1 Decision Model Calculator Process

The 'Calculator' version of the Decision Model acts as a macro-driven interface for accepting arrays of data inputs, running them through the economic and energy balance analyses, then collating all data outputs in tables for pivot analysis (Figure 35). Each scenario varies some inputs, and sets defaults for the remainder.

The detail of the Decision Model calculator operation is shown in Appendix C5 Scenario Analysis Decision Model Calculator.

The range of the high and low demand and supply datasets was used to test the size of response to particular variables within that range.

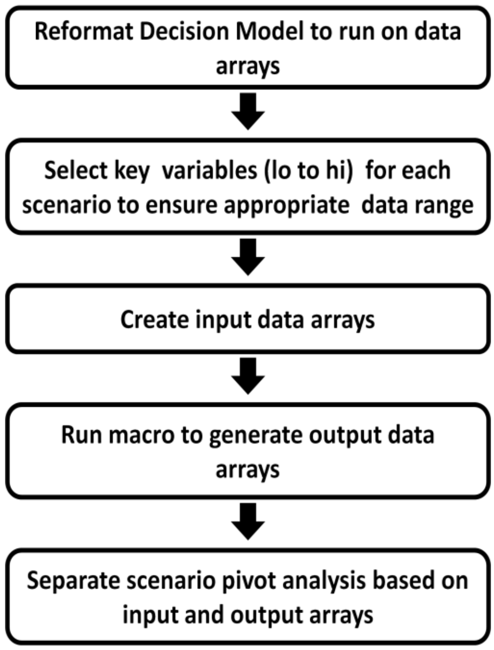


Figure 35: Decision Model Calculator Overview

4.3.2 Scenario Overview

The scenarios of interest to this study covered:

- electricity connection options, (introduced in section Subdivision Connection Options);
- economic sensitivity, (impact of economic variables introduced in section 3.2.4 Energy Management); and
- energy management, (impact of non-economic options on energy balance and economics).

Electricity Connection Scenarios

The connection scenarios (Table 14) are the basis of the connection scenarios analysed through the calculator model. For each scenario, economic criteria were held constant while the demand and supply were varied. The scenarios compare the standard radial connection, with different generation configurations for the Totarabank internal loop.

The strategy for scenario evaluation is to assess a range of outputs for system performance (in kWh) and short and long-term value, for insights into the relative benefits of each scenario for the various stakeholders.

The input data arrays for the connection scenarios are in Appendix C5.1 Scenario Data Arrays - Connections.

Table 14: Site Connection Scenarios

Scenario	Description	Key Features
1.Radial Connection	Baseline comparison	- Each lot is a 'generator' - Own network connection and net-billing meters.
2.Internal Loop – lot generation	Pre-set site installation of an internal loop with one site connection to the network (all lots can import). Meter options may impact what is possible for these scenarios.	- Each lot is a generator - Own 2-way meter connected to internal loop - Electricity managed internally, prior to any export (Internal 'net-metering') Import-export meter at site connection
3.Internal Loop – whole site generation		- Whole site can be used for generation, more potential to meet demand &/or export - Generators are communal assets - Each lot has a 2-way meter to monitor use - Import-export meter at site connection - Lots can take energy from grid or communal supply
4.Internal Loop – lot & site generation		- Combination of scenario 2 and 3 - Enable owner choice by having both lot and site generation - I-E meters for lot and site connections

Selected connection scenarios were used as default criteria for economic sensitivity, and energy management scenarios where supply and demand conditions were held constant.

Economic Sensitivity Scenarios

The basis of the economic sensitivity scenario is to set demand and supply against the most likely connection scenario, in order to explore the impact of the economic input criteria. The solar supply was set at a level (of 3.6kW) that is under consideration by developer as having moderate impact on energy provision.

The midpoint of the economic sensitivity analysis is the default data used for the connection scenarios. The potential impact of Feed-in tariffs was included in this scenario.

Economic sensitivity is explored primarily because the impact economics will continue to have on decision-making in New Zealand – even though it is not the only criteria on which decisions will be made for Totarabank.

The detail of the economic data arrays is in Appendix C5.2: Scenario Data Arrays – Economic Sensitivity.

Energy Management Options

The load management scenario is looking at the effects of shifting load from the end of the day to the middle, for the low demand scenario only (having the most detail on end-use). It is looking at the effects of keeping the same demand level but shifting/lopping the peak; and increasing the load for daytime consumption. This can be compared to the medium scenario, and to the lower load scenarios to see the impact on costs, of load increase for a changed profile.

Detail of the energy management data arrays is in Appendix C5.3: Scenario Data Arrays – Energy Management.

4.4 Model Validation

The purpose of the model validation process was to review the project Decision Model against the commercial energy design tools of RETScreen and HOMER in terms of operation, outputs and decision support for a multi-lot grid-integrated distributed generation installation. The process was guided by considering the following questions:

- What are the benefits/disadvantages of applying the Decision Model versus the other tools?
- How do the usability and outputs compare?
- Can the tools be used synergistically to deliver improved outcomes for such projects?
- Are there opportunities to further enhance the Decision Model for future use?

RETScreen Clean Energy Project Analysis Software (Natural Resources Canada, 2009) has been developed and made available globally by the Canadian Government. It has been designed as a decision support tool for the evaluation of clean energy projects using energy-efficient and renewable technologies. Conventional energy technologies are included for completeness, and the software is aimed at encouraging a wide range of commercial installations.

HOMER software (Homer Energy, 2009) also uses renewable and conventional technologies to model Distributed Generation installations, both on and off-grid. It was developed by the National Renewable Energy Laboratory (NREL), a division of the United States Department of Energy. It evaluates economic and technical feasibility, while allowing for variations in cost, resource and load.

4.4.1 Initial Energy Model Comparison

An initial high level functional comparison of the Decision Model was done against RETScreen and HOMER, from the perspective of decision support for a community energy system (Table 15).

Table 15: Energy model comparison (High Level)

	Model		
Feature	**RETScreen**	**HOMER**	**Decision Model**
Version	RETScreen4	Version 2.68	
Project Setup	Not intuitive for small grid connected DG	Clear options for grid connected DG	Based on grid-connected DG
Resource data	Climate data choice has Masterton, but not the closest to the site.	Imports location specific resource data, used with in-built data.	Uses location specific resource data.
Load Inputs	Gross Average power by month. No hourly option.	Hourly inputs by month, with variability factors. Use alternative daily averages as sensitivity factors. Single dataset.	Hourly inputs by month for multiple demand sets, for users to aggregate a site profile.
Technology Range	Huge range of generation and heating technology	Sufficient technology range aimed at DG. Option for own data.	Restricted range. Currently only solar and wind.
Economic Inputs	Import and export tariffs. Standard financial variables. Full details for technology cost & performance	Extensive options for technology cost and performance. Options for grid rates, export metering and forecasts. Standard financials.	Standard financial inputs. Choice of grid provider inputs. Flexibility of rate types. Higher level system costs.
Outputs	Three model method options providing different outputs depending on performance data. From high level capacity data down to export by month.	Huge array of optimisation and sensitivity outputs. Extensive simulation outputs for each system configuration down to hourly kWh. Advanced economic analysis.	Simple interface delivers simple outputs that link directly to choices for a community. Sensitivity function delivered separately via calculator model.
Flexibility to change options	Few choices with number of power systems allowed.	Advanced sensitivity options give flexibility on most inputs.	Flexibility with selections at interface.
Community Decision Tool	Need to use aggregated load and supply data for whole site as input. No scenario options.	Need to use aggregated load input for whole site. Supply sensitivity allows for site options.	Provides a community view based on a choice of options. Could link to HOMER.
Comment	Powerful tool for energy projects using few technologies, but wanting good economic data outputs.	Powerful DG analysis tool for economics and energy flow, for single load and multiple system scenarios.	The community profile aggregation approach is unique, but the analysis is not as powerful.

A review of the Village Power Optimisation Model for Renewables or ViPOR (National Renewable Energy Laboratory, 2009) was initiated, but attempts to source the software were unsuccessful. This model is understood to be a tool for designing village electrification systems by providing options for centralised grids and isolated power systems, depending on patterns of geography, distribution, load and resources. The information available indicated it is better suited to geographically dispersed communities – no further review was undertaken of ViPOR for this study.

The initial review concluded that further validation against RETScreen was of little value to this study as it is less well-suited to the type of grid-connected distributed generation project of interest to this study. A more detailed validation process (Figure 36) was subsequently carried out between HOMER and the Decision Model.

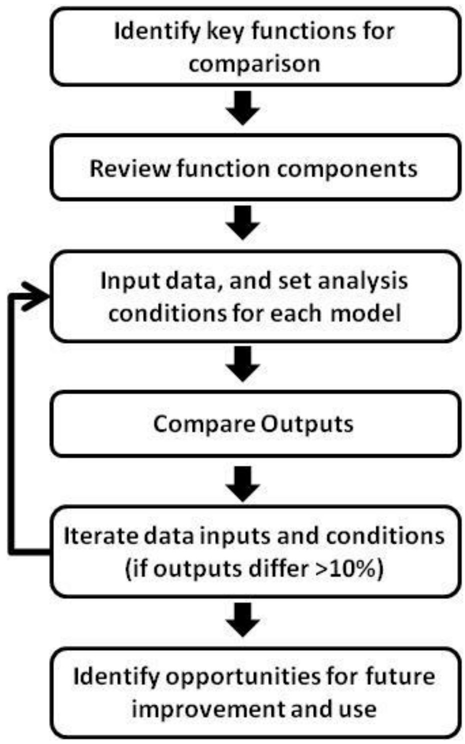


Figure 36: Validation Process

4.4.2 The Validation Process

HOMER's strength is as an economic modelling tool, based on hourly simulation of load and supply. The modelling of the energy balance resulting from the inputs for load and supply creates the platform for the subsequent economic analysis. This follows the same principles used to design the Decision Model as described previously in Figure 33 and Figure 34. HOMER does not have the flexibility contained in the Decision Model for the data aggregation steps to create the site load profile.

For a grid-integrated system, the energy balance also determines amount of energy exported back. The influence of the export fraction on the economic analysis depends on quantity of export, and how the metering system is modelled.

The dependence of the economic outcomes of each model on the energy balance means any validation against these is meaningless if the energy balances do not deliver comparable results. It was deemed more appropriate to validate the energy balance functions as opposed to the full model due to the extensive nature of the HOMER economic modelling capability. However, several key output criteria used in HOMER to rank and compare system configurations were compared with similar criteria used in the Decision Model in terms of components and rationale.

The functions selected for the validation process were based on:

- Calculating the supply system outputs.
- Calculating the load profile.
- Calculating the energy balance for import, export and net balance, including meter configuration.
- Reviewing key output criteria for system performance and economic outputs.

Each of these functions in the models are made up of a range of components that include equations, input data, and various conditions combining together to deliver the calculations required.

A comparison of functional components including input data and conditions used in HOMER to allow the best comparison with the Decision Model, are contained in Appendix C6.1 Comparison of Model Function Components. Clarifying the differences is an important part of understanding their effect on the model outputs.

The approach for the selection of input data and the other conditions and criteria associated with the various model functions must ensure that each model is working under comparable conditions. Data selection had to allow for the relative simplicity of the Decision Model, and the fact it was not designed to be the sophisticated optimisation model that HOMER is. This includes the fact that certain factors for efficiency, sensitivity and system performance are not an inherent part of the Decision Model. The main data inputs are collected in Appendix C6.2 Summary of Input Data Settings for HOMER, Table A12.

5 RESULTS

The results of this study are delivered in the context of developing a decision-support framework for a multi-lot development intending to invest in a grid-integrated distributed generation system. Presentation of the results will be done as follows:

1. Decision Model Outputs - how the Decision Model functions as a decision-support tool.
2. Scenario analysis – how the Decision Model outputs are used to explore scenarios for connection, economic sensitivity, and energy management.
3. Model validation using HOMER - how the Decision Model compares to the HOMER commercial economic optimisation tool.
4. Network Impact - use of Decision Model outcomes to show impact of site demand on the network.
5. Sustainability Assessment – how sustainability criteria influence decisions regarding system viability.

5.1 Decision Model User Outputs

The Decision Model was designed to support the decision process for investors, by providing a simple excel interface for user input of variable for supply, demand and energy management. The related outputs are presented in a series of 'snapshot' output user-focussed graphs located next to the input area. Users can alter the input data and immediately see the impact of their choice summarised in the graphs alongside. An example of this layout is contained in Appendix D Figure A18: Example of output graph layout for user interface.

The output graphs show a series of results derived from the underlying calculations previously outlined in the methodology chapters. The graphs are designed to provide a range of short- and long-term views of system performance, economics, site capacity, electrical energy balance, and estimates of household electricity cost. Although the graphs are summary only, there is a substantial amount of data from the Model calculations that is available if the user requires it for further analysis. Examples of output data are contained in Appendix C3.1 Summary Outputs for Monthly Energy Balance, and Appendix C4 Economic Analysis .

The content and format of the graphs have been designed to inform and educate users by providing a visually accessible link of economic choices supply and demand, to the consequential effects on the community energy system. Because the first priority was to support and inform, rather than optimise, the tool delivers a snapshot of the outputs in an immediately digestible format. Feedback was sought from the Totarabank developer in the development of the content and layout of the input-output user interface to ensure the Model was delivering appropriately as a decision-support tool.

This section compares Decision Model user outputs, for a defined set of user inputs based on:

- Constant economic criteria (based on the default criteria in Figure A14, page 169. (Note the Meridian export tariff equals the variable import tariff).
- Constant supply system criteria based on 3.6kWp solar PV, and one Proven 6kW P6 wind turbine. This system is for the whole site, and sized to stay under 10 kW.
- Two demand profiles – all eight houses having a low demand compared to all eight houses having a high demand. This demonstrates two possible extremes of consumption that could occur on the site.

5.1.1 Site Capacity

Outputs for the site system capacity measure the ability of the site infrastructure to meet the requirements of the site energy balance, based on the pre-set covenants of a 30amp maximum current per house, and a 50kVA site transformer. This means each house should not exceed a peak draw of approximately 7kW – so the transformer is currently sized to barely meet that peak for eight houses on the site. If power factor was to remain high, the peak power draw the transformer can manage is about 48 kW – well above the high demand level result.

The snapshot graphs (Figure 37) demonstrate the summer and winter peak draw for the site, at the chosen demand levels. To assess how well the infrastructure can meet those peaks, the adjoining capacity bars indicate capacity available in the transformer at two power factor levels, of 0.65 (low or poor power factor), and 0.95 (high, or acceptable power factor).

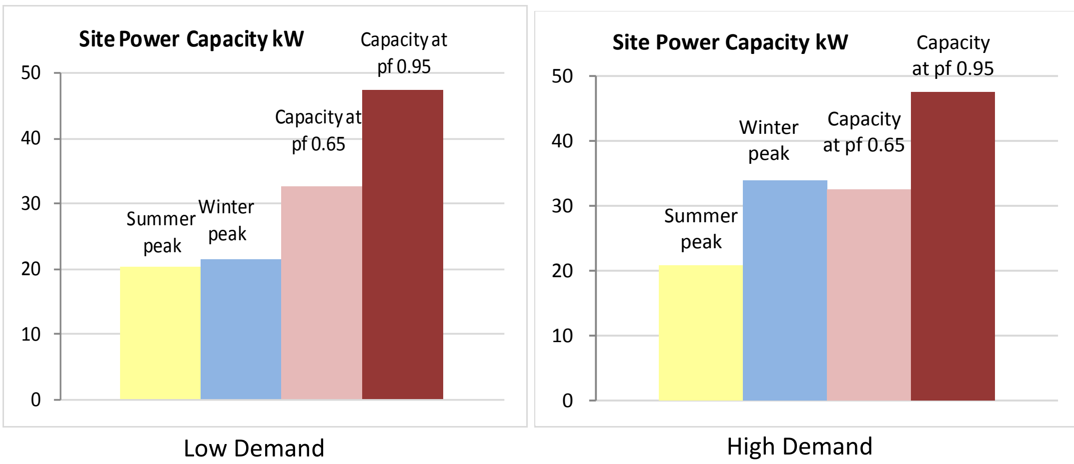


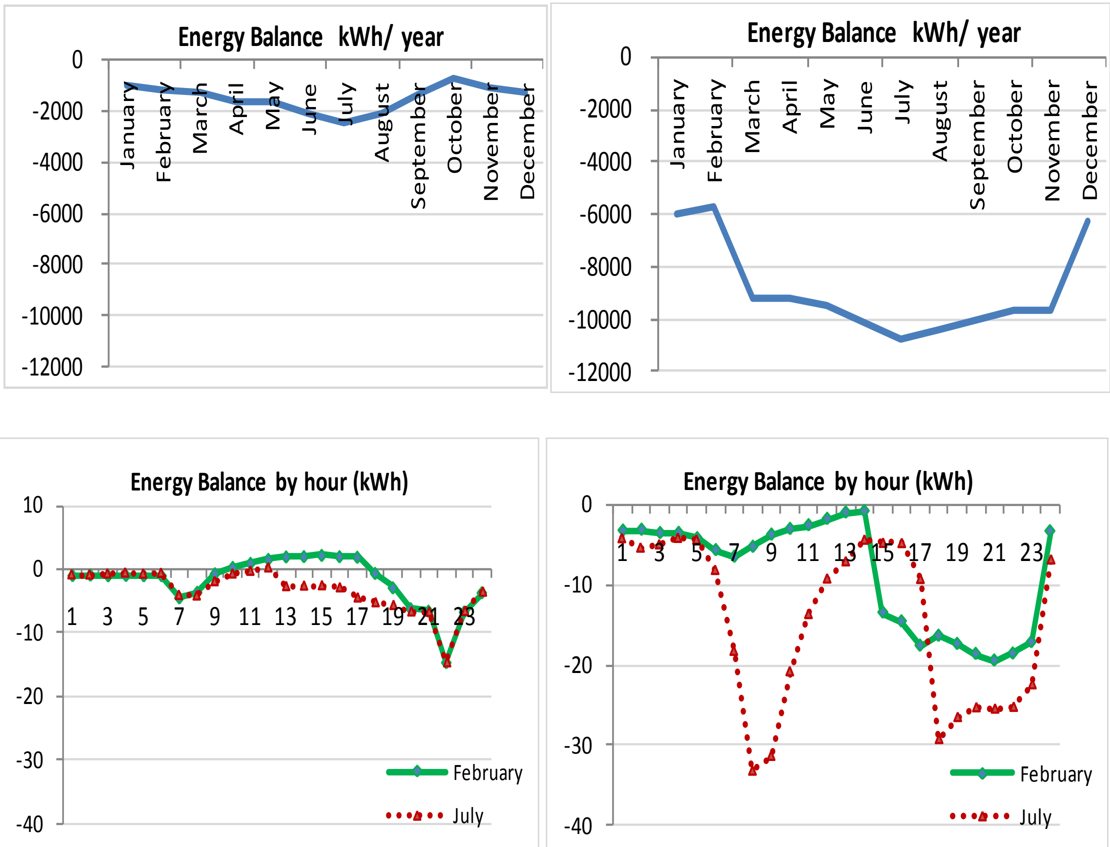
Figure 37: Site Capacity User Outputs

The low demand graph indicates there is not much difference between the summer and winter peaks, which is consistent with the assumptions that electricity is not used for space or water heating in winter. The difference in the seasonal peaks for the high demand fits with the increased electricity use for space heating and hot water boost.

Measuring the power factor can only be done once a system is in use, however it was deemed useful to provide an indication of how stretched the system could become if power factor was to drop. A residential site with multiple users is bound to have a fluctuating power factor due to the variation in the types of loads. Therefore, as estimates of site demand are explored, it is useful to maintain a view of the impact this could have on electricity infrastructure. Thus it can be seen in Figure 37 that the combination of high load user peak demand in winter with a low power factor will place the transformer under pressure. Measures would be needed to raise power factor; or the transformer will need to be upgraded.

5.1.2 Energy Balances

Electrical energy balance outputs over a day (in summer and winter) and over the year are shown in Figure 38 for the two demand levels.



Low Demand High Demand

Figure 38: Energy Balance User Outputs

Both types of graph provide snapshots of how much of the site electrical demand is met by on-site electricity generation systems over short and long term periods. These have been developed for a user to understand energy flow – as receiving a monthly invoice that shows a surplus or a deficit does not provide the detail of how the system responds on an hourly basis. Energy balance outputs by hour show periods of the day when excess supply may be available for export, or on-site utilisation depending on the desires of the individual users, and the site. Annual energy balances provide a summary by month of the net effect of supply versus demand, thereby reflecting what a monthly invoice[25] may consist of.

The graphs for low demand predictably show less fluctuation over a day, and annually, although for the system size chosen here there is still a net deficit over the year. Summer solar generation provides some excess during the day, but the net effect is still that demand exceeds supply. The high demand graphs show a more significant deficit (negative energy balance) across the seasons, and the year, particularly in winter. There are few options to utilise or export any excess electricity, and the major impact of the on-site generation will be to offset demand, to reduce monthly bills.

There is no 'right answer' in this situation for the desired energy balance outcome; when the purpose of the installation is to supplement network supplied electricity. These snapshots help inform users of different perspectives of how their demand patterns interact with on-site renewable generation, and ultimately set the boundaries of what the system should be delivering.

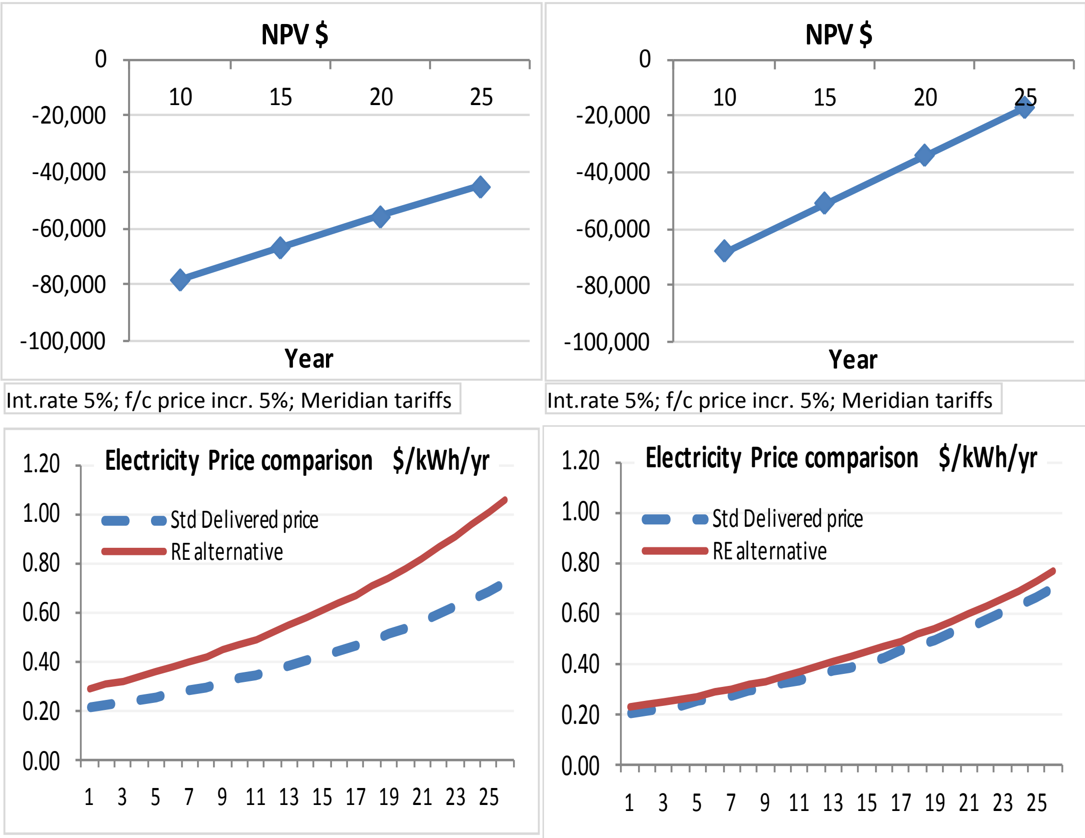
5.1.3 Energy Management Economics

Two long term economic criteria have been chosen for summarising into the graphs in Figure 39 – an estimate of Net Present Value (NPV), and an electricity pricing comparison. An explanation of the makeup of these criteria is found in Appendix C4.1 Economic Analysis: Key Criteria.

Economic results are shown predominantly over 25 years. NPV is a commonly used term for determining the financial performance of an investment where there is income and expenses over a period of time. It could be argued that NPV is a comparatively unfair measure for an investment scenario including renewable generation technology, due to the high capital costs and the relative cheapness of grid-supplied electricity. However, it has been included as a recognised term that should encourage debate and discussion in terms of its merit.

[25] The assumption in this comment is a retailer will be providing monthly invoices showing a net deficit (import) or a net surplus (export) for that month. Some retailers may do this annually, whereby users are billed monthly for their import only, and the effect of export is assessed annually. New Zealand is not treating this consistently at the time of writing.

The relative economics of electricity pricing in $/kWh is compared over time, for a standard delivered price of imported electricity, versus the internal price of renewable electricity delivered by a community energy system. The ‘RE alternative’ represented by the red line in the Electricity Price comparison graph, is the relative price of an alternative energy system, compared to standard tariffs. Both of these modelled price estimates include fixed daily lines charges.



Low Demand High Demand

Figure 39: Energy Management Economics User Outputs

It can be seen from both NPV graphs, that even after twenty five years the NPV is not estimated to approach positive figures. There are a number of contributors to the pattern of change over time and the size of the system NPV at the end of the period, discussed in more detail in the next section on scenario analysis. These include the size of the capital investment, the forecast increase in standard electricity tariffs, and the cost of capital. The negative NPV reduces (approaches zero) more rapidly for a high demand scenario due to the greater quantities of electricity that are offset by the use of on-site generation. As the demand levels decrease, the relative amounts of electricity consumed and offset are also decreasing, so there is less economic benefit in terms of imported electricity savings.

Demand level differences also noticeably affect the price comparisons. The 'RE alternative' price construct (in $ /kWh) has the following components:

- Costs ($) made up of fixed daily charge, the variable price of imported electricity (less export value), and the annualised capital charge
- Total demand in kWh

Imported electricity is directly impacted by the amount of export. Managing the demand, the amount of import and the capital costs all contribute to reducing the price to switch to an alternative. The attractiveness of a renewable energy alternative improves over time if:

- Standard delivered tariffs increase more than the cost of capital. (If cost of capital interest rate is higher than forecast price increases, the RE alternative attractiveness reduces, due to the impact of the capital investment.)
- Export tariffs are higher than import tariffs. If they are not, then utilisation of excess supply on-site becomes important for reducing the amount of import.

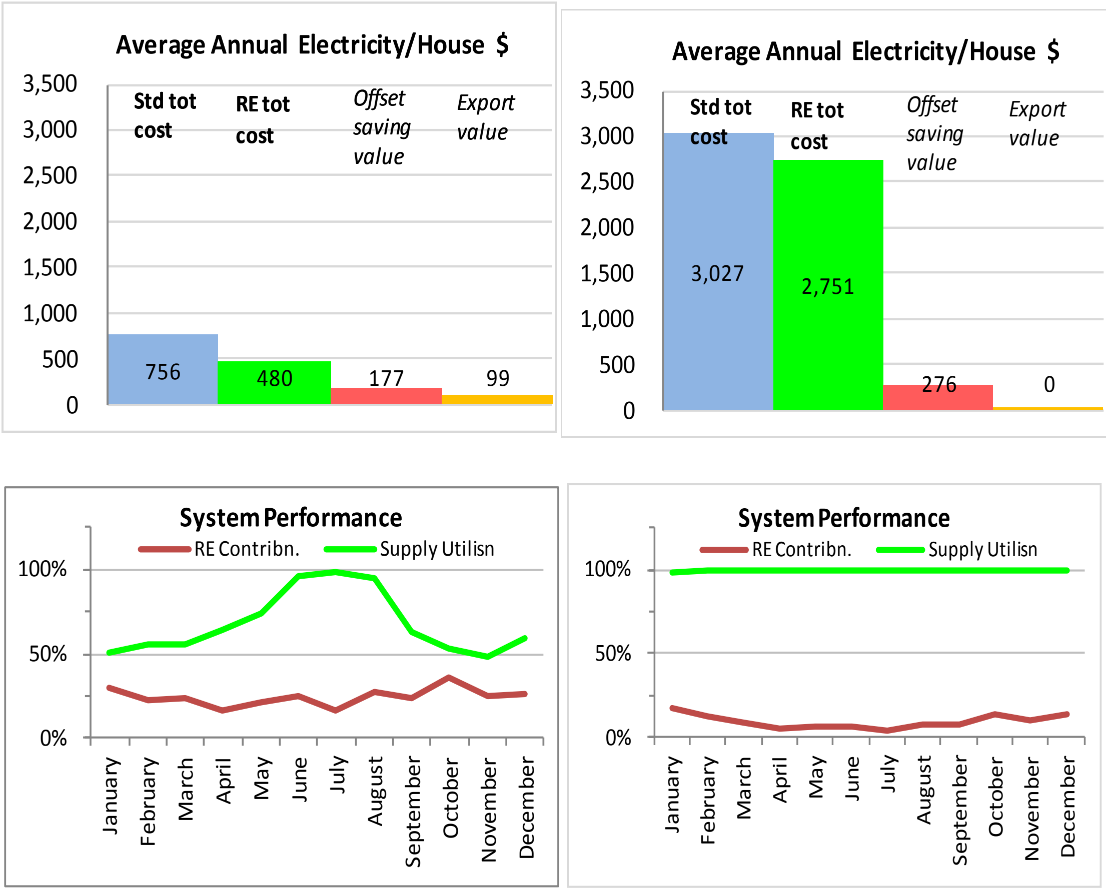
Figure 39 shows the relative difference in electricity price estimates is much smaller for high demand levels, due to the suppressing influence of a higher total demand on the RE alternative price. The price of renewables supplied on site decreases as demand increases, due to the amount of electricity that can be offset at standard prices. The low demand scenario, with its higher level of export for the same supply system, does not converge with the standard price – the export prices were not forecast to increase at the same rate as the standard price for imported electricity. If the low demand scenario had more on-site utilisation as part of the usage pattern, the attractiveness would improve.

Essentially the differences in the pricing graphs demonstrate the counter-intuitive nature of using a purely economic view to justify the benefits or otherwise, of a community energy system.

5.1.4 Annual Electricity Cost and System Performance

Annual electricity cost (as an average cost per house) has been grouped with system performance in Figure 40. These outputs summarise the short term impact to users, of energy system response to demand profile.

It was important to have a graphical representation of what most households first consider when considering energy issues – an estimate of annual electricity costs. The system performance graph provides a snapshot of the 'level of service' provided by an on-site community energy system in terms of how much of that electricity is utilised, and what proportion of it is being used to address site electricity requirements.



Low Demand High Demand

Figure 40: Annual Cost and System Performance User Outputs

The average annual electricity cost graph aims to provide a holistic view of cost estimates on a per house basis by comparing standard total cost of electricity ('Std tot cost') without any renewable systems, to the total cost of electricity using the chosen renewable system supply configuration ('RE tot cost'). The breakdown of the contributors to any cost reductions are shown in the red and orange 'value' bars – offset savings value represents the savings from reducing the amount of imported electricity, while the export value represents the value from surplus electricity not used on site exported back to the network. Predictably, annual costs are significantly higher for the high demand levels.

Figure 40 shows for each demand level, that the value of the cost reduction ($276/yr) is the same for both due to the tariff structure, but the low demand has a $99 contribution from export. If the value of the export tariff was to increase, the corresponding value of the contribution, and hence the overall cost reduction, would be higher for the low demand level. What is more likely in the New Zealand context, is a reduction in export tariff (See footnote 8, page 34) which will drive an increase in supply utilisation and a reduction in export to ensure maximum capture of value by households.

In terms of system performance, the contribution of renewable supply to overall demand is shown by the red line ('RE Contribn.'). As demand falls, there is a greater opportunity for the system to contribute. The green line showing how much of the available renewable supply is utilised ('Supply Utilisn.') approaches the 100% maximum as demand levels increase. Supply utilisation levels less than 100% indicate opportunities for export, or for increasing use on-site. The ability to maximise the available supply comes down to matching demand patterns with supply patterns. The site has to address multiple issues such as the feasibility of changing demand pattern versus storage of electricity for later use (to offset imports) versus investing in a smaller system.

Multiple fuels and renewable contribution

The low demand level is based on use of local biomass and solar for space and water heating. Therefore the full contribution of renewables for all end-uses is underestimated for the low demand profile, as it is quantified for electricity only. Although the full quantification of all fuels is not a focus for this work, it should be noted that the full contribution of renewables could arguably rise by up to 50% to account for the contribution of solar and biomass.

5.2 Scenario Analysis

In addition to the development of easy-access snapshot user outputs, further analysis was performed using the Decision Model to manage calculations of larger amounts of input data. Analysis was done against the series of scenarios introduced earlier in Section 4.3.2 Scenario Overview. A 'Calculator' version of the Decision Model was used to work through the arrays of input data to explore a series of scenarios relating to:

- Connection options
- Economic sensitivity
- Energy management

5.2.1 Connection Options

The details of the four scenarios for connection options are described in Table 14: Site Connection Scenarios. They differ by type of connection to the network (either as a standard independent ICP, or via the Totarabank internal site loop); and by generation location (on the house lot, and/or site-wide). A standard radial connection option was included for comparison with what the majority of housing developments use for electricity provision, whether or not a house decides to engage in a system for net-billing.

The rationale for the choice of system sizes for lot-scale generation was those that would be attractive and accessible for an individual house. Although a household could nominally put in a system of any size if they chose, total system sizes per lot were kept at less than 10kW.

The impact of connection type on costs, system performance and long-term economics was explored.

Radial Connection versus Loop Connection

Radial connection is based on one house lot-1 ICP, such that each household can make their own decisions about managing their electricity use without being connected to a communal system. Exploring the differences between radial and loop connections was done by comparing eight houses radially connected (Connection Option 1) with eight houses connected in the Totarabank loop (Connection Option 2: lot-scale generation only), using the same conditions for system size and demand profile.

The key outcomes from the analysis showed:

- There was no difference in either connection option in terms of energy balance or system performance for the same system sizes and configurations.
- The loop connection option had very similar long term economic outcomes (alternative price and NPV) compared to radial, underpinned by small differences in annual capital charge and fixed line costs.
- The fixed lines charge portion of annual costs added an extra $215/yr to radially connected houses when the same tariff base was used to compare loop and radial connections.
- For radial connections on a low demand profile a low user tariff can be an option as annual demand is less than 8,000 kWh. The low user tariff conditions applied resulted in higher overall annual costs for a radially connected house using distributed generation.

The factors having the greatest impact on differences between radial and loop connections are concerned with energy management and tariff structure. The costs contributing to the differences in capital charge are based on infrastructure requirements for metering, loop network management, and ICP connection. The loop connection builds in costs for a communal energy management system that is not required for the radial set-up. It also has the cost of a single ICP connection spread across the community system rather than the cost of one ICP per house. This has the effect of reducing annual costs by approximately $215/yr per house for loop connected houses.

The subsequent capital charges differed by 1 to 3% in favour of the radial connection, and this difference was reflected in the long term NPV. Higher demand levels delivered a slight improvement in NPV over the long term, but neither connection delivers a positive result.

The data is shown in more detail for costs and long term economics in Appendix D2.1 Comparison of Loop vs Radial Connection, Figure A19. Fixed charges also affect long term economics – these factors combined to show differences over the long term for the RE alternative price (shown in Figure 41).

The system sizes above 29kW are mixed solar-wind (Proven P2.5 turbines) configurations, and are highlighted as such to clarify the results. The graph represents data for eight houses under each connection option. Figure 41 has a standard electricity price[26] (without renewables) included on the graph to demonstrate where each connection option sits relatively. The standard prices are an estimate of the forecast electricity tariff for imported electricity.

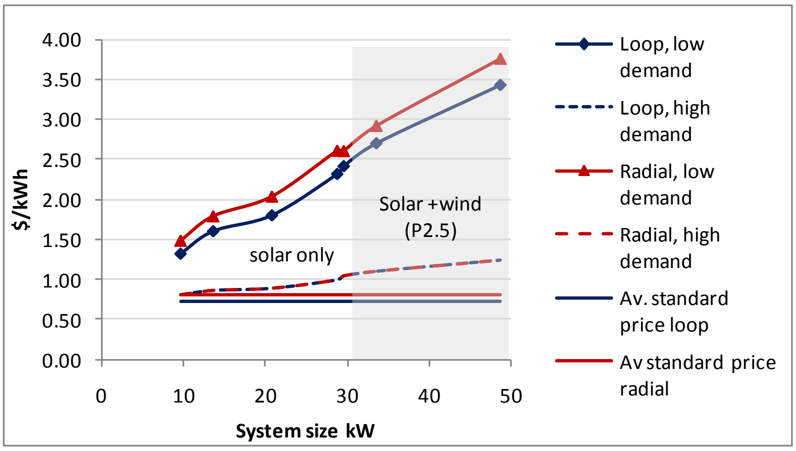


Figure 41: RE alternative price year 25, Radial vs. Loop connection

There is no real difference in the alternative price at high demand, and a slightly more favourable result for the loop connection at low demand. This is most likely due to the impact of higher fixed charges over time for radial connections. As was discussed earlier (in Figure 39,

[26] As for the RE alternative price, the standard price is the sum of variable plus fixed costs apportioned across an annual demand. Each demand level has a standard electricity price calculated by year for reference to the alternative.

page 103), the attractiveness of switching to a renewable alternative improves as demand rises; rather than with connection type.

In reality, infrastructure costs and requirements will vary as regulations and technology change, affecting the relative differences in system-set up costs. However, a bigger cost-advantage can be gained by using a loop connection to deliver advantages of a renewable system to more houses by spreading the system costs over a bigger demand (compared to a single house). This reduces charges for capital cost and makes the long term RE alternative price significantly more attractive.

Figure 42 shows the effect of tariff choice for a low demand household, on annual electricity cost. Two tariff options (Meridian Energy) were explored – the default 'Anytime continuous' standard tariff used for most of the analysis, and a 'Low User' Tariff (higher variable and lower fixed rates, with export valued at wholesale price).

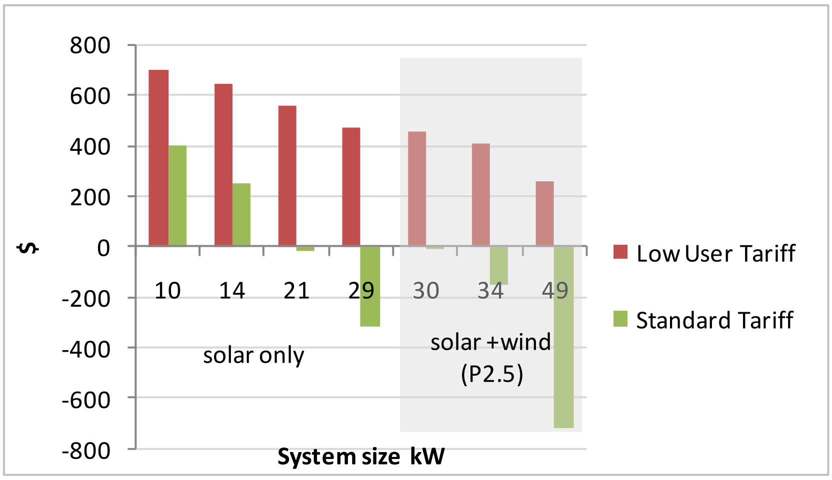


Figure 42: Radial connection annual electricity costs (per house), low demand

The low user tariff clearly disadvantages households using a renewable generation system, compared with a standard tariff. The difference increases with system size, predominantly because the export is valued at wholesale rather than at the higher variable rate. This is shown more clearly in Figure 43.

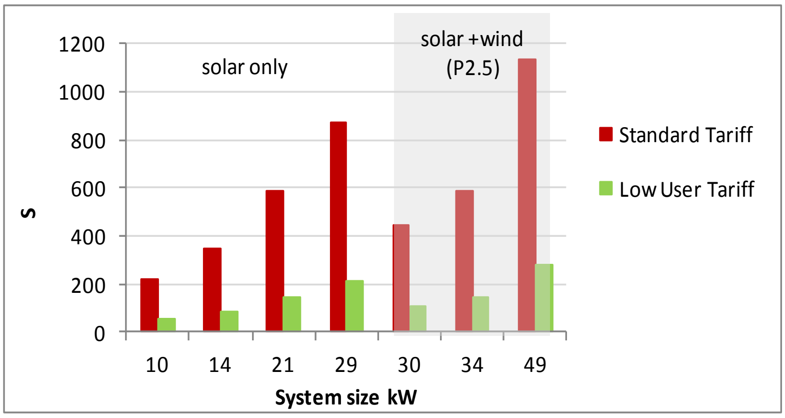


Figure 43: Export value component of annual electricity costs

The mixed solar-wind configuration shows a decrease in the export value - this is due to the increase in supply utilisation from the addition of wind generation reducing the amount of export. The increased supply is delivering more energy at a time when it can be used rather than exported.

Comparison of Loop Connection Options

The key outcomes from the analysis of connection options on the Totarabank loop were:

- Placement of the systems was less important than the size of the system. At this aggregated level of analysis, there were no significant differences between connection set-ups that were based on house-only, site-only; or a mix of both.
- Overall size of the system had the most direct impact on the main output variables of interest. The system size connected to the loop increased as the options progressed from site-only (smallest overall systems) to those involving each house lot.
- System configuration of solar only, compared to mixed systems of solar and wind showed differences in outputs for system performance and NPV. Based on the costs[27] used in this model the wind turbines provided a more cost-effective supply option than solar, particularly the larger Proven P6 turbine.

In order to verify the relationships between the options, raw output data was graphed for several variables against system size. These are shown in Appendix D2.2 Comparison of Loop Connection Options, Figure A20 to Figure A24. From the initial analysis of results, data was re-presented for these variables, in terms of low and high demand. The rationale for this is to

[27] It must be noted that system costs had to be anchored to a certain date so that analysis could be structured and completed. These costs are based on commercial pricing of complete systems available as of August 2009. Solar was in the region of $11 to $14/W; wind in the region of $6 to $12/W.

show the relative band of demand within which the system performance can be seen on the basis of system size, and the variables of interest.

Figure 44 shows the site cumulative electrical energy balance for a year on the basis of system size. It is based on the net impact of the monthly energy balances over the site based on the combination of import and export. Logically, it shows that the annual cumulative balance becomes more positive as system size increases. The trend lines indicate that a zero electricity energy balance can be achieved over a year for a system size band of approximately 20kW to 90 kW for the given range of site load profiles.

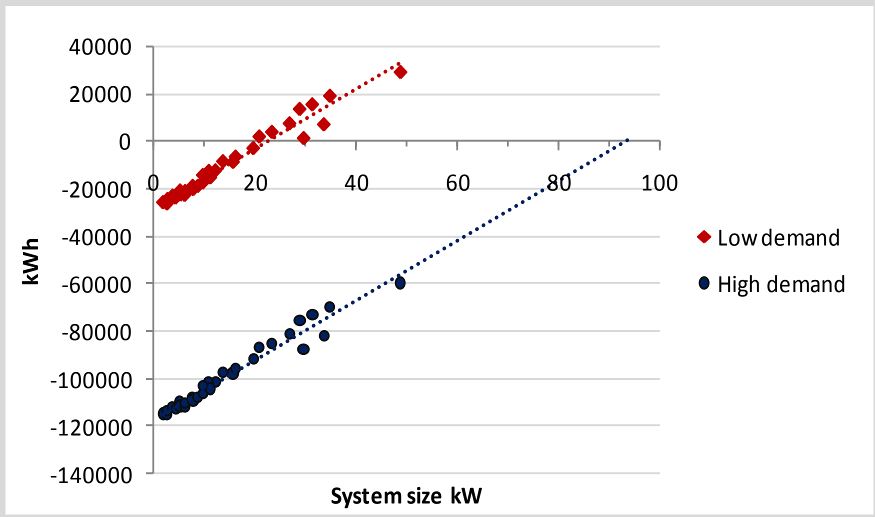


Figure 44: Annual Cumulative Balance (Electricity)

The trend observed for annual cumulative balance is consistent with that in Figure 45 – where increasing system size resulted in decreasing annual electricity costs for a household. For a low demand profile, a house with no renewable electricity supply would have an annual cost of $756, and a high demand house is estimated to have annual costs of $3027. Based on the default tariff structure used for the analysis, (where the import tariff equals the export tariff) – an annual zero electricity cost position sits in the system size range of 20kW to 90KW. This is the same as shown in Figure 44. As system size increases, a position of net return to the household can be achieved by electricity export (illustrated by the negative portion of the graph). However this still has to be assessed against the economic attractiveness of investing in the larger systems.

Another assessment factor will be the retail export contract if the site goes beyond a zero electricity balance to being a net exporter. A retailer may take the export tariff to a wholesale rate if the site goes beyond a zero annual balance, thus reducing the attractiveness of export beyond a certain level.

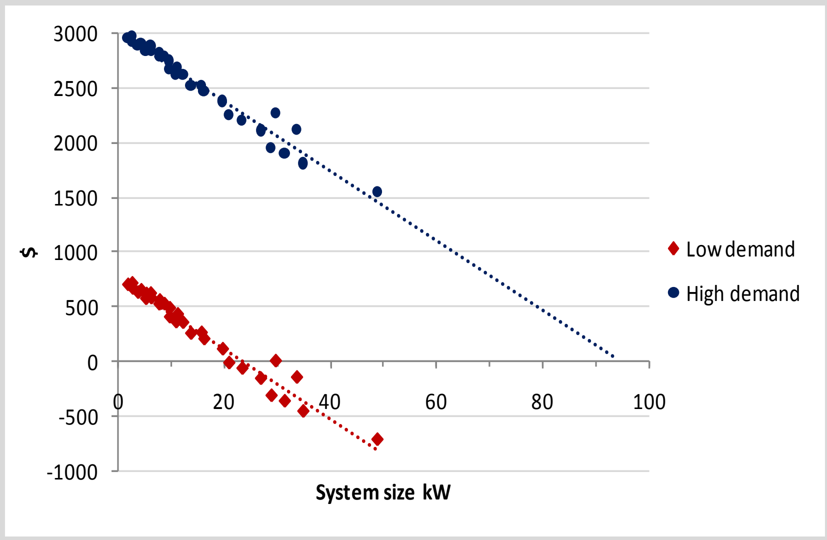


Figure 45: Annual Electricity costs by house

The challenge of managing the trade-off between 'returns' from a grid-integrated system, and the costs of creating those returns, is reflected in Figure 46. This shows the price for site supplied renewable electricity, the 'RE Alternative price' at year 25, alongside the standard price estimate for that year. The alternative price is an indicator of the price that would be paid for the alternative to grid supply. For smaller systems the price starts to converge with the standard price, making it attractive to switch to the renewable system.

The RE Alternative price increases, and diverges from the standard price, as system size increases, due mainly to the effect of the capital cost of the systems increasing with system size. This is most evident with the low demand data – where divergence is more significant with increasing size. In addition, the effect of spreading costs across a lower demand base has the effect of increasing the RE Alternative price; as does any increase in discount rate.

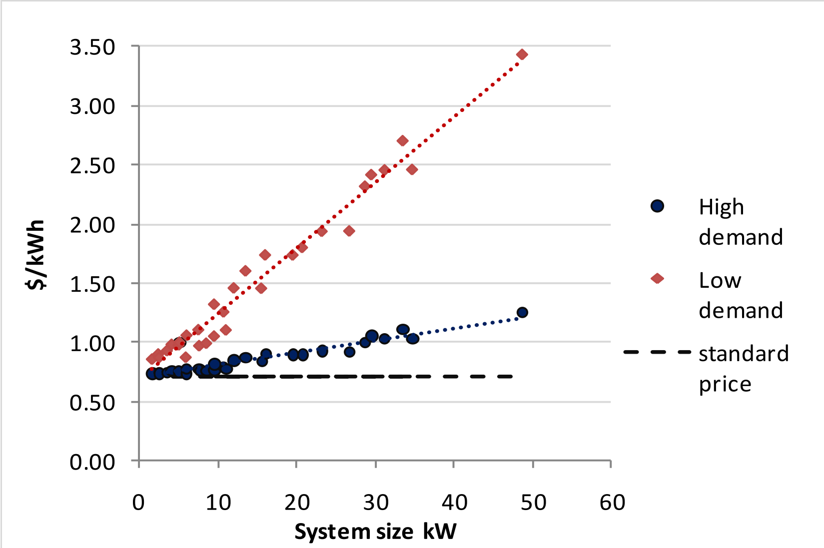


Figure 46: RE Alternative Price, year 25

Along with the RE Alternative price, Net Present Value (NPV) is the other main economic measure - results for site NPV at year 25 are in Figure 47.

It can be seen that differences in NPV become more apparent for the two demand levels once the system size moves beyond 20kW. NPV does increase (become more attractive) as system size decreases, with high demand tending to improve NPV attractiveness. There are a number of contributors to NPV, and these are explored further in economic sensitivity scenarios in Section5.2.2 Economic Sensitivity.

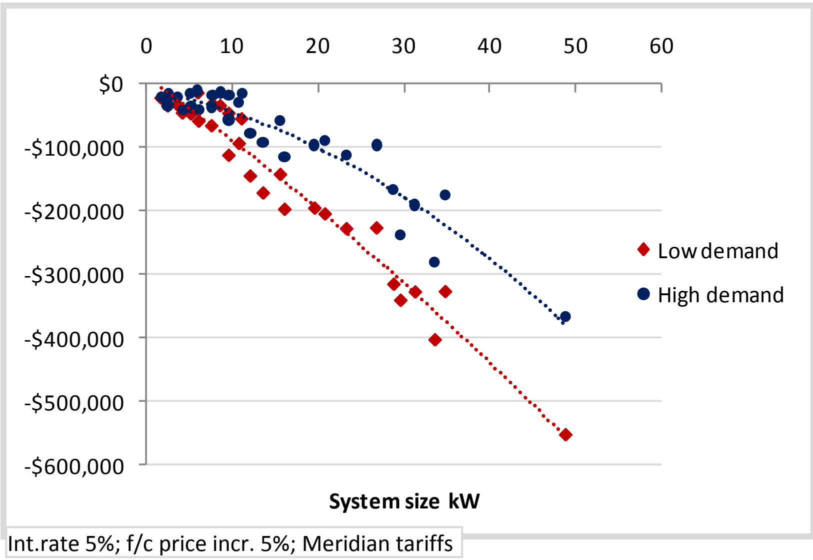


Figure 47: Site NPV, year 25

Based on the economic input settings used for the connection scenarios NPV remained negative after 25 years for all system sizes. An alternative view of the data was sought by exploring the influence of system configuration on NPV outputs. Figure 48 shows the result of plotting system configuration results at high and low demand levels. At both high and low demand levels, systems containing P6 (6kW) turbines were more economically attractive; with systems containing P2.5 (2.5kW) turbines the least. As was seen earlier, there is still convergence for the smaller systems.

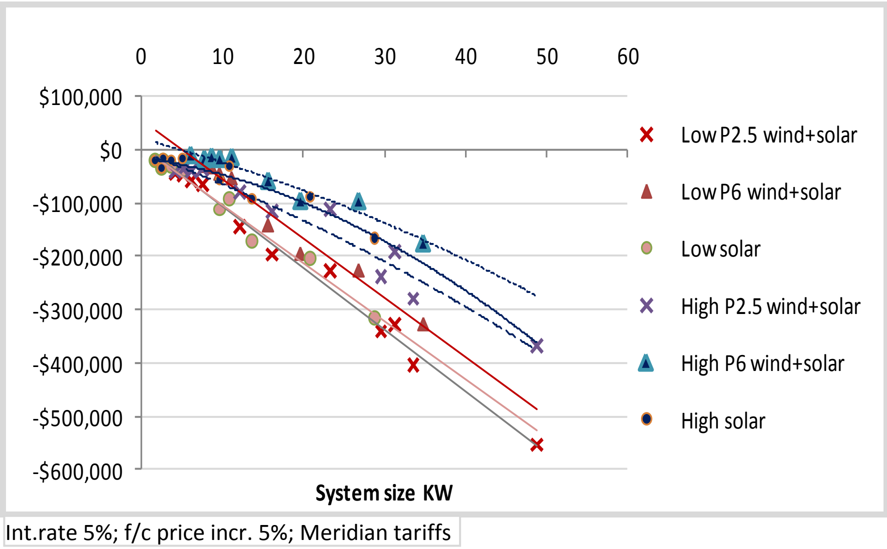


Figure 48: Site NPV, year 25 - comparison of system configuration

NPV was also calculated on an average per house basis to provide a perspective of value at the household level. Both site and house NPV data were ranked by attractiveness and tabulated against input and output data to get further insight into the contributors to NPV results, and to confirm the inputs for the economic sensitivity analysis. The ranking tables for the top 50% of NPV results are contained in Appendix D2.3 Connection Scenario Ranking by NPV, Figure A26 and Figure A27: Top 50% Connection Scenario NPV ranking with system performance measures..

The site system performance measures of % RE contribution to load, and supply utilisation are shown in the following graphs on the basis of system configuration at each demand level. The original connection plots for these outputs are shown in Appendix D2.2 Comparison of Loop Connection Options, Figure A23: Average % contribution to load by RE system and Figure A24: Average % supply utilisation of RE supply. Although there is a trend by system size, system configuration is also worth considering.

Figure 49 indicates system configuration has less influence as demand level increases. At low demand levels; there is greater divergence between mixed and solar only systems. System sizes less than 20 kW performed similarly; and unsurprisingly the contribution to load increases with system size. Wind does offer greater diversity, particularly in spring and autumn when winds increase but sun hours are inconsistent.

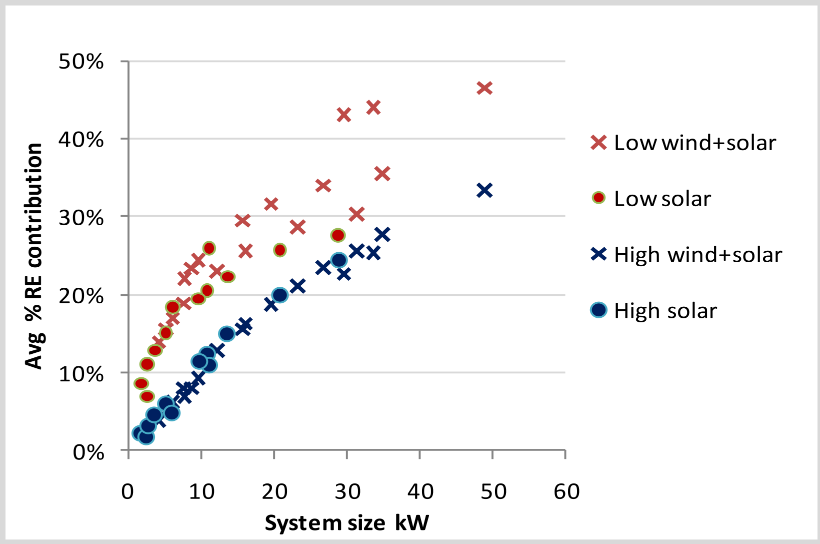


Figure 49: Average % RE contribution to load - comparison of system configuration

The differences in contribution to load by demand level (Figure 49) indicate that decreasing the site demand increases the ability of the supply system to contribute to meeting that demand. The implication is a well-performing house and occupants that manage load, can enhance their sustainability performance further in terms of decreasing network demand and increasing the renewable contribution to electricity use.

Supply utilisation is a function of demand level with system size (Figure 50). System configuration appears to favour systems including wind although the small increase in % utilisation may not be attractive enough for the extra investment.

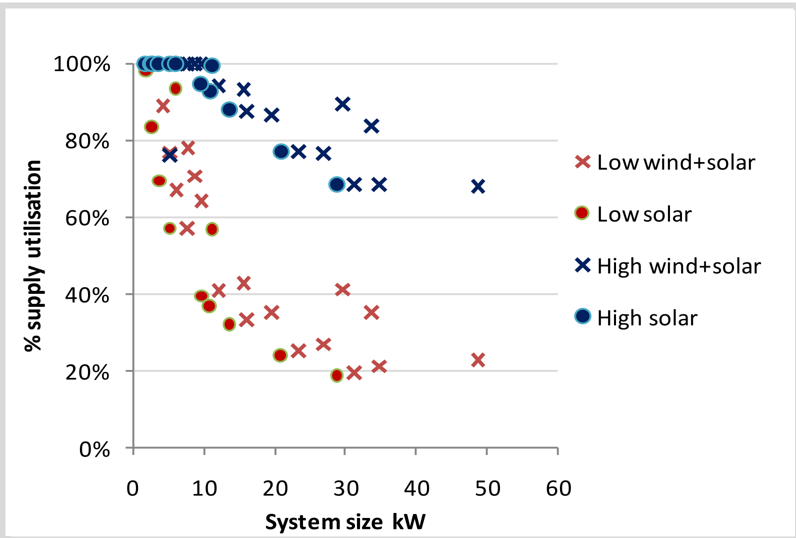


Figure 50: Average % supply utilisation - comparison of system configuration

As system size decreases there is more opportunity to use the supplied electricity.

This is also a function of demand profile as well as the amount of load on the system, and will be explored further in section 5.2.3.

The system performance results in the previous two graphs raise interesting questions about the basis for decision-making in terms of getting the best from a grid-integrated system. It is desirable to utilise 100% of the supply generated on-site especially if export tariffs are not attractive (less than standard pricing) and if standard pricing continues to increase. Correspondingly, contribution to load should also be as high as possible, but both measures are influenced by how much electricity is used at different times of the day. In this case, households need to want to actively manage their demand profiles to get the best from the system and that is not always desirable.

5.2.2 Economic Sensitivity

Economic sensitivity is of interest to because it represents a major influence on the decision process for assessing community energy systems in New Zealand. This market has little to regulatory or market incentives for installing small renewable systems so investors inevitably have to consider the influence of economic factors on the final decision (despite intentions to the contrary). Two site system configurations were analysed at high and low demand levels:

- The mixed system of 3.6kWp solar PV and one Proven 6kW P6 wind turbine; analysed to maintain consistency with section 5.1 Decision Model User Outputs.
- A solar-only system of 5.1kW. This was chosen as solar is modular, the economics are changing rapidly, and the site is not marginal for solar as it is for wind.

Both systems were in the top 50% of the NPV ranking tables on page 181, and sized to stay under 10 kW. The conditions for running the sensitivity analysis are shown in Appendix C5.2: Scenario Data Arrays – Economic Sensitivity. The retailer comparison of annual costs and long term economic outputs are summarised Appendix D2.4: Economic Sensitivity Support Data, Table A28.

Although many of the trends observed during this analysis were unsurprising, it must be noted that the results only apply to the parameters of this project. The key outcomes observed from the economic sensitivity analysis were:

- Long term NPV and RE alternative price are positively influenced by decreasing capital costs and interest rates; and by increasing tariff rates for import, export (low demand only) and gross feed-in. The effects (from a Totarabank perspective) are to ensure a positive NPV and bring the RE alternative price in line with standard tariffs so it becomes economically attractive to switch to an RE system.

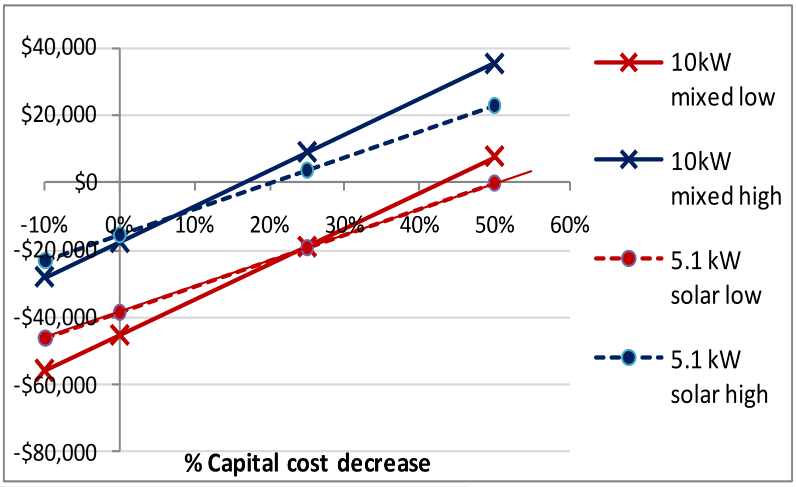
- As demand level increases, economic benefits are realised earlier, as opportunity to offset /save electricity is greater and costs can be spread across a bigger demand base. (This shouldn't be an excuse to raise electricity demand).
- System configuration has a smaller influence on economics than demand level, but mixed wind-solar systems realise economic benefits slightly earlier.

All variables can be altered together to explore a multivariate effect in the Decision Model although they are discussed individually in this section.

Impact of Capital Costs

Capital cost adjustment has a significant effect on long-term economic results. The negative cost adjustment was to show the effect of increased costs from the default position; the positive adjustments have looked to a cost decrease of up to 50%. Upfront investment cost is a major component of the NPV and RE Alternative price calculations.

Figure 51 shows the improvement in NPV at year 25 as capital costs reduce, with demand level influencing the cost reduction required to achieve breakeven. Based on the input data, the cost reduction range to achieve breakeven is from 15% to 50% depending on demand, and to a lesser extent, system configuration. The mixed systems have a slightly more positive response to reduced capital cost.



Int.rate 5%; f/c price incr. 5%; Meridian tariffs

Figure 51: NPV, year 25 vs. % capital cost adjustment

Figure 52 shows the influence of capital cost on the RE alternative price at year 25, relative to the standard price for electricity. It is desirable for the two prices to converge, or for the RE alternative to be lower in order for the switch to a renewable system to be attractive to system investors. The standard price forecast for year 25 is reached for high demand levels, for a capital cost reduction of nearly 50%. Forecasting the trend for low demand estimates the prices converge close to 70%.

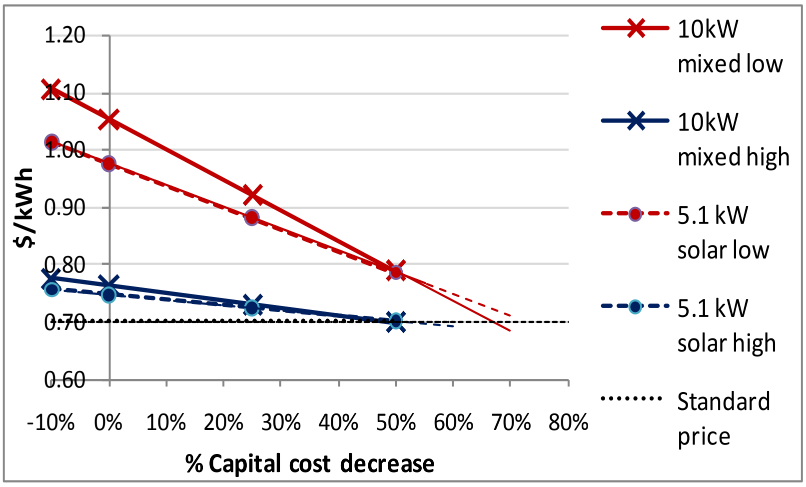


Figure 52: RE alternative price, year 25 vs. % capital cost adjustment

Demand and capital cost are the major drivers of the RE alternative price response. The lower the demand, the smaller the base across which the costs can be spread – such is the dichotomy of low demand and economic assessment. In this case, system configuration has less of an influence as the capital costs decrease.

Capital costs for renewable systems will decrease as market barriers are removed and scale economies can be achieved by producers (HydroTasmania, 2007), (East Harbour Management Services, 2006). As capital costs reduce, the financial attractiveness of RE systems increases.

Forecast increase in standard import tariff

Electricity prices are not decreasing with time. Part of the long term economic analysis for the Decision Model is forecasting the annual price increases for the standard tariffs that apply to importing electricity from the network.

The standard import tariff influences annual electricity costs; and the value of the savings derived from both lowering demand and utilising the site renewable supply. The NPV represents the net benefit of the site with renewable supply compared to a site without one. Therefore as the import tariff increases, so does the benefit of using renewables. This is demonstrated in Figure 53 – where the range for tariff increase is from 6% (high demand) to 10% (low demand). The system configuration is more sensitive to price increase as demand drops, with solar requiring the largest import price increase to achieve breakeven in year 25.

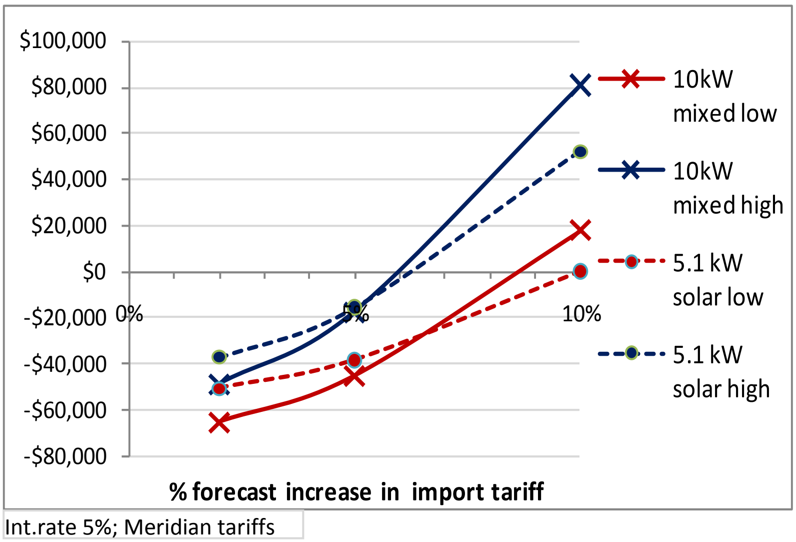


Figure 53: NPV, year 25 vs. % forecast annual increase in import tariff

Increasing import tariffs will also positively impact NPV breakeven time, beyond the 6% increase. This is demonstrated in Appendix D2.4 Economic Sensitivity Support Data, Figure A29.

As NPV becomes more positive with increasing import tariff, the RE alternative price also follows a similar trend to converge with standard pricing at approximately 8% to 10%. There is also less sensitivity to system configuration as shown in Figure 54. What is interesting is the small range within which both demand levels reach parity with standard pricing, making renewable supply increasingly attractive as import tariffs increase.

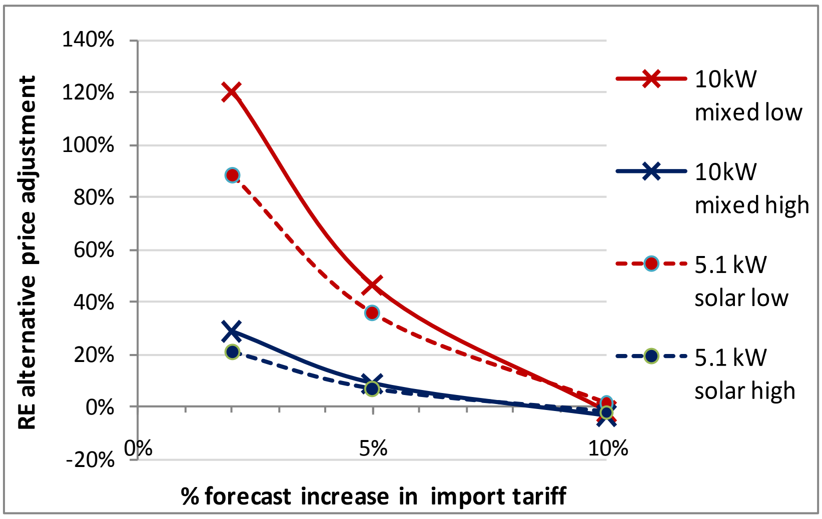


Figure 54: RE alternative price adjustment, year 25 vs. % forecast annual increase in import tariff

The equivalent position was explored for the forecast % change in export tariffs. The default position in the model is for zero change, based on the assumption that retailers in the current market have no incentive to increase export tariffs over time. The more likely scenario is that export tariffs will *decrease* as retailers move to eliminate any incentive for households to install such systems and receive a benefit for export. Currently retailers do not advertise export tariffs as they are unwilling to manage large-scale export from small distributed generation systems. Appendix D2.4 Economic Sensitivity Support Data, Figure A31 demonstrates the impact on NPV of changing export tariff forecasts, where the effect is small at low demand due to the export of surplus electricity. The actual tariff itself has a greater effect – this is explored further under export tariffs (below).

Interest rate for cost of capital

The cost of capital interest rate is that applied to the annual capital charge across the payback period of the investment. Increasing interest rate has a significant negative effect on NPV, as shown in Figure 55.

The RE alternative price at year 25, shows a similar trend becoming more attractive as interest rate decreases – this can be found in Appendix D2.4 Economic Sensitivity Support Data, Figure A30.

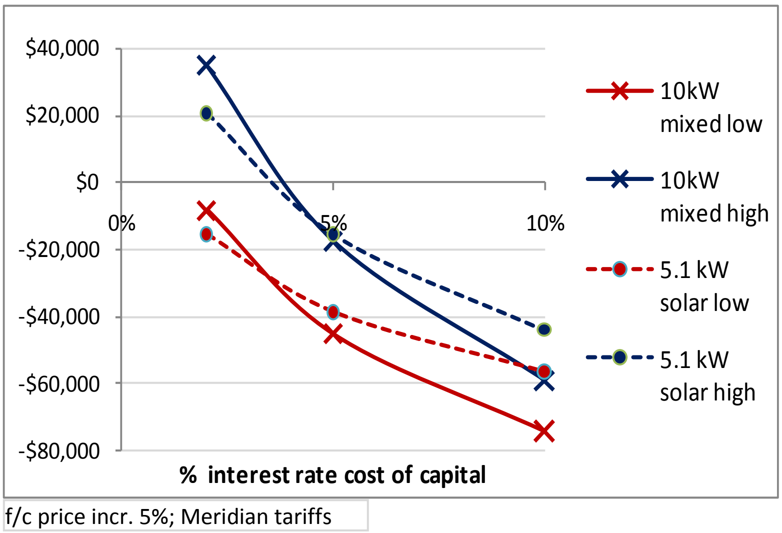
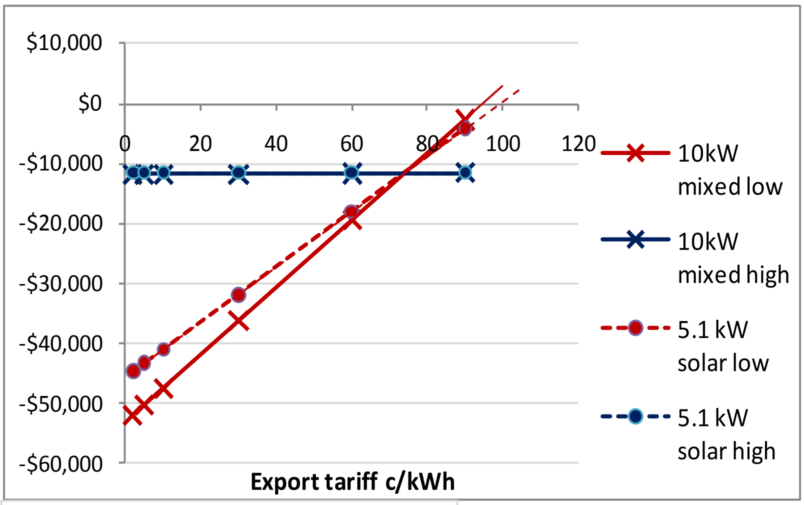


Figure 55: NPV, year 25 vs. % interest rate (cost of capital)

Export tariffs

A range of export tariffs were investigated that covered the range from low (wholesale price equivalent), to the high end (equivalent to potential rates for net feed-in tariffs or FiT's). These tariffs are paid on the net electricity surplus exiting the site/entering the network as measured by the export meters, once all on-site demand has been met.

It can be seen from Figure 56 that NPV becomes more positive as export tariff increases. The trend reduces with increasing demand level – at lower demand there is more electricity export occurring, and hence more financial reward. The indication here is that the tariffs need to be approximately 90c/kWh to achieve breakeven at 25 years.



Int.rate 5%; f/c price incr. 5%; Genesis tariffs

Figure 56: NPV, year 25 vs. export tariff rate c/kWh

Tariffs above the standard import tariff are unlikely to be seen from major New Zealand retailers in the foreseeable future; although they are becoming increasingly available internationally (refer to Section 2.1.3, page 34).

A more immediate effect of export tariffs is the impact on annual electricity costs for renewable grid-integrated systems. Figure 57 indicates a clear relationship between export tariff and annual cost. The higher supply rate from the larger system has the effect of reducing annual costs still further. Although a forecast has not been done on this data, an export tariff of at least $1.10/kWh would be required to achieve zero annual costs.

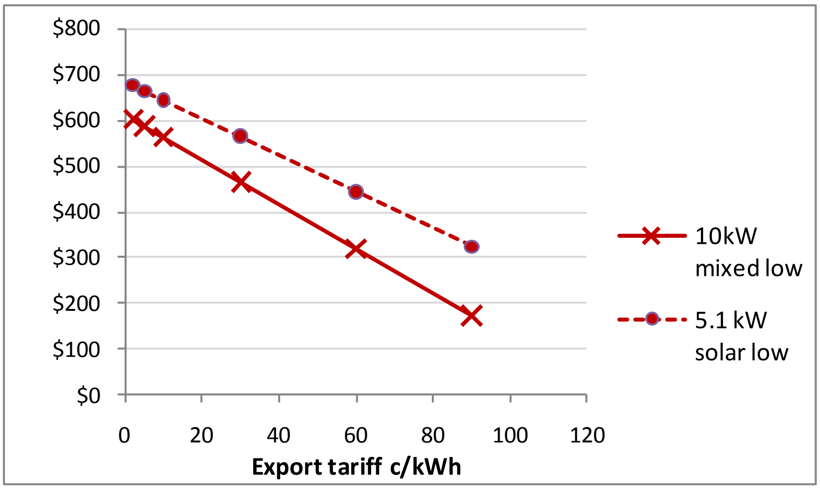


Figure 57: Annual electricity costs/house vs. export tariff c/kWh

Gross Feed-in Tariffs

Gross Feed-in tariffs, are not available in New Zealand. They have been recently introduced in Australia and used for a number of years in Germany. They work by valuing the total supply from the installed renewable system, regardless of how much is registered by the export meter. It was of interest to explore what impact they could have on a community energy system as a means of understanding how such incentive schemes work.

It can be seen from Figure 58, that Gross FiT's can have a significant positive impact on NPV. A positive NPV is achieved within the range of 20c/kWh (estimated) to 50c/kWh. It is clear why these price structures are used to widely incentivise uptake.

The positive impact of gross FiT's on annual electricity costs for each renewable system can be seen in Appendix D2.4 Economic Sensitivity Support Data, Figure A32. As the tariff rate increases, costs decrease and become net rebates.

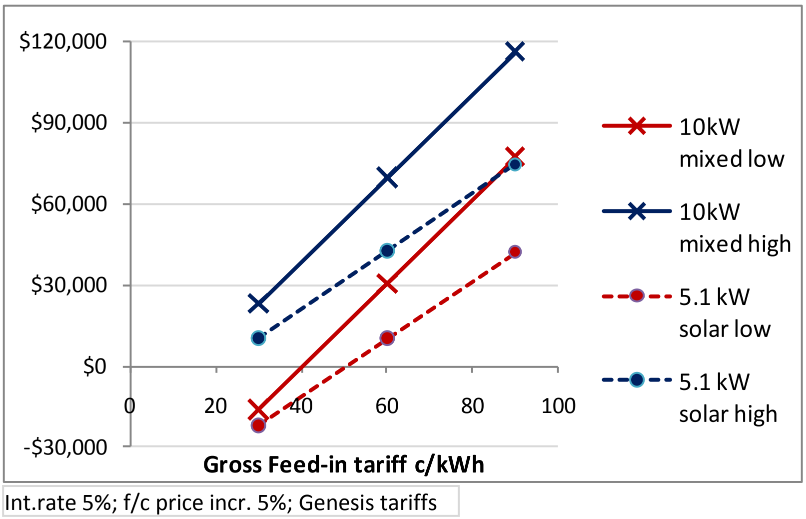


Figure 58: Impact of Gross feed-in tariffs on NPV at year 25

5.2.3 Energy Management

The energy management scenario explored the effect of changing demand patterns on annual costs, system performance and economics. The analysis used the low demand dataset only as this was the only one with sufficient detail on end-use that could then be modelled under alternative use options.

The scenarios used for the analysis involved:

- 'Peak shift' - shifting selected discretionary loads (cleaning, office equipment) from the end of the day to the middle. The daily load is the same as for low demand.

- ‘Peak shift + Occupancy’ – peak shifting is aggregated with daytime occupancy of the house by two people. The daily load increases under this scenario as well as load occurring during the day.
- These were explored for all lots, and for 50% scenario/50% standard low demand.
- Analysis results are based on the mixed 10kW system described earlier.

Key outcomes from the analysis showed:

- System performance improved relative to the low demand base for supply utilisation and RE contribution to load. This was the case for both peak shifting, and occupancy scenarios.
- Offset load increased with each scenario, indicating that increased usage activity during the day provided more opportunity to utilise on site supply and reduce import. This also has the effect of reducing export – which becomes negligible under the occupancy scenario.

Improvements in system performance relative to the low demand base are demonstrated in Figure 59. Peak shifting for the same load clearly improves the utilisation of on-site electricity; while the impact of increasing daytime occupancy is significant for supply utilisation. Occupancy increases the overall load; hence the contribution of renewables is proportionally not as great.

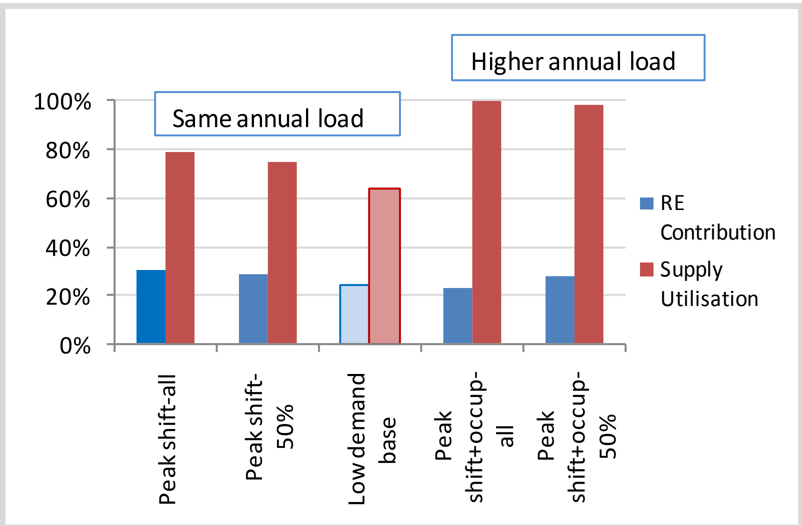


Figure 59: System performance for energy management options

Considering the energy management scenarios in terms of meter activity, shown in Figure 60; peak shifting delivers a small reduction in imports, increasing savings and reducing exports. The higher load occupancy scenarios have increased import levels (on site supply is not quite enough to meet daytime demand), but the effect of savings is still improved relative to the low demand base.

Increasing load during the day reduces the electricity normally exported as surplus, and in the case of peak shifting, reduces the amount of electricity normally imported at night when the on-site supply is not delivering. This is demonstrated in the 24 hour energy balance profiles for summer (February) and winter (July) contained in Appendix D2.5 Energy Management Support Data, Figure A33.

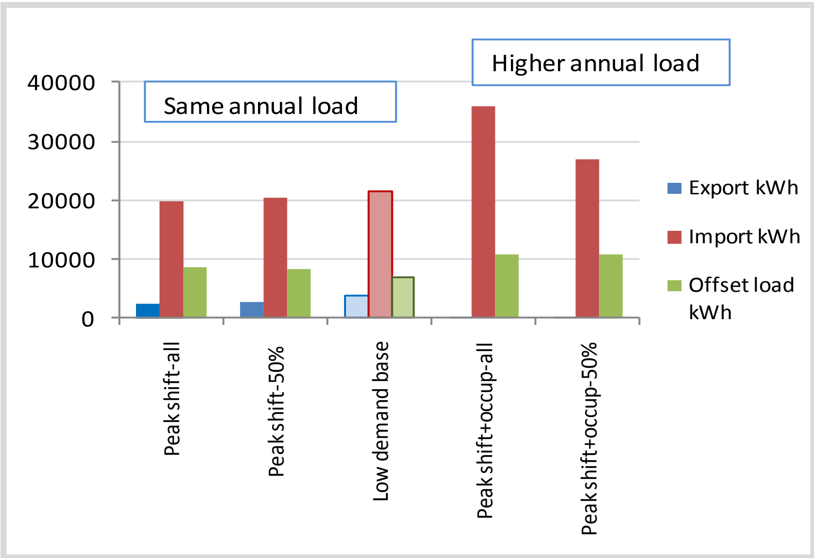


Figure 60: Energy balance performance for energy management options

The economic implication for active energy management is driven by the pricing regimes. If export tariffs are lower than import tariffs, there is an incentive to use more electricity during the day when it is generated (rather than exporting), driven by the value of avoided electricity import. However, increased use of electricity on-site should not be at the expense of efficiency.

If export tariffs are higher than import, then peak shifting or similar approaches may not be as attractive as exporting.

Storage of surplus rather than exporting is also a strategy for utilising surplus electricity in the same way as increasing usage during the day. The benefits of storage from an economic and service provision perspective are worth considering if cost-effective storage technology becomes available.

In this particular scenario, the long term economic outcomes from peak shifting were a small improvement in NPV driven by the reductions in imported electricity, and a small reduction in attractiveness of RE alternative pricing driven by the reduction in export value. The inclusion of daytime occupancy had a significant positive effect on both these measures driven mainly by the effect of increased demand, and the value of the offset. Further detail can be found in Appendix D2.5 Energy Management Support Data, Figure A34.

5.3 Decision Model Validation - HOMER

The processes outlined in Section 4.4 Model Validation, page 95, enabled the quantification of differences between the Decision Model and HOMER focussed on the energy balance. Extensive support data and information on the relative differences between the model structures, and functions are contained in Appendix C6 Model Validation.

The analysis focussed on the underpinning energy balance calculations on which both models depend for their subsequent analyses.

Two systems were compared – solar only (PV 5.1 kW), and mixed solar-wind (PV 3.6 kW with Proven P2.5 kW turbine).

The main outcomes of the validation work were:

- The fundamental approach to the energy balance was the same between the models.
- Differences based on total annual kWh for import and export ranged from 0% to 30% depending on the settings for daylight saving, inverter efficiency, and derating.
- Total annual differences were significantly better than inter-month differences; and import estimates had a significantly lower level of variation compared to export.
- Variations were smaller for the solar only system, compared to the mixed system.
- HOMER has few options for constructing and manipulating an aggregated demand profile based on multiple inputs – which represents the biggest difference between the models.
- Overall, the Decision Model compared favourably with HOMER in terms of function and output considering the difference in model complexity and intent.

The more detailed approach that HOMER has to setting conditions for data inputs for systems, resources and load resulted in key variables being identified for having the greatest effect on the comparison. These were the settings for daylight saving, inverter efficiency, and derating – a full explanation of these terms and their impact is found in Table A8: Model validation for supply systems. To illustrate how the validation results altered with variations in these settings, a comparison of the total annual differences for the two system configurations is shown in Table 16.

Table 16: Comparison of energy model validation results

			Daylight saving		NO Daylight saving	
System type	**Inverter efficiency %**	**PV derating %**	**% difference with Decision Model (positive = HOMER>DM; negative=DM>HOMER)**			
			Import	**Export**	**Import**	**Export**
Solar only	90	100	5	2	9	-2
	100	100	3	18	7	14
	100	90	5	5	8	1
	90	90	6	-10	10	14
Mixed	90	100	-8	11	-5	7
	100	100	-12	31	-9	26
	100	90	-11	19	-8	15
	90	90	-7	0	-4	-3

Daylight saving appears to negatively affect the mixed system results. No obvious factors could be found for this during this analysis, so more time may need to be spent to understand this effect. Overall the best match (the lowest % differences) were found with inverter efficiency and derating both set at 90% for mixed systems; and at 100% and 90% respectively for solar.

To illustrate how the monthly results varied in comparison to the annual totals observed above, the % differences for import and export estimates were plotted for both systems under the same conditions. The results are shown in Figure 61 and Figure 62. Export differences are greater during the winter months, with HOMER estimating a greater level of export.

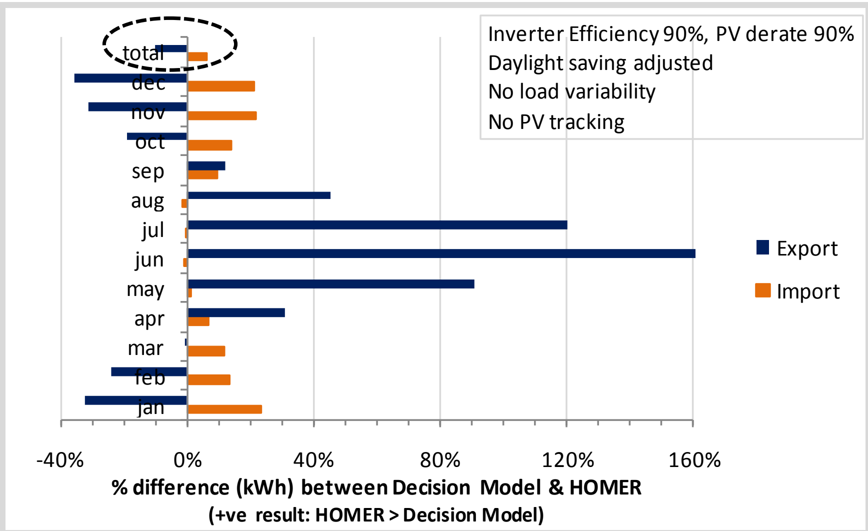


Figure 61: HOMER energy balance comparison, for PV 5.1kW system

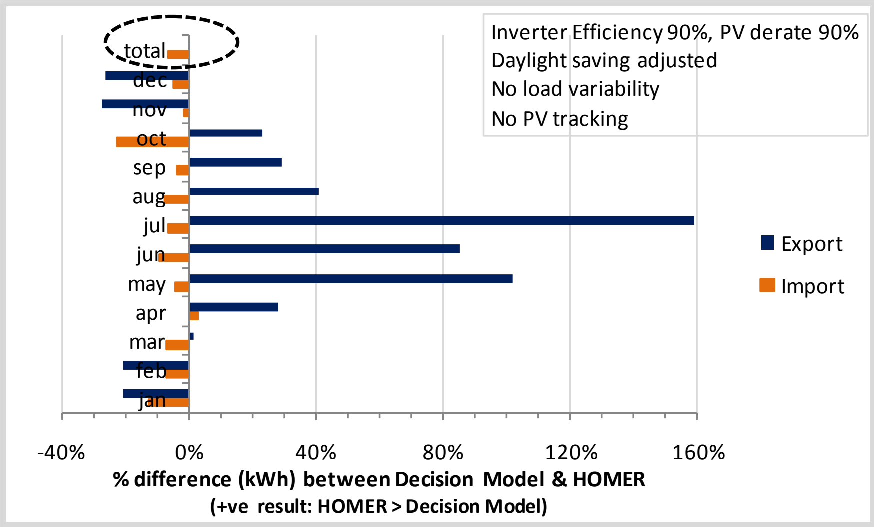


Figure 62: HOMER energy balance comparison, for 6kW solar-wind system

Despite the variations seen here, the seasonal kWh profiles of import and export were the same for both models, confirming the energy balance is moving in the right direction. The export portion is much smaller relative to import, so export variation is of less consequence than for import estimates – having a smaller influence on economic attractiveness.

5.4 Network Impact

Analysis of Decision Model outputs can provide a technical and economic perspective on network impact from the community energy system. The approach taken with this analysis is to quantify network impact in terms of avoided electricity import. The site will be seen as a single customer by the network Lines Company, and site demand is on the basis of all eight houses having the respective demand profiles.

Avoided import can be seen two ways – as an opportunity to make that energy available to other users (enabling better utilisation of lines infrastructure); and as lost revenue for the network (meaning costs to provide the service and infrastructure to Totarabank are not recovered as quickly). In this analysis, avoided import can be achieved by managing demand profile, and by the installation of the on-site community energy system.

Tariff trends will also drive where economic benefits will lie for avoided import. As import tariffs rise, the incentive to avoid import increases for the user – reducing income for the Lines Company and leading to a potential increase in fixed line charges to recoup margin and costs. Thus, if the Lines Company wishes to mitigate this, the option to incentivise export in sufficient quantity to be of use in network support can be exercised through appropriate export tariffs.

Demand Management and Avoided Import

Managing user behaviour, house performance and energy efficient technology are the first options available for reducing electricity import. The three profiles used in this study combine all these elements to create the differences between them. Figure 63 illustrates the overall annual differentials quantified by each demand level – where the top of each demand increment indicates the total annual import. The increments for medium and high demand represent the amount of import that can be avoided by moving to a low electricity demand. It should be noted that the medium and high levels represent all–electric fuel; while the low demand has significant contribution from non-electric fuels (solar, biomass, LPG).

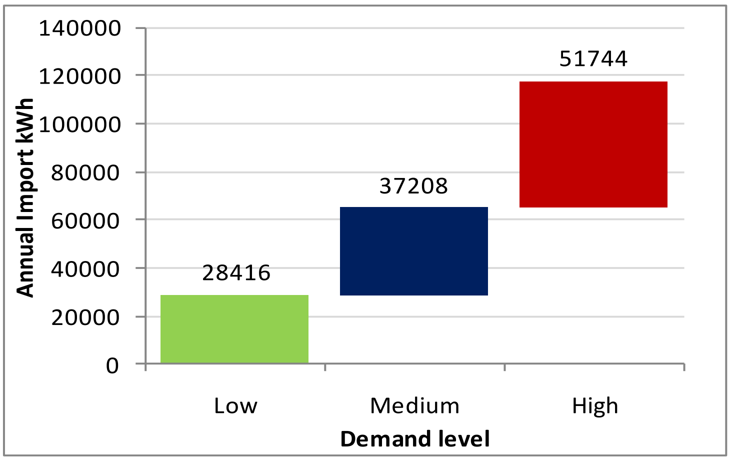


Figure 63: Annual site demand differentials kWh

Considering network impact from a daily profile perspective is important, as daily peak management for high usage periods is what determines decisions for infrastructure investment by a Lines Company. Figure 64 demonstrates the cumulative demand increments, by hour for an average summer day for the site.

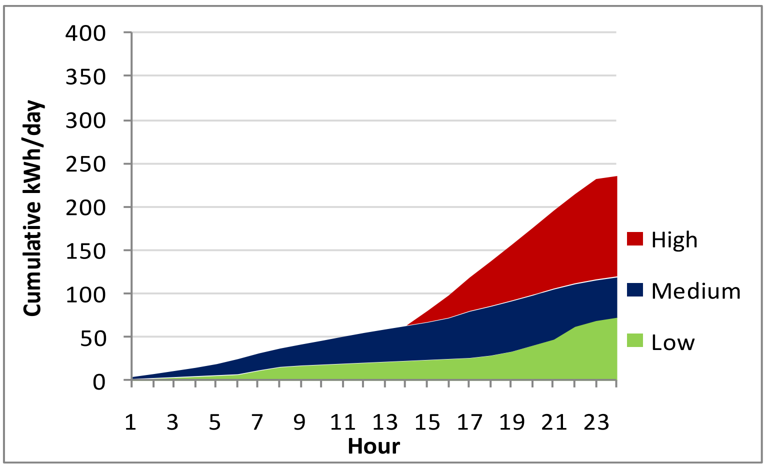


Figure 64: Summer daily profile cumulative demand differentials

The high increment is predominantly due to heat-pump driven space-cooling from mid-afternoon, hence the similarity in medium and high profiles for the first part of the day. Moving from space-cooling to natural ventilation and motivated users could avoid import of approximately 90 kWh/day, for the site.

Figure 65 demonstrates the same data but for an average winter day. Winter is generally the season that lines companies must invest for as the period where highest annual demand peaks occur. The differences here are much greater – moving to space and water heating based on solar and biomass used by low demand houses could contribute to achieving avoided import of approximately 174 kWh.

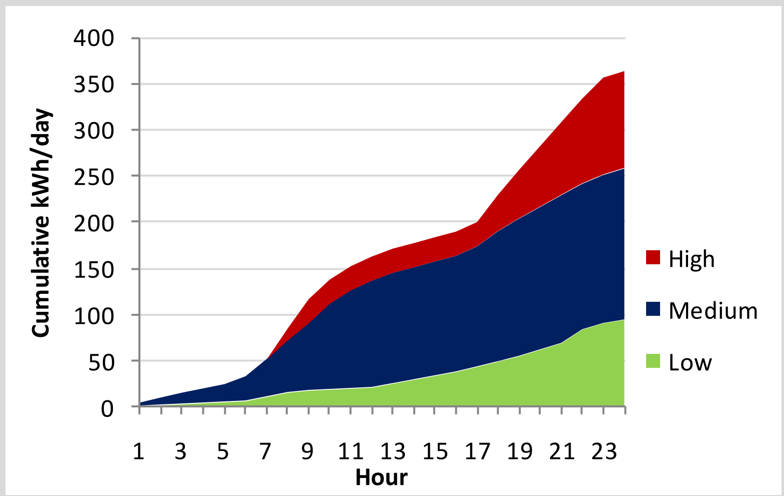


Figure 65: Winter daily site demand differentials

The outcome of these analyses suggests there are a number of opportunities to reduce or avoid import. How and whether these happen depends on who requires the benefit from doing it. Totarabank's efforts to keep demand lower rather than higher will have a definite impact on what the Lines Company will see in terms of off-take.

Community Energy Systems and Avoided Import

Contribution to import reductions from the installation of renewable supply systems are additional to import avoided through demand management. Based on the data used for earlier connection scenario analysis, the outputs for system offset (or savings) can also represent the potential avoided import. Figure 66 illustrates the increase in avoided import by system size (based on one year).

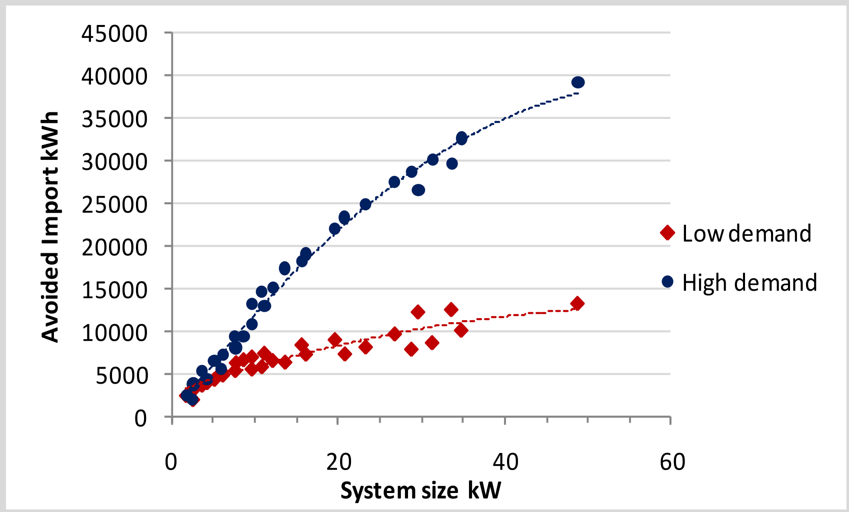


Figure 66: Avoided import (annual) by installed system size and demand level

The opportunity to reduce import levels increases with increasing demand; but at low demand the effect of export has to be considered. The export trend at low demand is shown in Figure 67. The effect of this is the network will see an increase in energy coming back onto the network, in addition to avoided import – without any reduction in network capacity. Depending on the installed system, import could be avoided in the order of several thousand kWh/year.

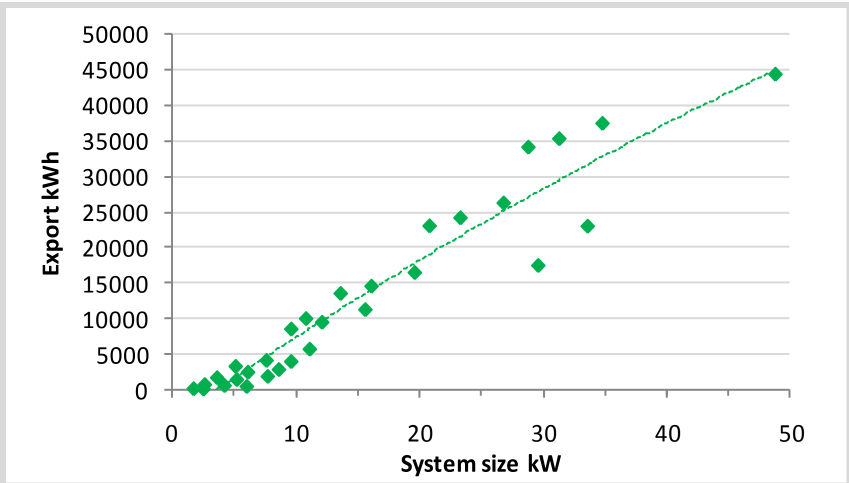


Figure 67: Annual site export, low demand

5.5 Sustainability Assessment

A set of sustainability indicators was proposed in Section 2.2.2 Indicators and Measures, Table 4 to contribute to the decision processes concerning energy management for a community energy system. The application of the indicators is presented in this section.

Questions and trade-offs to be considered to meet sustainability objectives may include:

- Identifying what is important to the community and therefore what may need to be compromised between the economic, technical, social and environmental elements.
- Identifying the balance between individual needs and the development philosophy.
- Finding a balance between fuel type and electricity demand – as electricity use reduces, identify other fuels that may be used instead, and their sustainability.
- Keeping demand low as a core philosophy to reduce resource use despite economic attractiveness increasing with electricity use when investing in renewable generation.
- Using as large a renewable supply system as can be afforded in order to displace as much network electricity as possible; and to improve resilience.

An example approach to applying the proposed indicators (Table 17) matches appropriate Decision Model outputs against each indicator, and notes how these may be applied to decision making. The Decision Model was not designed to provide all the answers for sustainable energy decisions, but to support as many as possible.

Table 17: Sustainability Assessment Example

	Indicator Description	Model Output	Application
Economic	Investment value over time, of system	NPV for the site, and by house	Higher NPV (preferred) over shorter time frame more likely for smaller RE systems less than 10kW total.
	Internal vs. external electricity costs (c/kWh)	RE alternative vs. Standard price	Easier to switch to RE as RE price converges with or moves below standard delivered electricity price.
	Energy expenditure by house and community	Annual Electricity costs	Lower costs preferred - linked directly to demand profile and system size.
	Investment in local economy	N/A	Local resources for installation and servicing increase with system size.
Environmental	Contribution to pollution reduction	System size, and offset in kWh	Improves with reduced demand and higher use of renewable electricity and energy.
	Reduction in imported electricity	Offset (savings from grid displacement)	Imports reduce with bigger RE systems and with lower demand, balanced against cost of bigger systems.
	Efficiency of resource provision and use	Supply utilisation %	Increased use of RE supply (low and high grade) preferred but linked to load profile
	Total energy supply per person	Electricity RE supply less export + import	Lower demand requires less supply. Then balance supply against energy source to get maximum from local options.

	Indicator Description	Model Output	Application
Social	Ability to manage system complexity	N/A	Complexity increases with technology for multiple supply systems and internal loop management.
	Security of supply and resilience to changes.	N/A	Improves with Increased site provision of low and high energy.
	Comfort and health of owners	N/A	Personal choice – link with consequences of demand increase, and energy source
	Positive community spirit	N/A	Site challenge – to get a unified approach to overall sustainability
Technical	Reduction in peak loads	Not provided, but may be possible	Loop energy management and community awareness of demand profile needed. Incentivised by Lines Company.
	Energy and electricity fraction delivered by renewables.	RE contribution %	Prefer as high as possible using site RE low and high grade sources. Can measure electricity, look to quantify the rest.
	Average hourly kWh delivered	System output	Prefer as high as possible for maximum efficiency for investment.
	Reliability and standards of systems	N/A	Expect AS/NZ standards, warranty, system support and qualified installation.

Decisions taken from a holistic sustainability perspective must ultimately depend on the preferences and objectives of those who are making them particularly when social elements are considered. Taking an aggregated approach for a development like Totarabank will require consultation and compromise as individual needs are balanced against the needs and objectives of the site. Many of the indicators are interlinked; and influenced by demand in terms of level and use pattern. It seems straightforward here to construct a table of measures and outcomes - in reality these will evolve as community residents learn more about decision consequences. Directly interacting with the technologies, the relationship between resource and energy output, and the impact on daily decisions regarding energy use will raise awareness and allow future decisions to be more enlightened.

On the issue of selecting technology options for managing sustainability, Elliot (2007) states:

> "*It must be recognised that the technological, economic and social context is changing, and there is a need to learn as we go along. The best long-term overall balance between the various options and scales will probably only emerge as the sustainable energy system develops, and as more experience is gained with the new systems and associated infrastructure.*"

The Totarabank development has the ability to start small with renewable system installation, and expand as economics, technology options and social factors change. The desire to learn from experience may be one of the best investments to be made.

6 DISCUSSION

There are few examples in New Zealand of multi-lot developments with sustainable energy management principles including the use of grid-integrated renewable distributed generation. Totarabank itself appears to be unique using the approach of individual residences in a development connected to a common grid with a single meter to the distribution network.

This research intended to better understand the balance between the technical and economic viability of these systems within pre-set covenants for house performance and energy use by:

- assessing how the Totarabank principles and infrastructure may work in the context of including grid-integrated distributed generation in the development,
- modelling how a mix of grid-integrated distributed generation will impact the value of energy generated on-site and implications of a communal approach to energy management and,
- identifying the key factors to be considered for practical management of energy use relevant to the site and development principles.

What has transpired from the development of the Decision Model, and the corresponding analysis of results, is the complexity and range of decisions required for a development such as Totarabank. This stems from the use of the tool to evaluate the impact of grid-integrated renewables for a range of wide demand-supply options, rather than for just sizing the system to meet peak demand. Combining this approach with the underlying principles of sustainability of the development meant the complexity of the decision making was not just focussed on purely technical or economic outcomes.

The site covenants for energy efficiency, infrastructure and resource use do not provide any barriers to grid-integration of an on-site communal energy system. They do make a significant contribution to demand level by promoting energy efficient house performance and the use of low-grade energy for heating. Monitoring the impact of site energy balance on the loop infrastructure, and on individual house connection may create a natural limit to demand especially in winter.

The value of the electrical energy generated on site is influenced economically by the size of the chosen system (and therefore the cost), the cost of consumption, and the demand across which the cost is spread. This creates a pull towards smaller systems, and/or higher demand, and drives the increased utilisation of system outputs. In contrast, the non-economic factors that influence the value include improved site resilience, greater contribution of local renewables to site energy use, and the opportunity for improving awareness of sustainable energy use among the residents. Such factors can encourage the installation of larger supply systems if economics are less of a barrier; and if the residents choose to make that decision.

For a grid-integrated system, the remaining factors influencing system choice are reduced cost of storage, and export tariffs. The ability to export surplus electricity is a driver to having grid-integration. Internationally exporting is used as an incentive to install a DG system; in New Zealand it is seen as a necessary evil of satisfying a small sector of the market. For Totarabank, export tariffs become another factor in the overall energy management strategy (Figure 68) rather than being a reliable source of income to offset capital investment.

		Energy management implications		
Tariff Structure	**Surplus electricity**	**Economics**	**System performance**	**Load Management**
Export > Import	Export to network	Improve as *export* tariffs rise relative to import tariff.	Supply Utilisation % drops. RE contribution to load increases initially then levels off, depending on profile matching	Demand profile managed to maximise export
Export = Import	Use either approach			
Export < Import	Use on site or store	Improve if *import* tariffs rise thereby increasing value of offset savings (reduced import)	Supply Utilisation approaches 100% (more so for higher demand.) RE contribution increases with profile matching.	Demand profile managed to better match supply profile IF the community wants to maximise efficiency of site system.

Figure 68: Energy Management implications for a grid-integrated system

The overall approach to energy management is significantly influenced by user behaviour. In the course of this research, a number of assumptions were made regarding the impact of user behaviour on the amount and period of electricity use. The Beacon data supplied for the demand profiles contained an element of user behaviour that demonstrated an issue of 'take back'. A well-performing house reduces the energy costs, which are then 'taken back' by more energy intensive behaviour – seen also with changing hot water use with the installation of solar water heating; or the extended use of heat pumps.

It is difficult to quantify the true impact of this effect, but it has to be acknowledged. How user behaviour is monitored and addressed on the site will be dependent on the network management systems available, how they are used and how the residents respond to the information. Clearly smart meters have a role to play here, but the attitude of the market will dictate in the short-term how users will access the benefits.

The Communal Approach

User behaviour is one social element of the sustainability picture that is not extensively researched in New Zealand – yet has the potential to create significant electricity savings if applied across many households.

A potential benefit of the Totarabank approach is the combined effect of a number of people choosing to live in an environment focussing on managing energy use. Residents should be provided with the information to build and develop this awareness without removing their ability to make decisions on personal comfort and lifestyle. It is an evolution of the 'eco-community' approach that uses a broad environmental philosophy for living, but doesn't necessarily focus on the interaction between lifestyle and technology.

Elliot (2007) makes a similar point discussing solutions to a sustainable energy future; in that the interaction between technology and society will create new ideas for change. Local community projects provide opportunities to develop how technology may be used, and how lifestyle (i.e. user behaviour) may be adjusted. This drives the adoption and development of technology for social as well as market acceptance while delivering benefits from both technical and social change.

These principles were demonstrated in the IEA study on solar communities (IEA-PVPS Task 10, 2008), where over time a number of effects were seen in urban communities connected to renewable generation. What is of interest here is the aggregated effect of raised awareness on a variety of issues such as reduced energy use, increased community spirit, house values, and environmental impact; when each house was connected individually to the local network. Even though each household still remained independent in terms of their energy decisions, an aggregated benefit was still observed. Therefore, a potential benefit of the Totarabank project is through achieving similar or better outcomes influenced by the connection of an internal grid. The use of a range of technologies will drive awareness of energy use - from the experience of building an energy efficient house, to the system for information delivery on electricity use.

These international case studies also demonstrated the network impact from urban energy projects – predominantly from improved grid stability at peak periods. In California this was manifested by significant peak savings of up to 70%. Clearly the cause and timing of peak demand has much to do with how distributed energy projects will mitigate it; but the benefits were measurable.

Network impact in terms of capacity support is best achieved through appropriate scale, in order to be attractive to Lines Companies. The international approach of utilising multiple house urban developments demonstrates this – although individual house owners are involved, the benefit is achieved by aggregation. End-users in New Zealand, whether they are residential or commercial have yet to be seen as a means of achieving similar outcomes due to a variety of economic, and market factors.

Economic and market factors – is bigger better?

Lack of government impetus for promoting smaller scale renewables has resulted in the emphasis on large scale public funded generation that can (theoretically) be delivered for a lower unit price (Barry, 2007). Large scale means large negative impact from an environmental and social perspective, tempered by the positive economic benefit from infrastructure development plus the short and long-term employment spin-offs.

There is an opportunity to identify and cordon off areas of national significance that should never be made available for development; and to investigate the areas of demand growth identified in the latest Energy Data File (MED, 2008). The next step is then to incentivise smaller/private investors in the areas of need to develop local generation and provide some small incentives to those who wish to participate in the technology. This is along the lines of the concepts proposed by Barry (2007) to promote the development of community owned small scale wind alongside larger wind farms. This could encourage better community acceptance as well as match need to resource, support local networks, and release private investment. Large developments still have their place to ensure security for large users wanting low priced electricity.

The concept of "consumer ownership" has also been promoted by IRL in their research on micro-generation technologies in distributed energy systems. IRL suggested (Gardiner, 2007) that encouraging the uptake of micro-DG can constructively support local network capacity as well as deliver energy. Incentives could be on the basis of avoided transmission and distribution costs with pricing to encourage feed in of capacity/excess electricity at network peak periods. Technology owned and operated by the end-user reduces investment by generators and distributors - especially if it is incentivised in areas where it could support the network.

A similar approach was proposed as part of the Australian Solar Cities Program to promote distributed PV systems (Maine & Chapman, 2007). It was based on rewarding electricity users who can guarantee their peak electricity demand will be managed at a level low enough to reduce retailer exposure to high spot prices.

The current government opposition to instruments such as Feed-in Tariffs and rebates for increasing the uptake of renewable energy needs to be considered in the context of subsidies and support for other initiatives such as the availability of crown land and other support for new extractive industries to create new income. What is the difference between these and the support of FiT's, or any other pricing incentive that would create down stream business for the renewable energy industry?

Incentivising the uptake of small-scale renewables will impact on Government profits from SOE's. From a layperson's perspective, such 'support' appears undesirable because it has a negative impact on SOE profit. The other initiatives are seen by Government as creating new money, even though the net financial flow is probably similar. It seems more acceptable to pay out a large chunk than to sacrifice it, even though the benefits of business creation and consumer wealth are still the same.

Business created with a stronger link to private enterprise has direct accountability for generating profit, and has to be linked to user need in order to achieve it. This is probably one of the greatest weaknesses in the NZ retail electricity market, in that the market is supply, not user-driven. Linking this back to the earlier discussion on benefits of a communal approach, opportunities exist to deliver financial benefits at the end-user and the network levels. These can create down-stream benefits from more efficient resource use and reduced environmental impacts. However it would require a benefit re-distribution and a more strategic approach to long term energy management.

As any nation's policy and strategy around energy delivery broadens, arguably so does the distribution of a variety of energy systems and approaches to energy management. New Zealand has a narrow strategy aimed at increasing fossil fuel use (thereby reducing market penetration of renewables) and ensuring security of supply underpinned by the desire to keep the profit margins flowing back to the government. The market here is motivated by the use of energy as another tax so that electricity sales support Government spending.

International energy economies are driven by the need to reduce dependence on fossil fuel, and take a wide variety of approaches to achieve this. New Zealand conversely is increasing dependence on fossil fuel for security of supply, and is providing limited incentives for the release of private equity to fund new approaches in energy management (predominantly for joint ventures in geothermal development). Incentivising private investment in energy generation for private consumption to enhance peak reduction and demand management is an alternative to direct government subsidies, thereby releasing funds for other areas of government investment.

Energy policy and strategy in New Zealand remains under review, and there are a number of examples in the literature of policy options that could be adapted (Barry, 2007), (Passey & Watt, 2008), (Sovacool, 2009). Steps that could be taken now to promote and support sustainable energy use could include: the improvement of energy efficiency protocols for residential housing developments, streamlining consent procedures for renewable systems, documenting pricing options for small-scale grid-integrated systems, and encouraging the technology suppliers to promote system pricing options to encourage uptake.

The biggest step for New Zealand to take remains the application of innovative, not short-term political thinking. If Totarabank represents one means of demonstrating how to achieve a sustainable energy future, what will be the next? All the stakeholders in the New Zealand Energy market have the capability and the means to identify those future innovations – they now need to find the courage, the motivation and the vision.

7 CONCLUSION and RECOMMENDATIONS

Research Conclusions

The Decision Model decision-support tool has been developed to guide investment in grid-integrated distributed generation systems for an eight lot subdivision developed on sustainable principles. This tool has been designed to support decisions and discussion at a household and site level, using a combination of Model outputs in graphs and data tables. Detailed scenario analysis was also undertaken to further explore options for connection placement, economic sensitivity and energy use options.

The significant criteria influencing the viability of a community energy system are complex and often interrelated. Technically, the placement of the systems was less important than the size of the system. There were no significant differences between connection set-ups that were based on house-only, site-only; or a mix of both. Comparing loop and standard radial connection options demonstrated no difference in terms of energy balance or system performance for the same system sizes and configurations. The loop connection option had very similar long term economic outcomes (RE alternative price and NPV) compared to radial, underpinned by small differences in annual capital charge and fixed line costs.

Overall size of the system had the most direct impact on the main output variables of interest (annual costs, long-term economics, and system performance). Configurations of mixed systems of solar and wind, compared to solar only had more positive outputs for system performance and NPV.

Economically, long term NPV and RE alternative price are positively influenced by decreasing capital costs and interest rates; and by increasing tariff rates for import, and export (low demand only). Configuration has a smaller influence on economics than demand level – as demand increases, the economic position improves due to the ability to spread the cost.

This represents an economic challenge to Totarabank which may be best met in the short term by installing a mixed system sized between 5 and 11kW. As the NPV position improves with time and the RE alternative price comes in line with standard tariffs it may become more economically attractive to switch to an RE system and increase the size of any installed system.

A range of options for managing energy-use were explored, from the impact of energy efficiency approaches, to demand profile management. Energy use options that reduce or avoid electricity import are driven by who benefits, what behaviours are required to achieve them, and the fuel used – these factors contributed to the three electricity demand profiles developed for this research. Energy efficient house design combined with low-grade renewable energy sources other than electricity for heating and cooling were estimated to save for the site in summer approximately 90 kWh/day, and in winter 174 kWh/day based on the scenarios used.

Peak shifting and daytime occupancy scenarios indicated that system performance improved relative to the low demand base for supply utilisation and RE contribution to load. Offset load increased for each scenario, indicating that higher usage activity during the day provided more opportunity to utilise on site supply and reduce import. This also has the effect of reducing export – which becomes negligible under the occupancy scenario.

In summary, the Decision Model provides a number of opportunities to support decisions and analysis when:

- engaging with Lines Companies and retailers during the process of installing a system and negotiating a contract. Potential energy balance logistics for the single ICP can be explored from a number of perspectives;
- seeking a more in-depth economic analysis through a complementary economic tool such as HOMER; and
- educating and informing current and potential residents about the impact of energy efficient living, in terms of annual cost estimates and lifestyle decisions.

Maintaining and updating the background data and analytical processes in the Decision Model will be important for its ongoing relevance as a decision support tool.

Recommendations for Future Research

The Decision Model compared favourably with HOMER in terms of function and output considering the difference in model complexity and intent. Although HOMER has few options for constructing and manipulating an aggregated demand profile based on multiple inputs, it delivers a thorough economic analysis. Clarifying and improving the link between the two tools would provide a complete evaluation process for complex energy systems exploring grid-integration options.

Research into technology solutions to cost-effective small-scale electricity generation, management and storage must continue. Although storage opportunities were not specifically quantified in this research, the forecast trends for export incentives will represent a significant opportunity for technical solutions for on-site storage and management of surplus electricity.

There are very few properly constructed examples of energy research conducted in a community context. There is significant value in ongoing monitoring of outcomes at Totarabank (or any energy system of similar scale) in terms of:

- the technical performance of an installed grid-integrated community energy system as part of the internal loop grid;
- the impact of metering and information delivery tools to influence energy management; and
- the impact of user-behaviour and energy efficiency covenants on demand management (particularly the impact of increased use of local renewables as part of the overall energy mix).

It is important to note research monitoring can be done from the perspective of the network as well as the residential development. Better understanding could lead to opportunities for distributors, technology suppliers and end-users if the stakeholders are prepared for the benefits to be applicable to all.

Most post-implementation system monitoring in New Zealand appears sporadic and anecdotal. This represents a huge future opportunity in energy research, where the effort involved in implementation should be matched by rigorous monitoring and reporting to ensure lessons are learnt and transferred. While the case-study approach is useful, even more benefits are gained if pre- and post- monitoring work is properly structured and analysed.

In addition, a more collaborative approach to undertaking and assessing consumer-focussed energy research is needed. The barriers faced in this project in extracting data from BRANZ, line companies, and retailers are an unfortunate example of insular and anti-competitive thinking prevalent in New Zealand today.

Incentivising and promoting residential developments with a specific strategy for managing energy including use of local renewables is an opportunity for action in New Zealand and a topic for further research and monitoring. Real demonstration of action by motivated people and organisations is needed to continue debate and improvement.

8 APPENDICES

APPENDIX A: CHAPTERS 1 and 2 SUPPORT MATERIAL

A1 Totarabank Overview

Detail is provided on the Totarabank philosophy, energy covenants, and site layout (Duncan, 2007).

Philosophy (from "Designing Resilient Communities", (Duncan, 2007))

The challenge facing land developers is to create an environment that provides a degree of resilience against factors that could jeopardise the needs of inhabitants, whilst meeting aesthetical, fiscal, legislative, and market requirements. At the same time, the development should aim to reduce its contribution to climate change.

Electricity Generation

All lot owners shall are responsible for 1/8th of the electricity costs associated with running Lot 9, and shall be charged on a monthly basis. Similarly, should the electricity generated by communal facilities (i.e. wind turbine) on lot 9 exceed the electricity consumption on lot 9, each lot owner shall be entitled to 1/8th of the proceeds from any sale.

Electricity generated by the communal facilities and used by lot owners shall be charged to the lot owner at the same rate as that charged by the energy supply retailer supplying the site, on a monthly basis. It shall be calculated by meter measurements from both the individual lots, and the main grid meter. The proceeds of such sales shall be added to the funds of the Totarabank residents' society. Each calendar month the readings from each meter shall be recorded and tallied against the main grid connection meter. The organization of meter readings shall be decided by the Association.

Electrical Efficiency

All Developed Properties at Totara Bank Development shall be limited to a maximum current of 30 amperes by way of a 30A circuit breaker/trip. All developed Properties shall have no more than one such meter board/circuit breaker connection to the electrical reticulation. A practical consequence of this requirement is that a combination of electric water heating and electric cooker is unlikely to be tenable.

Solar/renewable energy water heating

Every building on the Developed Properties shall use a renewable energy source to supply at least 60% of the energy requirement for supply of hot water. It is envisaged that solar water heaters will be used as the dominant method of water heating.

Coppicing Firewood

The coppicing firewood area in lot 9 is intended to be cropped annually from 2008 onwards such that 1/8th of the area is cropped each year, and then allowed to re-grow for the following eight years. The firewood collected from such cropping shall be equally distributed between the owners of lots 1-8. The organisation of firewood shall be decided by the Association.

Building Performance Index (BPI) versus Building floor area

All residential buildings shall conform with the following energy efficiency criteria as measured against the BRANZ software program "ALF3" or subsequent edition. Owners are encouraged to strive for as low a BPI as is practicably achievable.

Floor Area (m^2)	Max B.P.I
100	0.085
125	0.080
150	0.075
175	0.070
200	0.065
225+ over	0.060

Site Layout

Totarabank solar obstruction contours and lot layout (Lamige, 2008) are shown in Figure A1. These were the result of the solar design principles established by Duncan (2005).

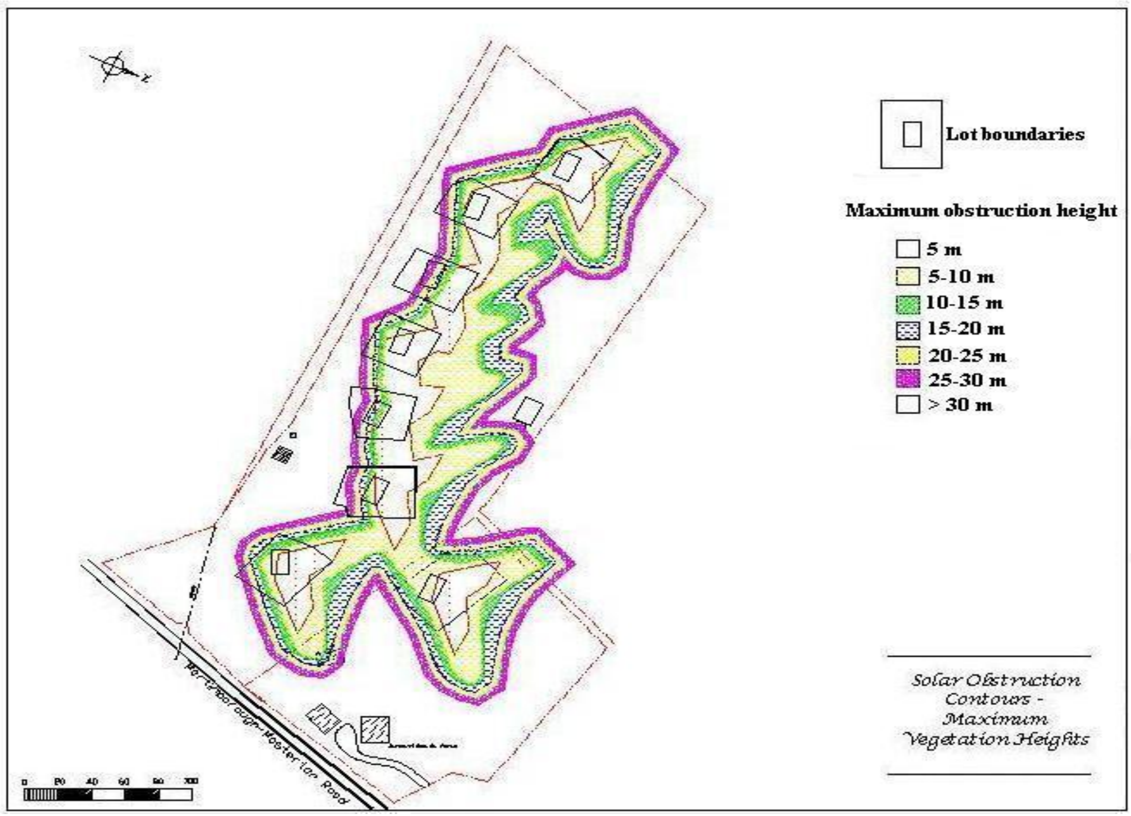


Figure A1: Totarabank Solar Contouring and Lot Layout

A2 NZ Electricity Market History

The significant electricity market reforms from 1993[28] onwards saw vertical market integration dismantled to create a wholesale market to promote competition.

Major events in 1993 included the setting up of a framework for wholesale trading, known as MARIA (Metering and Reconciliation Information Agreement). This is a set of rules governing participants in the trading and contracting of electricity, competition for customers, market surveillance, and reconciliation of information for metering and billing.

Further structural developments removed more monopoly practices, to ensure choice of suppliers for consumers, access to customers by suppliers and lower electricity prices through competition. In 1998, the Electricity Industry Reform Act (EIRA) formalised this, through the separation of integrated retailing, generation, transmission and distribution businesses.

In 2001, a market review following the winter supply shortages assessed how well the market reforms were delivering objectives of cost effectiveness, reliability and environmental sustainability. In 2003, the Electricity Commission of NZ (ECNZ) was formed to regulate and oversee the ability of the industry to meet these objectives. Reviews and regulatory changes have continued since 2001, to address sustainability and security of supply, pricing, energy efficiency, distributed generation, transmission investment and market design.

After considerable consultation, in 2007 the Labour Government released the New Zealand Energy Strategy to 2050 (NZES), and the NZ Energy Efficiency and Conservation Strategy (NZEECS). Following the election of the National-led coalition in 2008, a new Government Policy Statement (GPS) on Electricity Governance was issued in March 2009, preceding a review of the previously issued strategies, in addition to a review of market structure. The outcome of these reviews (by MED) is unlikely to be known until later in 2009.

In May 2009, the Minister of Energy and Resources released the Government's revised GPS. The most recent revisions fall into three broad categories:

- Emphasise the priority the government accords to security of supply policy.
- Express the government's desire to facilitate small grid upgrade investments by streamlining the investment approval process;
- Removing references to the New Zealand Energy Strategy (NZES) and New Zealand Energy Efficiency and Conservation Strategy (NZEECS).

[28] Information sourced from the Electricity Industry section of the MED website: http://www.med.govt.nz/templates/StandardSummary____393.aspx, March 2009.

A3 Sustainability Indicators

Indicators and measures for sustainability relevant to energy and new buildings in a community context are listed here. The following tables are taken from different sources, and the contents summarised in Section 2.2.2 Indicators and Measures.

A3.1 Sustainable Rural Power

The criteria and measures identified to support the investigation of sustainable rural power (Murray, 2005) for each of the sustainability goals are shown in Table A1.

Table A1: Energy Sustainability criteria and measures, (Murray, 2005)

Economic		Environmental		Social		Technical	
Local economy	Cost of Energy (levelised)	Environmental benefits	Carbon emissions	Social Impacts	Workload (to manage a complex system)	RE Industry benefit	Experience gained by RE industry
	Net Present Cost (25yrs)		Grid capacity displacement [1]		System complexity	Peak Load reduction	Morning/Midday/ Evening peak (% of peak load reduction)
	Local investment (capex & O&M)	Wind Impacts	Wind infrastructure	Social benefits	Employment	System availability	RE fraction (% total energy used from the RE supply)
	Net grid purchase (imported electricity)		Turbine Swept area (visual impact)		Skill base		Mean kWh (mean hourly energy delivered by system)
RE Industry	Value of RE equipment (depreciation)				Perceived well-being (security of supply, autonomy, environ. good). [2]		
	Maintenance costs						

[1]: every kW of RE capacity displaced the need for expansion of more fossil fuel capacity as network load increases

[2]: more technologies in the system the greater the perceived well-being

A3.2 National Value Case for Sustainable Housing Innovations

Beacon measures for residential sustainability (Beacon Pathway, 2007):

Table A2: Residential Sustainability (Beacon Pathway)

Economic	Environmental	Social	Technical
• Improved financial position for residents (e.g. reduced direct costs of living; increased long-term value of property)	• Fewer resources being used • More sustainable resources used • Being used more efficiently and • Less pollution from resource use	• More comfortable homes • Better health • Neighbour that is pleasant and safe to live in	• Better productive efficiency (higher output for reduced/same input) • Consumer value of a service equals the cost of the resource used to produce it

A3.3 Development of Renewables Framework for Decision-Making

The research done on behalf of Beacon Pathway Ltd, (Armstrong & Ryan, 2009) developed an analytical framework for decision making to determine which renewable energy options would be best suited to different types of New Zealand homes and neighbourhoods. The framework approach in this report enables the assessment of a range of renewable/low energy options.

A series of criteria to assess renewable technologies has been produced as part of the decision making framework, shown in Figure A2.

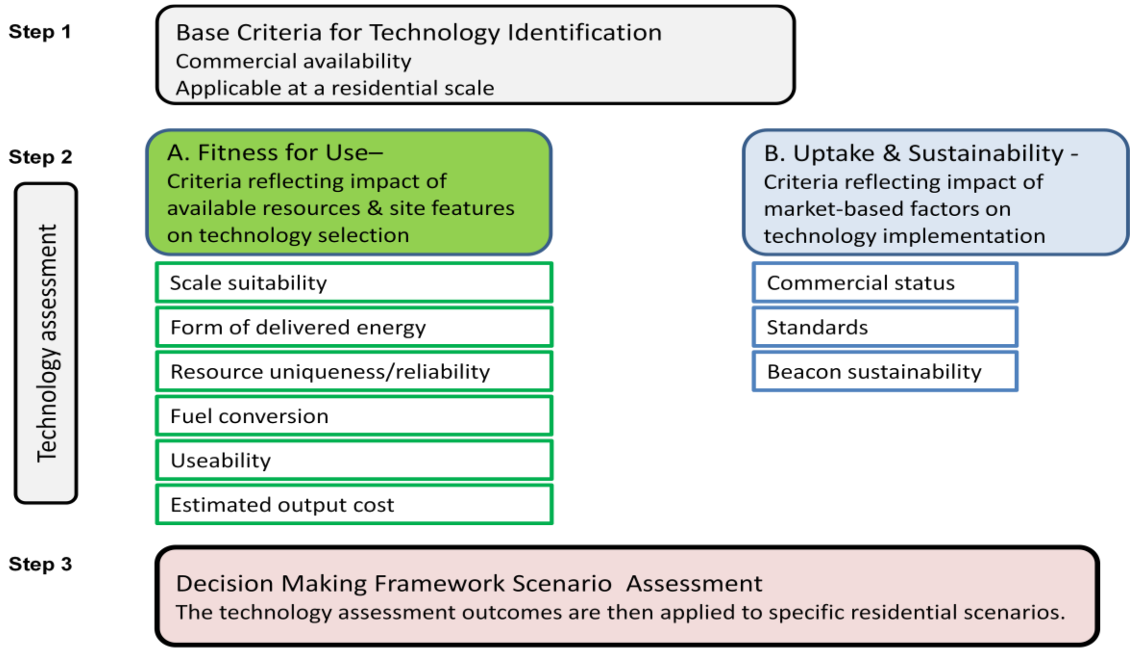


Figure A2: Assessment Criteria - Renewable Energy

The specific criteria from Figure A2 of interest to this study are:

2Aa. Usability – is technology reliable, durable, and convenient to operate (i.e. to deliver energy, is a minimal or active input required by owner?)

2Ab. Estimated output cost (c/kWh) – cost range that delivered energy could fall into by 2020 (<20c/kWh; 20-50c/kWh; >50c/kWh). These cost options are chosen as a comparative reference against current retail electricity prices (i.e. less than, similar, greater than).

Step 2B: Uptake and Sustainability Criteria

2Ba. Commercial Status in NZ

i. Uptake rate - Is this high, low or developing in the NZ residential market?

ii. Development Required to Build Uptake - are further developments required to increase uptake such as technology, capital cost, education, regulation?

iii. Economy of scale - are there opportunities to improve cost to consumers?

2Bb. Standards - do these exist for quality of construction, installation and performance?

2Bc. Beacon sustainability criteria, in Table A3 (compiled from previous reports) that may be negatively impacted by implementing the technology:

Table A3: Beacon Sustainability Criteria

Sustainability Criteria	Description
Technical	Can the technology provide a technical solution to some of the barriers in the New Zealand context?
Economic	Issues from economic aspects of the technology (including pay back and contribution to the asset value of households).
Environmental	Issues from environmental impact of the technology, and any existing LCA information.
Social	Issues concerned with social aspects of the technology.
Cultural	Cultural impact of the technology in the NZ context.
General/Regulatory	Issues of location dependency, territorial authority and regulatory impact (support from NZES and NZEECS). Fit with Beacon's Renewable energy and High Standard of Sustainability (HSS) targets.

A3.4 Statistics New Zealand:

Energy Indicators for Measuring New Zealand's Progress Using a Sustainable Development Approach (2008)

Statistics NZ were developing and reporting on a series of indicators based on sustainable development. Energy was included as a reporting area, as sufficient supplies of energy are essential for meeting needs, supporting the economy, and maintaining people's standard of living - while limiting the impact on the environment. (Statistics NZ, 2008)

According to the Statistics NZ website,

> *" In contrast to the target trends, the proportion of electricity generated from renewable sources has decreased and greenhouse gas emissions from the energy sector have increased. Households are spending a greater proportion of their income on energy in the home. As a nation, New Zealand is more dependent on imported energy in 2007 than it was in 1990."*

Maintaining a focus on this will continue to be important despite fluctuations in Government policy. The set of energy indicators found on the website, are shown below in Table A4:

Table A4: Statistics NZ Energy Indicators

Indicator	Description
Total Primary Energy Supply/Person	Total amount of energy provided for energy transformation (the conversion of energy from one form to another) and use by consumers. An indicator of how efficiently energy is used.
Energy Intensity of the Economy	Compares production in the economy (as measured by real GDP) with total energy demand (as measured by total consumer energy). Measures whether reliance on energy to generate economic growth is increasing or decreasing.
% Electricity Generation from Renewable Resources	Percentage of electricity generated in New Zealand from renewable sources: hydro, geothermal, biogas, wood, and wind.
Household Expenditure on Energy used in the home by Income group	Expenditure on energy in the home includes expenditure on electricity, gas (mains), coal, and firewood; not transport. (Higher pricing means more barriers for low income houses).
Energy Dependency	Extent to which a country relies on imports to meet its energy needs.
Energy-related greenhouse gas emissions	Emissions from transport, energy generation, petroleum refining, gas processing, and solid fuel manufacturing.

Source: http://www.stats.govt.nz/Publications/NationalAccounts/sustainable-development/energy.aspx

A4 Metering

Meter types that may be applicable to a multi-lot development are shown below. TOU meters are commonly used by commercial customers, but the functionality could be available in future to residential connections.

Table A5: Summary of Meter Types

Meter Type	Function	System Size
Standard (kWh meter)	• Standard 'static' meter that registers electricity use in kWh. Two separate kWh meters are wired to measure import and export; or an import-export meter is used that does both. • Meters are manually read on a monthly or bi-monthly cycle. • No facility for logging activity, or for measuring in units less than 1 hour. • Billing shows activity on a monthly aggregated basis	All residential systems
Time-of- Use (TOU)	• Digital meter measuring electricity use in half hour intervals, with data stored for later retrieval. • Half-hour intervals coincide with the wholesale spot market trading intervals, so tariffs can vary accordingly. • Tariffs vary over 24 hours, so billing is done on basis of time-of-use. Customers can adjust demand accordingly. • TOU meters can be owned by customer, who must then reconcile all half-hourly data back to the wholesale market clearing manager. This requires costly back-office systems.	Commercial retail customers only (compulsory for larger systems over 345kVA)
Advanced Metering Systems (AMS)	• Advanced Metering Systems (AMS) or 'smart' meters that can be wired for import-export functions. • A range of capabilities for two-way communication with retailer, direct link to house circuits for ripple control, measuring energy to half-hour intervals and recording energy use. • Read remotely by retailer- data then available hourly to retailer, but monthly to customer (inequitable).	All systems – currently at residential level

Adapted from Distributed Generation Metering Guide, (SEANZ, 2008); www.contactenergy.co.nz; (Beatty, 2008)

A4.1 Benefits of Advanced Metering

The Advanced Metering Policy of 2008 (sourced from Appendix 2 of ECNZ's Advanced Metering Policy, (ECNZ, 2008b)) presents a view of how technology can deliver benefits to all energy stakeholders. These benefits are another way of considering future possibilities for Demand-side management in New Zealand.

(2.1.1) Advanced metering systems by themselves will be of little value unless they give rise to material beneficial changes in the way electricity is generated, delivered, and consumed.

Provided that they are correctly configured and information that can be made available is used, these new systems should assist to:

(a) impact on distribution, transmission and generation of the ability to support financial incentives to alter consumer behaviour via suitable pricing signals;

(b) provide regular and accurate meter readings;

(c) reduce network non technical losses by decreasing the incidence of theft or fraud and vacant premise consumption;

(d) reduce costs to generate and deliver electricity;

(e) improve the reliability of the overall electricity network;

(f) minimise barriers to competition in both generation and retail;

(g) provide increased and relevant information to electricity users to assist in promoting the efficient use of electricity and enable consumers to make their own decisions on cost conservation;

(h) provide a platform for future energy-focused innovation; and

(i) provide an increased accuracy in the settlement process, allowing retailers to optimise their contracted positions against consumer load.

(2.1.2) Specifically, distributors should also benefit from use of AMI by using the systems to:

(a) check on distribution asset loadings (transformers, cables) and shuffle assets into best locations;

(b) reduce network technical losses by providing the ability to reduce peak loads on portions of their networks;

(c) track temperatures of distribution transformers and be warned of life shortening temperatures;

(d) identify points of failure on a network;

(e) check voltage limits (high and low) on a low voltage feeder to ensure it is within compliance limits;

(f) ensure that remote load control signals have been received;

(g) manage and identify issues relating to network losses.

(h) offer capacity limited rates to encourage improvement of load factor on their networks; and

(i) manage capacity limiting of demand, which could also be used in dry years to share electricity consumption within a region.

A5 Energy Efficient Housing Example

The requirements for new housing being constricted at Lochiel Park in South Australia (Bishop, 2008) are an example of specifications that aim to reduce residential energy consumption, and peak loads. Of particular interest are the sizing requirements for heating and cooling loads, the specifications for appliance input loads, and the process for peak load reduction.

The point to consider for NZ developments is the application of the approach to managing specific loads, and the use of house design as the first step to achieving overall efficiency.

Building Energy Efficiency

- 7.5 star AccuRate rating (which sets conditions on house design to achieve this)
- Cross ventilation and vertical stack ventilation
- Increased levels of insulation (R2.5 in the external walls; R3.5 or R4.0 in the ceiling)
- External retractable shading and double glazed windows for some or all windows.
- mandatory ceiling fans to be fitted to promote air flow through the homes.
- Use of plantings for summer shading

Heating Technology -preferred

- High efficiency non-ducted gas fired heating systems;
- Solar-boosted gas fired hydronic radiator and in floor systems;
- Solar combi (hot water and space heater) systems;
- Solar air heating systems;
- 6 Star, non-ducted heat pump systems; and
- Geo exchange loop connected systems.

Other heating systems allowed if they can be shown to have an equivalent or reduced greenhouse gas emissions (NO Gas heaters with rating of under two stars, electric resistive heaters, with a maximum input power exceeding 2.4kW; or solid / liquid fuel heaters of less than 50% thermal efficiency).

All applications should include a heat load calculation for each conditioned space in the home.

Cooling Technology – preferred

- Indirect and direct evaporative coolers (including ducted systems);
- 6 Star heat pump systems (excludes ducted); and Geo exchange loop connected systems.
- Reverse cycle systems with digital scroll technology having an equivalent of 6 Stars or 3.5 EER and a Demand Response Enabling Device.

All plans should include a cooling load calculation for each conditioned space in the home.

The sum of the maximum electrical input power at rated conditions of 35 deg C ambient temperature for all coolers must not exceed the following: Small House: 2.0 kVA; Medium House (110 to 185 m2): 3.0 kVA; Large House (185 m2): 4.0 kVA

Note that kVA is distinct from kW, and depends on the power factor of the system. Some advanced systems have power factor correction.

Lighting

Building design should maximize use of natural light and minimise energy use for lighting.

Rooms and spaces without direct access to daylight through windows should be fitted with tube based skylights or roof lights. If roof lights larger than 250 mm diameter (or equivalent area) are used they should be fitted with double glazing and operable sunshades.

Install only energy efficient lighting in every room and outdoors having a maximum of 30 lumens per watt rating. (Note that low voltage lighting is not necessarily low energy lighting.)

Reducing Peak Load

Purchasers are encouraged to install a load management device aimed at reducing peak load. The device to be supplied to all participating residents by Schneider Electric will provide a range of maximum loads with a corresponding tariff rebate to be paid by ETSA Utilities (South Australia's Electricity network authority). Circuits in the home will be wired to the re-programmable device so that if the agreed maximum load is reached a warning light and tone will indicate that the first circuit is about to be switched off. Generally the first circuit will be the air-conditioner. If the load is still higher than the maximum agreed, a second circuit will be switched off and so on until the load is reduced.

APPENDIX B: CHAPTER 3 SUPPORT MATERIAL

B1 Beacon Monitoring Data Background

Summary taken from the BRANZ monitoring report prepared for Beacon Pathway (French, Heinrich, Jacques, Kane, & Pollard, 2007).

The NOW Home® is a house building approach, or concept, for sustainable houses, designed with the 'average' New Zealander in mind.

Waitakere NOW Home® Construction

- Insulated concrete slab foundation
- Concrete tile roof
- Ceilings and walls are heavily insulated
- Entire building is double glazed.
- Sited to maximise the benefits of passive solar heating, mainly via the polished (no carpets) concrete slab.
- Passive ventilation
- A solar water heater is installed on the roof, and a water tank collects from the roof.
- All light fittings are high-efficiency compact fluorescent types (where possible – for some fittings they are not available)
- The range, fridge, dishwasher and washing machine are new efficient models

Occupancy

Occupied since September 2005 by a family of four (two adults, two children). The two children were of preschool age. A home computing business was established during the tenure.

Conclusions

- The Waitakere NOW Home® in its first year of occupation had an energy consumption (electricity) of 7400 kWh. In the second year consumption had increased to around 8,000 kWh due to occupant behaviour – **data for this report was based on year 2 consumption**. Based on the HEEP data the NOW Home®'s total energy consumption could be said to perform well against new houses in the Auckland region as well as against 4 person households with pre-school age children where the average savings are approximately 33%.

- The Waitakere NOW Home® used 45% less energy than the previous home the NOW Home® occupants rented, with a smaller seasonal variation of energy usage in absolute terms.
- The water heating, refrigeration and lighting electrical end-uses were seen to use a smaller proportion of the total household electricity use (they used 22%, 5% and 6% respectively) than was the case for an average house in HEEP (34%, 15%, and 12%).
- The solar water heating is providing a high proportion of the water heating needs in summer but not in winter (as expected).
- Over 50% of electrical energy could not be assigned to an end-use category (Table A6).
- The large size of the 'unknown' category is of concern and more work was required to examine this. The occupants had a number of computer and entertainment appliances that contributed to this 'unknown' load (in particular the main 'big screen' TV (rear projection), the office computer and the computer server)
- Information on the appliance usage behaviours have not been collected from the Waitakere NOW Home® occupants as the survey information collected from them has been based more around attitudes and experiences, specifically comparing this home with their previous home.
- Despite not having any regular heating, the winter temperatures in the Waitakere NOW Home® are good. The mean winter evening temperature in the Living Room is 19.4°C. The heater was only used for three nights over the winter.
- The occupants found the home extremely comfortable to live in from a thermal performance perspective

Table A6: End Use Summary for Beacon Data

END USE SUMMARIES	NOW home electricity + solar	HEEP 10 electricity
Water heating	22%	34%
Space heating	0%	12%
Lights	6%	12%
Oven	6%	7%
Frig-freeze	5%	15%
Other plug appliances	59%	20%
water pump	2%	
Total	100%	100%

B2 BRANZ Data Request for Raw Demand Data

Table A7 below sets out the detail for the specific data sets requested from BRANZ, sourced from the Beacon Pathway Waitakere NOW Home monitoring program. The request is based on discussions held with Andrew Pollard - BRANZ scientist; Vicki Cowan – Beacon Knowledge Manager; and a confidentially supplied draft Beacon report (NO102).

<u>Please note</u> that only two months (representative of summer and winter) were requested, and no detail for end-use was provided due to BRANZ' extreme reluctance to supply data, and the large expense involved in purchasing a comprehensive year dataset that included end-use. (They alone are responsible for a compromised data set for this project.)

Table A7: Raw Data Request

#	Priority	Data set description	Assumptions
1	1	24 hour total consumption profile (kWh), monthly average for July 2006.	Averaging of each 10min interval for a 24hour period, across every day in the month.
2	1	For data set 1 (July 2006) is it possible to get standard deviation included, or an indication of the highest values in the interval set??	
3	1	Data set for Figure 10 in Report NO102 (mean daily consumption for total electricity use, & the SHW boost element, shown by month for a 12 month period)	Data set is already generated so no supply issues.
4	2	24 hour total consumption profile, monthly average for February 2007	As for July 2006 24 hour profile.
5	3	24 hour total consumption profile, monthly average for July 2007.	As for July 2006 24 hour profile.

BRANZ NOTES

The solar water heater boost data presented in Figure 10 (and requested in item 3) is an approximation (filtered) as noted in Section 2.6 of the NO102 report.

The data extracted will be the total occupant electricity which will be taken as the measured total for the house less the measured (or estimated) electrical energy use by the Waitakere NOW Home® monitoring equipment.

For the daily values dataset, the measured or estimated electrical boost energy will also be provided.

The daily profiles will be constructed by calculating a mean value for the data points and is expressed in Watts. The daily values are constructed from summing up the contributing data points and are expressed as kWh.

B3 Seasonal Data Adjustment

The adjustment ratios and seasonal data examples for low, medium and high demand profiles, are shown in Figure A3.

Seasonal Data Example

Medium & High Scenarios — All electric load, so more seasonal variation

Season Ratios		Adjustment	Basis
Summer	Dec, Jan, Feb	none	Feb
Autumn	Mar,Apr,May	43%	from Feb
Winter	June,July,Aug	none	July
Spring	Sep,Oct,Nov	59%	from Feb
Hours adjusted	6 to 23 (18hrs)		

Low Scenarios

Less variation- no reliance on electricity for thermal loads
Use Feb data for spring summer autumn
Use July data for winter

SINGLE HOUSE

	Summer	kWh		Autumn	kWh		Winter	kWh		Spring	kWh	
Hour	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
1	0.14	0.42	0.42	0.14	0.42	0.42	0.14	0.54	0.54	0.14	0.42	0.42
2	0.14	0.42	0.42	0.14	0.42	0.42	0.14	0.69	0.69	0.14	0.42	0.42
3	0.14	0.46	0.46	0.14	0.46	0.46	0.14	0.65	0.65	0.14	0.46	0.46
4	0.14	0.46	0.46	0.14	0.46	0.46	0.14	0.57	0.57	0.14	0.46	0.46
5	0.14	0.54	0.54	0.14	0.54	0.54	0.14	0.58	0.58	0.14	0.54	0.54
6	0.14	0.72	0.72	0.14	1.03	1.03	0.14	1.07	1.07	0.14	1.15	1.15
7	0.57	0.83	0.83	0.57	1.18	1.18	0.57	2.34	2.34	0.57	1.32	1.32
8	0.49	0.70	0.70	0.49	1.00	1.00	0.57	2.58	4.21	0.49	1.12	1.12
9	0.20	0.59	0.59	0.20	0.84	0.84	0.28	2.33	3.96	0.20	0.93	0.93
10	0.14	0.56	0.56	0.14	0.79	0.79	0.14	2.64	2.64	0.14	0.88	0.88
11	0.14	0.58	0.58	0.14	0.82	0.82	0.14	1.80	1.80	0.14	0.92	0.92
12	0.14	0.56	0.56	0.14	0.79	0.79	0.14	1.31	1.31	0.14	0.88	0.88
13	0.14	0.51	0.51	0.14	0.72	0.72	0.53	1.07	1.07	0.14	0.80	0.80
14	0.14	0.49	0.49	0.14	0.70	0.70	0.53	0.74	0.74	0.14	0.78	0.78
15	0.14	0.50	2.10	0.14	0.71	2.99	0.53	0.80	0.80	0.14	0.79	3.33
16	0.14	0.61	2.21	0.14	0.87	3.16	0.53	0.76	0.76	0.14	0.97	3.51
17	0.14	0.98	2.58	0.14	1.40	3.68	0.69	1.28	1.28	0.14	1.55	4.09
18	0.35	0.72	2.32	0.35	1.02	3.31	0.70	2.08	3.71	0.35	1.14	3.68
19	0.57	0.79	2.39	0.57	1.12	3.41	0.73	1.71	3.34	0.57	1.25	3.79
20	0.87	0.83	2.43	0.87	1.19	3.47	0.87	1.57	3.21	0.87	1.32	3.86
21	0.87	0.89	2.49	0.87	1.27	3.55	0.87	1.59	3.22	0.87	1.41	3.95
22	1.85	0.75	2.35	1.85	1.07	3.35	1.85	1.56	3.19	1.85	1.19	3.73
23	0.85	0.56	2.16	0.85	0.80	3.09	0.85	1.20	2.84	0.85	0.89	3.43
24	0.48	0.43	0.43	0.48	0.43	0.43	0.48	0.88	0.88	0.48	0.43	0.43
Daily Tot	**9.0**	**14.9**	**29.3**	**9.0**	**20.1**	**40.6**	**11.8**	**32.3**	**45.4**	**9.0**	**22.0**	**44.9**

Figure A3: Seasonal Data Adjustment Example

These base profiles were then aggregated within the Decision Model according to the selections made for developing a Community profile.

The months making up each season were aggregated as inputs for the site Energy Balance.

B4 Energy Management Inputs

B4.1 Retail Costs and Tariffs

- Five retailers were identified as available in the Wairarapa region and their residential tariffs were sourced. Retailers were Contact, Meridian, Empower, Genesis, Energy Online.
- Only Meridian and Contact (Empower) had specific tariffs for exports. The remainder were paying wholesale spot rates for any exported surplus.
    - Meridian offered a 1: 1 tariff up to a net zero on an annual bill basis (although this was very difficult to verify)
    - Contact was offering 17.285 c/kWh, although this was under review during 2009.
    - Genesis was paying wholesale rates – for this reason, whole prices were kept as a manual input for the Decision Model, so they could be elevated as part of exploring the net Feed-in tariff scenario.

Other Charges

DG system installations attract additional charges according to system size. These costs were sourced from MED Regulation Fee Schedules (MED, 2007a), and Powerco DG policy (Powerco , 2008a). The cost summary is shown below in Figure A4:

	<10kW	>10kW
Customer Network Losses		
Network Connection	200	500
Retailer DG Admin fee	100	100
Application Fee (PowerCo)	0	500
Testing & inspection	60	120
Electrician certification		
Total Other Charges	**360**	**1220**

Figure A4: Other Charge Cost Summary

B4.2 Financial Inputs

These are subject to market conditions at the time the model is being used. Default data values were subsequently set to enable financial sensitivity and scenario analysis.

- Payback time (years) was used to create an annual capital charge for the purposes of generating an internal Renewable Energy price.

- A capital adjustment factor was included to adjust capital costs up or down for sensitivity purposes, and to allow for any major price shifts in the market.
- Cost of Capital rates used reflected Bank mortgage rates at the time.
- Forecast price increases:
    - Standard price increases were used to examine the effect of year on year increases for the standard import tariffs. These have been significant.
    - Export tariff price adjustments were included to test sensitivity to long term reduction of export tariffs (over time they will approach the whole sale rate).

B4.3 System Capital Cost Summary

System Cost Summary						
PV	Units	**1.2**	**1.7**	**2.6**	**3.6**	**5**
	Cost $	16700	24296	30900	44,800	57800
Wind	Units	**Skys3.7**	**P2.5**	**P6**	**P15**	
	Cost $	18367	30000	40000	130000	
		community				
Network Management	Unit	Estimates	house	Use level		
SMA Islanding Inverter		4,000				
Metering/monitoring/collect	UTL, Pulse or AMS or ?	5,000				
Misc items (PC or wireless system)		3,000	800			
kWh meters 2 per house	Q1mR @ $120 ea	1200	240	10		
	Network TOTAL	**13,200**				
Installation % equip cost	**15%**					
(site prep, harware, labour, legal etc)						
TOTAL CAPITAL COST	**Chosen PV/Wind system*#systems+Network Total+Installation*system cost**					

Figure A5: System Cost Summary

Cost Summary

- Based on the PV system size categories established for the Solar supply inputs.
- A range of costs were sourced from five supplier websites and brochures; grouped according to the size categories then averaged to derive a $/Watt.
- Costs included inverters, panels, clamps & cabling, voltage regulators, power point trackers, and display units
- Turbine costs were sourced and averaged from four supplier websites, then compared with direct quotes provided by the Developer. The most recent costs were used.
- Costs included tower kits and turbines (with associated cabling and accessories)
- The installation cost was set at 15%. This was based on the work of Sigot (2008) who surveyed a range of installation costs for solar and wind systems.

B5 Demand Data Benchmarking- HEEP

A summary of the data request, and an overview of the data received is detailed here. It must be noted that the process for obtaining a dataset from the HEEP database is extremely complex, time consuming and expensive, making it difficult to achieve the best result for research purposes, or to seek assistance.

B5.1 Request for HEEP Monitoring Data V3

The table below sets out the detail for the specific data sets requested from BRANZ, sourced from the HEEP database. The request is based on email discussions held with various BRANZ staff as well as reference to HEEP reports and the BRANZ website.

Background to the Request

The data sets used to date are based on 10 min data averaged to provide a 24hrs profile for summer and winter (i.e 30 days data averaged to give an average representation of 24hrs for that month). I have also constructed a set from the ground up similar to what is done for designing stand-alone systems, using appliance power/use per hour by end-use application (cooking, heating etc).

A HEEP analysis would provide a comparative set of data that represents 'standard' houses in the lower east North Island. (There are no other known data sets for energy efficient houses in this region.)

Suggested Data Groups

Region:

Lower North Island - as representative of Wairarapa region. If the cost increases with the number of locations, this list is shown in order of priority:

Code	Location		#
First Priority locations(Lower East NI)			
X	Wellington	Wellington	38
kt	Tamatea North	Napier	10
kw	Wairoa	Wairoa	10
kc	Waikanae	Kapiti Coast	10

Demographics: Households as Family of 4 (minimum)

Fuels: Electricity, followed by All Fuels

Heating: With/without Woodburners

House Age: Post 1978 (mandatory insulation)

Group 1: Lower East NI,

Group 2: Lower East NI, houses post 1978

If there are better groupings please recommend them.

Data Set Analysis Options

If hourly profiles (Time of Use) are not possible, what is the next best option? Average energy use by month would still be helpful.

#	Priority	**Request**	**Assumptions**
1	1	24 hour total consumption profile (kWh), monthly average for a February (summer) & July (winter). *Do I need to select a year or is it done across the HEEP monitor period?*	It is possible to average data for a 24hour period, across every day in the month.
2		As for # 1 , but for April & October (this is to get a representative month for spring & autumn)	As above

Questions of Interest

How does the seasonal consumption profile change for occupants in houses situated in the lower east North Island? *I am mainly interested in deviations from my data sets.*

Note: It was hoped to extract information on energy end-use, particularly in houses post 1996 but this was too expensive.

Delivered Data

Locations: All 4 locations were included, total of 69 houses

End Uses: 49 had electric hot water; 17 had gas hot water; 34 used solid fuel

Datasets: Total Electricity, All Fuels (electricity, gas, LPG, solid fuel), Solid Fuel burners, Hot water usage by electricity including solar boost; and by all fuels excluding wetbacks

B5.2 Benchmarking Comparison Graphs

The graphs below (Figure A6) the show the seasonal comparisons between low, medium and high demand profiles. The largest differences are for the shoulder seasons – the high demand profile created for this project had extra electricity load added in for autumn cooling, and spring heating or cooling.

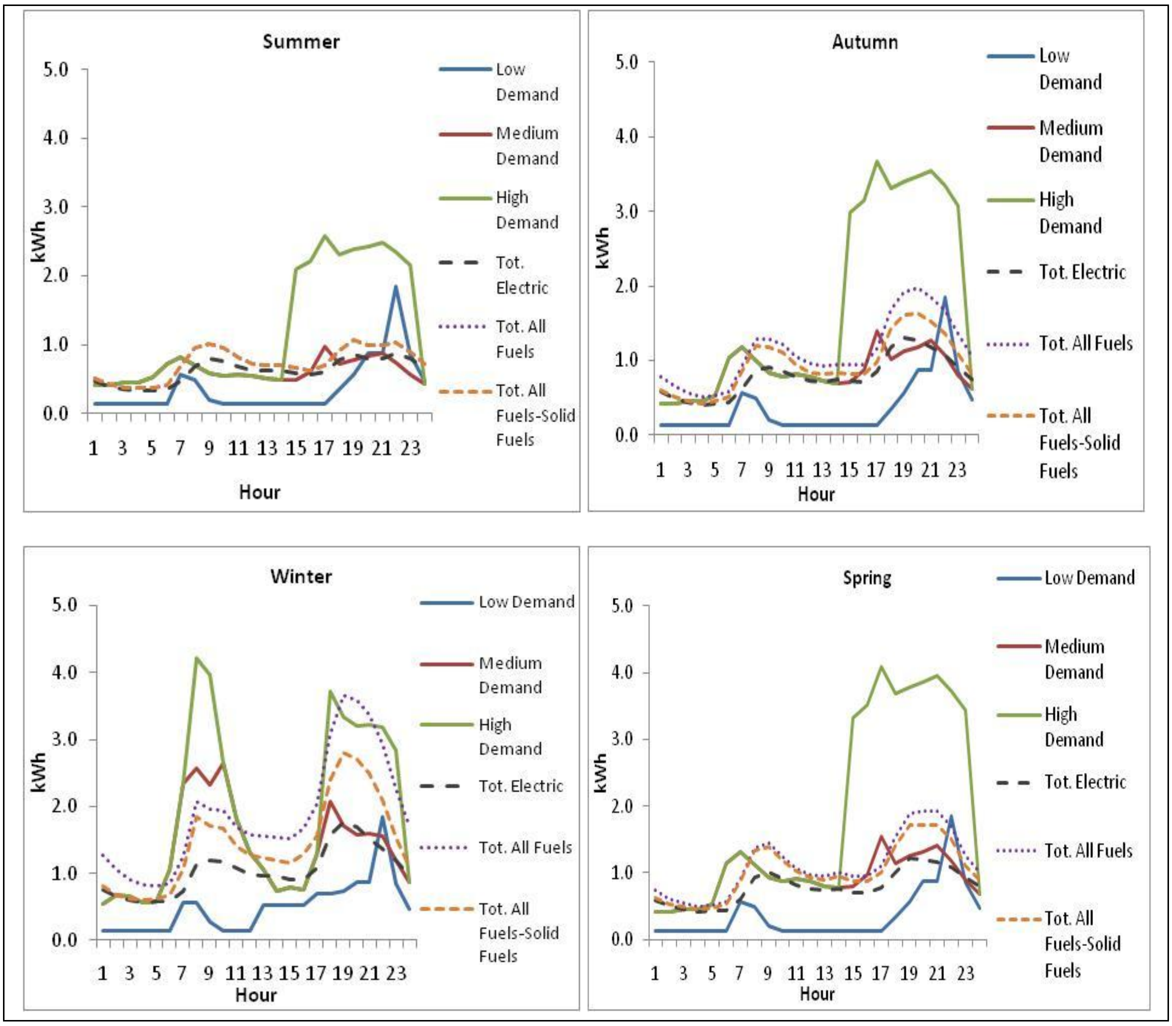
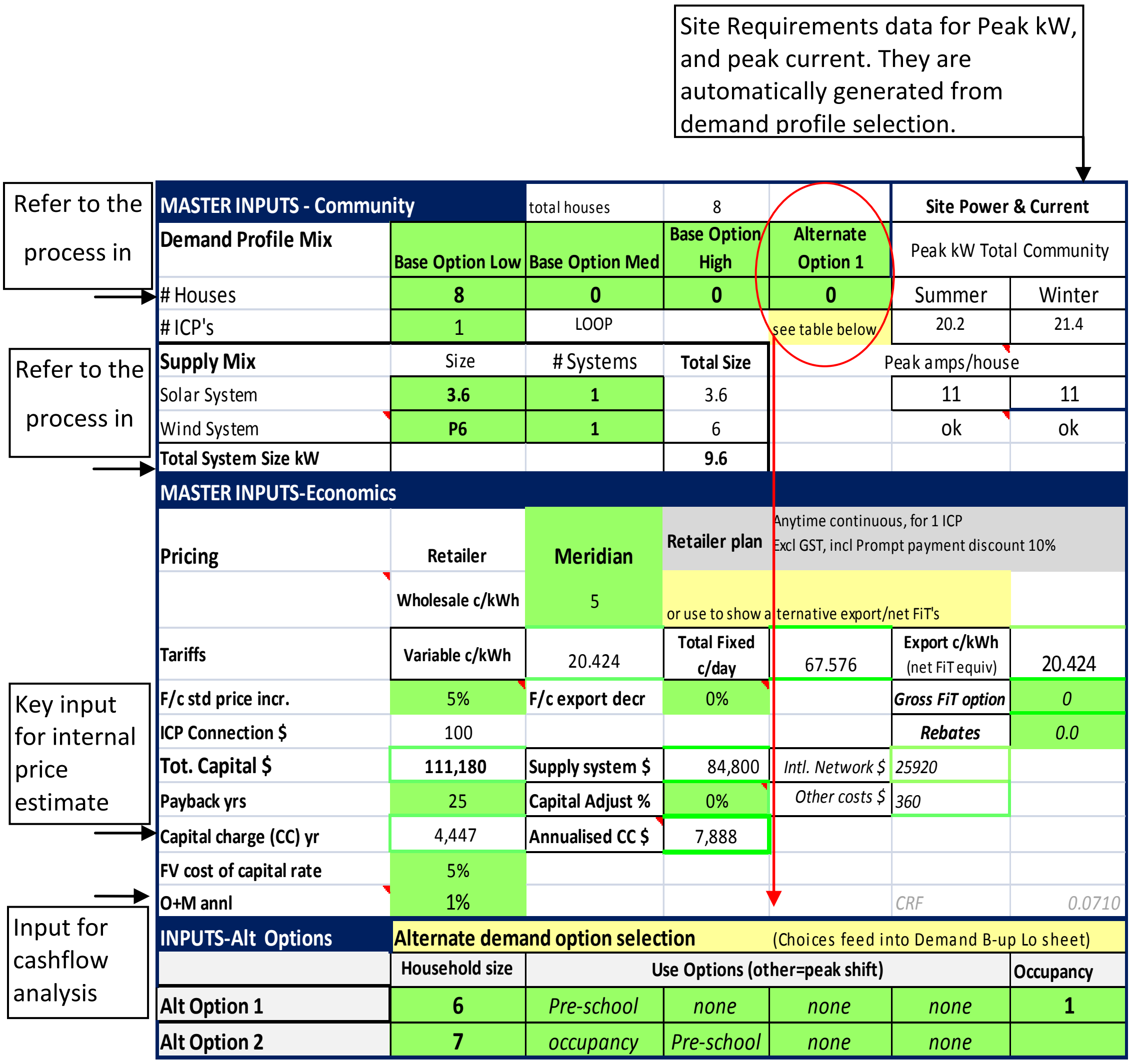


Figure A6: Seasonal Benchmarking against HEEP Lower North Island dataset

APPENDIX C: CHAPTER 4 SUPPORT MATERIAL

C1 Decision Model - Input Section

Below is an example of the Section of the Model where the user manually inputs the data required to initiate energy balance and economic analysis. The green cells represent manual inputs and selections from drop down lists. The white cells are automatically generated as a result of the data in the green cells. This input interface drives all the decision model outputs described in Section 4.2 Process Detail.



MASTER INPUTS - Community		total houses	8		**Site Power & Current**	
Demand Profile Mix	**Base Option Low**	**Base Option Med**	**Base Option High**	**Alternate Option 1**	Peak kW Total Community	
# Houses	**8**	**0**	**0**	**0**	Summer	Winter
# ICP's	1	LOOP		see table below	20.2	21.4
Supply Mix	Size	# Systems	**Total Size**		Peak amps/house	
Solar System	**3.6**	**1**	3.6		11	11
Wind System	**P6**	**1**	6		ok	ok
Total System Size kW			**9.6**			
MASTER INPUTS-Economics						
Pricing	**Retailer**	**Meridian**	**Retailer plan**	Anytime continuous, for 1 ICP Excl GST, incl Prompt payment discount 10%		
	Wholesale c/kWh	5	or use to show alternative export/net FiT's			
Tariffs	**Variable c/kWh**	20.424	**Total Fixed c/day**	67.576	**Export c/kWh** (net FiT equiv)	20.424
F/c std price incr.	5%	**F/c export decr**	0%		***Gross FiT option***	*0*
ICP Connection $	100				***Rebates***	*0.0*
Tot. Capital $	**111,180**	**Supply system $**	84,800	*Intl. Network $*	*25920*	
Payback yrs	25	**Capital Adjust %**	0%	*Other costs $*	*360*	
Capital charge (CC) yr	4,447	**Annualised CC $**	7,888			
FV cost of capital rate	5%					
O+M annl	1%				*CRF*	*0.0710*
INPUTS-Alt Options	**Alternate demand option selection**			(Choices feed into Demand B-up Lo sheet)		
	Household size	**Use Options (other=peak shift)**				**Occupancy**
Alt Option 1	**6**	*Pre-school*	*none*	*none*	*none*	**1**
Alt Option 2	**7**	*occupancy*	*Pre-school*	*none*	*none*	

Figure A7: Input Interface Example

<u>Total Capital Cost</u>: Sum of Supply system + Internal network+ installation + other costs

<u>Capital Charge</u>: (Total Capital Cost)/ payback years

Details on the Economic inputs are also found in B4 Energy Management Inputs.

C2 Community Demand Example

The example data below (Figure A8) is taken from the sheet aggregating the demand input data to create the community demand profile. The “# Houses” comes from the manual input section of the spreadsheet. When a number is entered, data is automatically extracted from the appropriate demand dataset, multiplied up and aggregated along with any other house scenarios that have a selection against them.

This is repeated by season, and the seasonal outputs summarised in the “Community Seasonal Demand” columns.

These columns are the inputs to the energy balance calculator in the Model interface sheet

SUMMER BASIS						***Community: Seasonal Demand***			
House Scenario	**Base Option Low**	**Base Option Med**	**Base Option High**	**Alternate Option 1**	Community Total	Summer Month	Autumn Month	Winter Month	Spring Month
# Houses	**0**	**8**	**0**	**0**	8	summer basis	summer basis	winter basis	summer basis
Household Size	*4*	*4*	*4*	*4*	SUMMER	no change	0600-2300	no change	0600-2300
Peak Power kW	*0*	*8.0*	*0.0*	*0*	**8.0**				
Hour									
1	0.00	3.37	0.00	0.00	**3.37**	3.37	3.37	4.33	3.37
2	0.00	3.34	0.00	0.00	**3.34**	3.34	3.34	5.50	3.34
3	0.00	3.64	0.00	0.00	**3.64**	3.64	3.64	5.24	3.64
4	0.00	3.68	0.00	0.00	**3.68**	3.68	3.68	4.57	3.68
5	0.00	4.30	0.00	0.00	**4.30**	4.30	4.30	4.63	4.30
6	0.00	5.79	0.00	0.00	**5.79**	5.79	8.27	8.56	9.19
7	0.00	6.64	0.00	0.00	**6.64**	6.64	9.47	18.75	10.53
8	0.00	5.62	0.00	0.00	**5.62**	5.62	8.03	20.60	8.92
9	0.00	4.69	0.00	0.00	**4.69**	4.69	6.69	18.65	7.44
10	0.00	4.45	0.00	0.00	**4.45**	4.45	6.35	21.14	7.06
11	0.00	4.62	0.00	0.00	**4.62**	4.62	6.60	14.39	7.34
12	0.00	4.44	0.00	0.00	**4.44**	4.44	6.34	10.47	7.05
13	0.00	4.05	0.00	0.00	**4.05**	4.05	5.78	8.55	6.43
14	0.00	3.92	0.00	0.00	**3.92**	3.92	5.60	5.92	6.23
15	0.00	3.98	0.00	0.00	**3.98**	3.98	5.68	6.37	6.32
16	0.00	4.88	0.00	0.00	**4.88**	4.88	6.97	6.07	7.75
17	0.00	7.83	0.00	0.00	**7.83**	7.83	11.17	10.27	12.42
18	0.00	5.74	0.00	0.00	**5.74**	5.74	8.19	16.64	9.11
19	0.00	6.29	0.00	0.00	**6.29**	6.29	8.98	13.68	9.98
20	0.00	6.66	0.00	0.00	**6.66**	6.66	9.51	12.59	10.57
21	0.00	7.10	0.00	0.00	**7.10**	7.10	10.14	12.71	11.27
22	0.00	5.99	0.00	0.00	**5.99**	5.99	8.55	12.45	9.51
23	0.00	4.50	0.00	0.00	**4.50**	4.50	6.42	9.62	7.14
24	0.00	3.47	0.00	0.00	**3.47**	3.47	4.95	7.02	5.51
						119.01	162.03	258.74	178.09
Tot	0.0	119.0	0.0	0.0	119.0	357.02	486.08	776.22	534.28

Figure A8: Aggregating Community Demand

C3 Electrical Energy Balance and Meter log

Figure A9 shows an energy balance data log example for January, and July; with the corresponding import /export meter log for the same months in Figure A10.

COMMUNITY ENERGY BALANCE BY MONTH

Month	JANUARY			JULY		
Hour	**SUPPLY**	DEMAND	**BALANCE**	**SUPPLY**	DEMAND	**BALANCE**
1	0.09	3.37	-3.28	0.07	4.33	-4.27
2	0.08	3.34	-3.26	0.06	5.50	-5.44
3	0.08	3.64	-3.57	0.12	5.24	-5.12
4	0.08	3.68	-3.60	0.17	4.57	-4.40
5	0.07	4.30	-4.23	0.11	4.63	-4.53
6	0.07	5.79	-5.73	0.16	8.56	-8.41
7	0.35	6.64	-6.29	0.18	18.75	-18.57
8	2.09	5.62	-3.54	0.15	20.60	-20.46
9	4.38	4.69	-0.31	0.12	18.65	-18.54
10	6.46	4.45	2.01	0.60	21.14	-20.54
11	8.61	4.62	3.99	1.89	14.39	-12.50
12	9.98	4.44	5.54	3.20	10.47	-7.27
13	11.11	4.05	7.06	3.87	8.55	-4.68
14	11.27	3.92	7.35	3.75	5.92	-2.17
15	10.83	3.98	6.85	3.40	6.37	-2.97
16	9.52	4.88	4.64	2.86	6.07	-3.21
17	8.36	7.83	0.53	2.00	10.27	-8.27
18	6.50	5.74	0.76	0.64	16.64	-16.00
19	4.52	6.29	-1.77	0.06	13.68	-13.62
20	2.49	6.66	-4.17	0.11	12.59	-12.48
21	0.60	7.10	-6.51	0.10	12.71	-12.62
22	0.22	5.99	-5.77	0.09	12.45	-12.36
23	0.07	4.50	-4.42	0.09	9.62	-9.53
24	0.06	3.47	-3.41	0.08	7.02	-6.95
Total	**97.9**	**119.0**	**-21.1**	**23.9**	**258.7**	**-234.9**
Hourly averages	4.1	5.0	21.1	1.0	10.8	

Figure A9: Energy Balance Log example

EXPORT & IMPORT METER LOG BY MONTH

	January		**July**	
Hour	**EXPORT**	IMPORT	**EXPORT**	IMPORT
1	0	-3.28	0	-4.27
2	0	-3.26	0	-5.44
3	0	-3.57	0	-5.12
4	0	-3.60	0.00	-4.40
5	0	-4.23	0.00	-4.53
6	0	-5.73	0.00	-8.41
7	0	-6.29	0	-18.57
8	0	-3.54	0	-20.46
9	0.00	-0.31	0.00	-18.54
10	2.01	0.00	0.00	-20.54
11	3.99	0.00	0.00	-12.50
12	5.54	0.00	0.00	-7.27
13	7.06	0.00	0.00	-4.68
14	7.35	0.00	0.00	-2.17
15	6.85	0.00	0.00	-2.97
16	4.64	0.00	0.00	-3.21
17	0.53	0.00	0.00	-8.27
18	0.76	0.00	0.00	-16.00
19	0.00	-1.77	0	-13.62
20	0	-4.17	0	-12.48
21	0	-6.51	0	-12.62
22	0	-5.77	0	-12.36
23	0	-4.42	0	-9.53
24	0	-3.41	0	-6.95
Total	**38.7**	**-59.8**	**0.0**	**-234.9**
CHECK Import+export vs Balance	-21.1	-21.1	-234.9	-234.9

Figure A10: Meter log example

C3.1 Summary Outputs for Monthly Energy Balance

Figure A11 shows the Energy Balance site summary demonstrating the progression from daily to monthly outputs, over the whole year. The monthly and total year data cells are inputs for the economic analysis sections of the Model. This output summary also demonstrates the range of data generated by the Model.

SUMMARY -OUTPUTS	MONTHLY												
ENERGY BALANCE	31	28	31	30	31	30	31	31	30	31	30	31	
	January	February	March	April	May	June	July	August	September	October	November	December	Total Yr
Avg Daily Load (kWh)	119.0	119.0	162.0	162.0	162.0	258.7	258.7	258.7	178.1	178.1	178.1	119.0	
Avg Daily Supply (kWh)	97.9	77.8	67.7	43.6	35.2	26.7	23.9	41.3	52.5	79.0	95.0	77.5	59.8
Supply ratio S/L %	82%	65%	42%	27%	22%	10%	9%	16%	30%	44%	53%	65%	33%
Avg hourly load (kWh)	4.96	4.96	6.75	6.75	6.75	10.78	10.78	10.78	7.42	7.42	7.42	4.96	
Avg hourly supply (kWh)	4.08	3.24	2.82	1.82	1.46	1.11	0.99	1.72	2.19	3.29	3.96	3.23	
Meter daily export (kWh)	38.7	25.8	11.3	1.5	0.0	0.0	0.0	0.2	2.4	10.0	20.2	22.8	
Meter daily Import (kWh)	59.8	66.9	105.6	120.0	126.9	232.0	234.9	217.6	128.0	109.1	103.3	64.3	
RE contribution to load %	50%	44%	35%	26%	22%	10%	9%	16%	28%	39%	42%	46%	27%
24hr Energy Balance (kWh)	-21.1	-41.2	-94.31	-118.46	-126.87	-232.00	-234.88	-217.45	-125.55	-99.07	-83.13	-41.52	
Total Month Export kWh	1200.5	721.2	349.3	45.2	0.0	0.0	0.0	5.6	73.0	309.4	606.0	706.4	4017
Total Month Import kWh	1855.2	1873.9	3273.0	3599.0	3933.0	6959.9	7281.2	6746.6	3839.6	3381.2	3099.7	1993.6	47836
Total Month Balance kWh **pos:>** supply,neg:>load	**-655**	**-1153**	**-2924**	**-3554**	**-3933**	**-6960**	**-7281**	**-6741**	**-3767**	**-3071**	**-2494**	**-1287**	**-43819**
Total Month Std load kWh	3689	3332	5023	4861	5023	7762	8021	8021	5343	5521	5343	3689	**65628**
Total month supply kWh	3034	2180	2099	1307	1090	802	740	1280	1576	2450	2849	2402	**21809**
Total Offset Load kWh	*1834*	*1458*	*1750*	*1262*	*1090*	*802*	*740*	*1274*	*1503*	*2140*	*2243*	*1696*	**17792**
Supply Utilisation	60%	67%	83%	97%	100%	100%	100%	100%	95%	87%	79%	71%	**82%**
export %	40%	33%	17%	3%	0%	0%	0%	0%	5%	13%	21%	29%	**18%**
Load Factors	0.62	**SUMMER**	0.49	**WINTER**									

Figure A11: Energy Balance Outputs by Day and Month

C4 Economic Analysis

Figure A12 shows the monthly, annual and long term (10 years only for illustrative purposes) economic analysis outputs from the Decision Model.

ECONOMIC ANALYSIS	BY YEAR	export tariff reduction starts at 'D18' per year, in shaded year, based on current NZ market trend to reduce export taraiffs over time.									
		Gross FiT, as an alternative scenario, increase at the same rate that the export tariff reduces, to retain an incentive to invest.									
	payback year	1	2	3	4	5	6	7	8	9	10
export tar to DECR from year x	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
export tariff	20.424	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42
Gross FiT	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fixed Tariff	67.58	70.95	74.50	78.23	82.14	86.25	90.56	95.09	99.84	104.83	110.07
Variable tariff	20.42	21.45	22.52	23.64	24.83	26.07	27.37	28.74	30.18	31.68	33.27
Std Fixed cost	247	259	272	286	300	315	331	347	364	383	402
Std Variable cost	5,804	6,094	6,399	6,719	7,055	7,407	7,778	8,167	8,575	9,004	9,454
Total Std F+V	6,050	6,353	6,671	7,004	7,354	7,722	8,108	8,514	8,939	9,386	9,856
RE var I-Emth cost	3,590	3,810	4,040	4,281	4,535	4,802	5,081	5,375	5,684	6,008	6,348
Total RE I-Emth F+V cost	3,837	4,068	4,312	4,567	4,835	5,116	5,412	5,722	6,048	6,390	6,749
Value Offset Load	*1,419*	*1,490*	*1,565*	*1,643*	*1,725*	*1,812*	*1,902*	*1,997*	*2,097*	*2,202*	*2,312*
Value Export	*794*	*794*	*794*	*794*	*794*	*794*	*794*	*794*	*794*	*794*	*794*
***Cost** Import*	*4,385*	*4,604*	*4,834*	*5,076*	*5,329*	*5,596*	*5,876*	*6,170*	*6,478*	*6,802*	*7,142*
Capital Charge, FV	4,447	4,670	4,903	5,148	5,406	5,676	5,960	6,258	6,571	6,899	7,244
Std delivered price	0.21	0.22	0.23	0.25	0.26	0.27	0.29	0.30	0.31	0.33	0.35
TB RE price, tot RE I-Emth	0.29	0.31	0.32	0.34	0.36	0.38	0.40	0.42	0.44	0.47	0.49
TB RE price, capchg/supply	*0.41*	*0.43*	*0.45*	*0.47*	*0.50*	*0.52*	*0.55*	*0.58*	*0.61*	*0.64*	*0.67*
Gross FiT Total	*247*	*259*	*272*	*286*	*300*	*315*	*331*	*347*	*364*	*383*	*402*
TB Gross FiT price	*0.17*	*0.17*	*0.18*	*0.19*	*0.20*	*0.21*	*0.22*	*0.23*	*0.24*	*0.26*	*0.27*
ECONOMIC ANALYSIS	CASHFLOW ANALYSIS										
revenue: offset+rebate	2213.68	2284.64	2359.16	2437.40	2519.56	2605.82	2696.40	2791.50	2891.36	2996.21	3106.31
revenue: offset+incomeGross FiT	1666.02	1749.32	1836.79	1928.63	2025.06	2126.31	2232.63	2344.26	2461.47	2584.54	2713.77
Investment $,Tot Capital RE	-111180.00										
Investment $,Tot Capital non R	-100.00										
Annual expenses - O+M	-848.00	-890.40	-934.92	-981.67	-1030.75	-1082.29	-1136.40	-1193.22	-1252.88	-1315.53	-1381.30
Variable Import costs, RE	-4385	-4604	-4834	-5076	-5329	-5596	-5876	-6170	-6478	-6802	-7142
Fixed costs	-246.65	-258.99	-271.93	-285.53	-299.81	-314.80	-330.54	-347.06	-364.42	-382.64	-401.77
Total RE net	-114446	-3469	-3682	-3905	-4140	-4387	-4646	-4918	-5204	-5504	-5819
Total Gross FiT	-114993	-4004	-4204	-4414	-4635	-4867	-5110	-5366	-5634	-5916	-6211
Total non RE standard	*-6150*	*-6353*	*-6671*	*-7004*	*-7354*	*-7722*	*-8108*	*-8514*	*-8939*	*-9386*	*-9856*
NPV RE											-$141,820
NPV Gross FiT net											-$82,353
NPC non RE											*-$63,481*
FINAL NPV RE										*site*	***-$78,339***
										house	-$9,792

Figure A12: Economic Output Example, for 10 years only

C4.1 Economic Analysis: Key Criteria Description

There are two economic criteria used to assess economic performance in this project, for which further explanation is provided:

RE Alternative price \$/kWh - is the relative price of an alternative energy system (in this case the internal Totarabank system), compared to standard tariffs. In determining price for a partial substitution of energy from grid purchase, it is necessary to determine the residual energy purchase costs as well as the cost of the capital equipment and any associated operating costs for the alternative technology.

$$\text{RE alternative} = \frac{\text{Capital charge} - (\text{Fixed costs} + \text{Variable import costs} - \text{export value})}{\text{Total demand}}$$

RE Alternative price long term - Building in inflationary increases and interest rates causes the RE price curves to increase over time. RE price curve convergence between grid (delivered) and on-site electricity is influenced by the relative size of these factors – for example if electricity price increases make a greater contribution than the interest rate on capital, economic attractiveness of on-site electricity improves and the RE alternative price curve will converge sooner with standard grid supply. Conversely if financing the investment occurs at a higher rate than energy price rises, on-site renewable attractiveness reduces.

NPV site – is the net benefit of having a renewable energy system versus the standard cost of electricity without it. The NPV calculation for this project is constructed as:

$\text{NPV site} = \text{NPV}_{\text{RE system}} - \text{NPC}_{\text{standard electricity}}$

For selected years and discount rate,

$\text{NPV}_{\text{RE system}}$ = (Value of offset + export) – (Total capital costs + fixed costs + variable import costs + annual O&M)

$\text{NPC}_{\text{standard electricity}}$ = ICP connection costs + fixed costs+ variable electricity costs

The effect of assessing the net benefits over standard electricity supply is to acknowledge the significant costs of electricity over a long term period that customers pay without consideration. If standard grid-supplied electricity prices increase over time, this has the effect of improving the net benefit of a site system; as the savings have a greater value yet the standard costs of connection and usage continue to climb.

C5 Scenario Analysis Decision Model Calculator

Figure A13 explains the process principles for the operation of the Decision Model calculator used for generating data arrays used for scenario analysis.

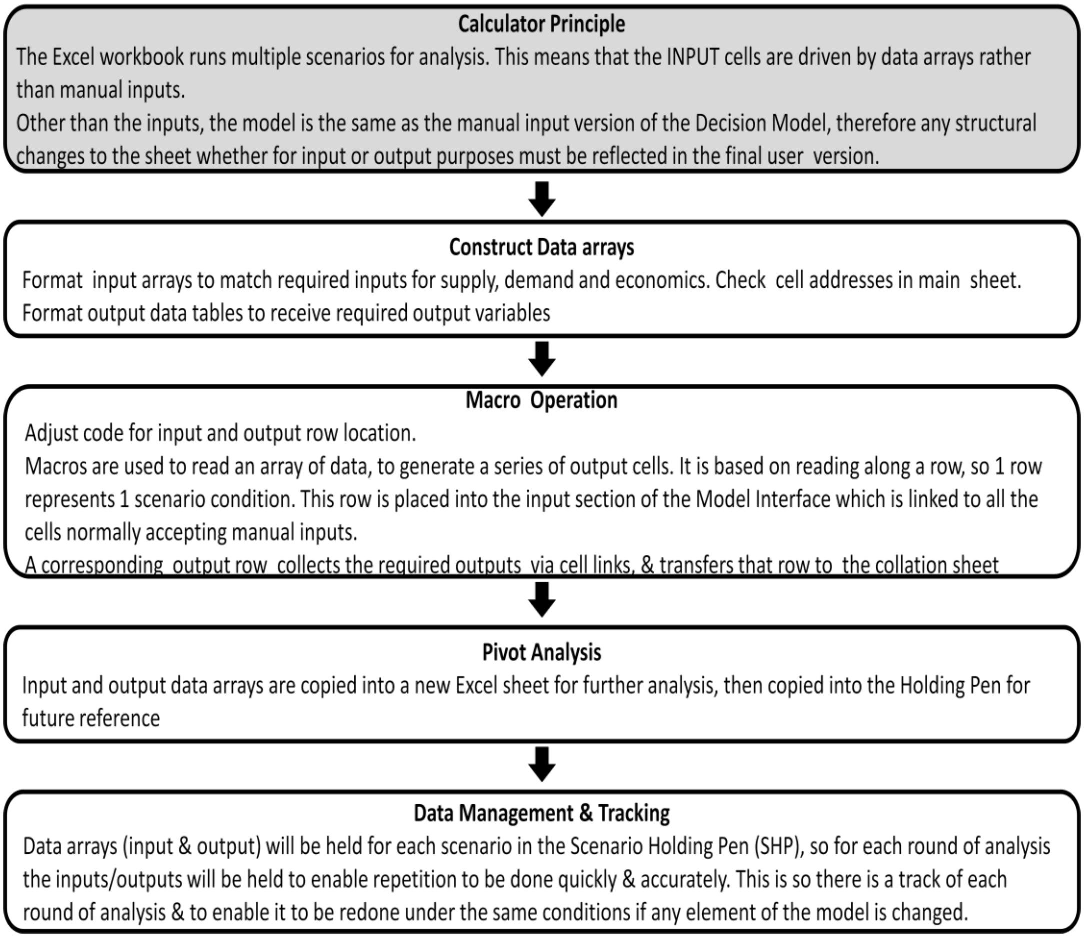


Figure A13: Decision Model Calculator Process

<u>C5.1 Scenario Data Arrays - Connections</u>

The connection scenarios used the following default criteria held constant for the economic inputs (Figure A14). The detail of the supply and demand criteria, by scenario are shown in Figure A15. Note that even while supply combinations are consistent, the number of systems varies by scenario, resulting in a range of overall system sizes.

	percentages shown as fraction of 100								
				Economics					
Retailer	**W/sale pr**	**f/c pr incr**	**f/c exp de**	**payback**	**Capt.Adj 9**	**FVCC**	**O+M**	**Gross FiT**	**Rebate**
Default is Meridian anytime contin. user	**5**	**0.05**	**0**	**25**	**0**	**0.05**	**0.01**	**0**	**0**
1House Low User	for low demand, Connection scenario 1 ONLY								

Figure A14: Connection Economic criteria

INPUT ARRAY									
Connections			**Demand**				**Supply**		
Scenarios	**Low**	**Medium**	**High**	**AltOption**	**# ICP**	**Size wind**	**size solar**	**#syst wind**	**#syst solar**
Connection # 1 Radial connec. Each house as generator with own ICP	#1 radial connection implies independence with system decision. Low demand options set at Low user level as import will be <8,000kWh pa; & redone at default position for direct comparison with Connection scenario #2. To get parity with other scenarios, 8 houses are modelled.								
Repeated for Medium &	8	0	0	0	8	none	1.2	0	8
High Demand	8	0	0	0	8	none	1.7	0	8
Medium & High	8	0	0	0	8	none	2.6	0	8
demand use Meridian	8	0	0	0	8	none	3.6	0	8
	8	0	0	0	8	P2.5	1.2	8	8
	8	0	0	0	8	P2.5	1.7	8	8
	8	0	0	0	8	P2.5	2.6	8	8
	8	0	0	0	8	P2.5	3.6	8	8
	8	0	0	0	8	P2.5	0	8	0
Connection #2 Internal loop Each house as gen	wind included in option #2 on assumption lot owners would want the choice.								
Repeated for Medium &	8	0	0	0	1	none	1.2	0	8
High Demand	8	0	0	0	1	none	1.7	0	8
	8	0	0	0	1	none	2.6	0	8
	8	0	0	0	1	none	3.6	0	8
	8	0	0	0	1	P2.5	1.2	8	8
	8	0	0	0	1	P2.5	1.7	8	8
	8	0	0	0	1	P2.5	3.6	8	8
Connection # 3 Internal Loop Whole Site Gen.	Most likely scenario of choice for developer. Assumed the 10kW cutoff is not a limiting factor for analysis purposes								
Repeated for Medium &	8	0	0	0	1	none	1.7	0	1
High Demand	8	0	0	0	1	P2.5	1.7	1	1
	8	0	0	0	1	P6	1.7	1	1
	8	0	0	0	1	none	2.6	0	1
	8	0	0	0	1	P2.5	2.6	1	1
	8	0	0	0	1	P6	2.6	1	1
	8	0	0	0	1	none	3.6	0	1
	8	0	0	0	1	P2.5	3.6	1	1
	8	0	0	0	1	P6	3.6	1	1
	8	0	0	0	1	none	5.1	0	1
	8	0	0	0	1	P2.5	5.1	1	1
	8	0	0	0	1	P6	5.1	1	1
	8	0	0	0	1	P2.5	0	1	0
	8	0	0	0	1	P6	0	1	0
	8	0	0	0	1	none	10.8	0	1
Connection #4 Internal loop Combined h+s gen	#4: solar only (no wind) option included in scenario #3 so not repeated here								
Repeated for Medium &	8	0	0	0	1	P2.5	1.2	1	8
High Demand	8	0	0	0	1	P2.5	1.7	1	8
	8	0	0	0	1	P2.5	2.6	1	8
	8	0	0	0	1	P2.5	3.6	1	8
	8	0	0	0	1	P6	1.2	1	8
	8	0	0	0	1	P6	1.7	1	8
	8	0	0	0	1	P6	2.6	1	8
	8	0	0	0	1	P6	3.6	1	8

Figure A15: Connection Scenario Data array

C5.2 Scenario Data Arrays – Economic Sensitivity

The inputs for economic sensitivity scenario are shown in Figure A16 below:

Economic Sensitivity	Demand					Supply			
Scenarios	Low	Medium	High	AltOption	# ICP	Size wind	size solar	#syst wind	#syst solar
Site generation based on two systems sized to stay under 10kW	Default for supply-demand settings based on MOST LIKELY connection scenario for Totarabank. Economic criteria run against low & high demand, with a P6 turbine & 3.6kW in the mixed system; & 5.1 kW solar in the solar only.								
5.1kW solar	8	0	0	0	1	none	5.1	0	1
10kW mixed	8	0	0	0	1	P6	3.6	1	1
	Repeated for high demand								

Economics									
Retailer	**W/sale pr**	**f/c pr incr**	**f/c exp de**	**payback**	**Capt.Adj %**	**FVCC**	**O+M**	**Gross FiT**	**Rebate**
Used wholesale price to alter export tariff, with Genesis as the retailer. The first entry line for Meridian is the **default** dataset for Economic inputs									
Meridian	5	0.05	0	25	0	0.05	0.01	0	0
Contact	5	0.05	0	25	0	0.05	0.01	0	0
Meridian	5	0.05	0	25	0	0.05	0.01	0	0
Empower	5	0.05	0	25	0	0.05	0.01	0	0
Genesis	5	0.05	0	25	0	0.05	0.01	0	0
Genesis	2	0.05	0	25	0	0.05	0.01	0	0
Genesis	10	0.05	0	25	0	0.05	0.01	0	0
Meridian	5	0.02	0	25	0	0.05	0.01	0	0
Meridian	5	0.1	0	25	0	0.05	0.01	0	0
Meridian	5	0.05	0.05	25	0	0.05	0.01	0	0
Meridian	5	0.05	-0.05	25	0	0.05	0.01	0	0
Meridian	5	0.05	0	10	0	0.05	0.01	0	0
Meridian	5	0.05	0	20	0	0.05	0.01	0	0
Meridian	5	0.05	0	25	-0.1	0.05	0.01	0	0
Meridian	5	0.05	0	25	0.2	0.05	0.01	0	0
Meridian	5	0.05	0	25	0.5	0.05	0.01	0	0
Meridian	5	0.05	0	25	0	0.02	0.01	0	0
Meridian	5	0.05	0	25	0	0.1	0.01	0	0
Meridian	5	0.05	0	25	0	0.05	0.02	0	0
Meridian	5	0.05	0	25	0	0.05	0.05	0	0
Meridian	5	0.05	0	25	0	0.05	0.01	30	0
Meridian	5	0.05	0	25	0	0.05	0.01	60	0
Meridian	5	0.05	0	25	0	0.05	0.01	90	0
Meridian	5	0.05	0	25	0	0.05	0.01	0	1000
Meridian	5	0.05	0	25	0	0.05	0.01		10000
Genesis	30	0.05	0	25	0	0.05	0.01	0	0
Genesis	60	0.05	0	25	0	0.05	0.01	0	0
Genesis	90	0.05	0	25	0	0.05	0.01	0	0

Figure A16: Economic Sensitivity Scenario Data Array

C5.3 Scenario Data Arrays – Energy Management

Demand 'Alternate option' is used as the mechanism for exploring load management. Low Demand scenario is used as the base as this is where the detailed use options have been built up. The medium/high profiles have high baseload as the main contributor and not enough is known about other usage options to make changes. It appears the Medium scenario data is relatively well spread in summer and the biggest change could be to change when the water heating load comes on in winter.

Supply options as for economics scenario - most realistic based on Totarabank developer feedback.

Alternate options set at household size of 4; and daytime occupancy rate of 2. The data array is shown in Figure A17.

Economics									
Retailer	**W/sale pr**	**f/c pr incr**	**f/c exp de**	**payback**	**Capt.Adj 9**	**FVCC**	**O+M**	**Gross FiT**	**Rebate**
Default is Meridian anytime contin. user	**5**	**0.05**	**0**	**25**	**0**	**0.05**	**0.01**	**0**	**0**

INPUT ARRAY									
Energy Management	**Demand**					**Supply**			
Scenarios	**Low**	**Medium**	**High**	**AltOption**	**# ICP**	**Size wind**	**size solar**	**#syst wind**	**#syst solar**
Internal Loop Whole Site Gen.	Default for supply-demand settings based on MOST LIKELY connection scenario for Totarabank. Alt. Option settings manually updated for each set (Other, and Other+occupancy). Other= a peak shift option; Occupancy = 2 people at home during day. Combinations (all lots or 50% lots) of alt options & standard low demand profile used .								
Peak shift -all	0	0	0	8	1	P2.5	3.6	1	1
Peak shift - 50%	4	0	0	4	1	P2.5	3.6	1	1
Peak shift -all	0	0	0	8	1	P6	3.6	1	1
Peak shift - 50%	4	0	0	4	1	P6	3.6	1	1
Peak shift+occupancy-all	0	0	0	8	1	P2.5	3.6	1	1
Peak shift+occupancy-50%	4	0	0	4	1	P2.5	3.6	1	1
Peak shift+occupancy-all	0	0	0	8	1	P6	3.6	1	1
Peak shift+occupancy-50%	4	0	0	4	1	P6	3.6	1	1

Figure A17: Energy Management Scenario Data Array

C6 Model Validation

C6.1 Comparison of Model Function Components

The tables below (Table A8 to Table A11) provide more detail for the functions of particular interest to the validation process - those of supply, demand, energy balance and key decision variables. These functions have various sub processes, or components that make up the total contribution of those functions to the outputs of each model. Understanding what impact the differences in each component has will deliver more value to the outcomes of the validation process. Further detail on the HOMER functions can be found in the Help Function in the software tool.

Table A8: Model validation for supply systems

Function: Supply systems (Solar and Wind)		
Components	**HOMER**	**Decision Model**
Resource Data	Solar data must be adjusted to Greenwich Mean Time (GMT). Data added as daily average/ month or for a year are set against built-in data by location, for extra terrestrial radiation.	Solar data and wind data based on measured resource data, on daylight saving time. Alternative methods used to generate output data (described in Figure 32: Site Supply Aggregation).
System Inputs	Wind data hourly inputs adjusted for hub height, power output from chosen power curves, air density ratio, weibull factor. Solar PV has 4 size options, plus numerous performance settings. Wind turbine multiple options.	Multiple size options for PV. Fewer turbine options, but more could be added. System inputs in HOMER to achieve equivalence: No PV tracking, default array setting. Wind system used default advanced parameters. Inverter efficiency 90% and 100%
PV Output	$PV_{output} = Y_{PV} f_{PV} (G_T / G_{T,STC})$ The radiation ratio implies incident radiation (test conditions) $G_{T,STC}$ is always greater than incident radiation on the array G_T, so ratio is <1. Also, application of derating factor f_{PV} can reduce output according to conditions. Y_{PV} is the capacity rating of the PV array.	Equivalent PV output ; $PV_{output} = Y_{PV} * G_T$ Because no derating is used in Decision Model, it is set at 90% and 100% for the HOMER validation. Y_{PV} sizes were kept consistent for the validation. The effect of the radiation ratio is to deliver a lower PV output result in HOMER.
Sensitivity	Extensive sensitivity options for optimising system inputs	Sensitivity applied through the calculation model.
Effect of Differences	The system output calculations for HOMER are based more on first principles and have more options for optimising system performance. They could be considered to be more accurate, and are likely to be lower. Adjusting for GMT means the HOMER outputs may also differ due to demand profile data being offset by an hour relative to solar data, compared to how these datasets match in the Decision Model.	

Table A9: Model validation for load profile

Function: Load Profile		
Components	**HOMER**	**Decision Model**
Input Load Data	Daily load data can be varied by weekday/ weekend/month, or a single profile applied to the year. One dataset only is entered.	Daily load profiles varied by month, and by options such as occupancy, household size, peak shifting. Multiple datasets entered.
Load Variability	A daily noise factor randomly varies the profile size; an hourly noise factor perturbs the profile shape.	No load variability options applied in this model, so for the HOMER validation, the daily and hourly perturbations were set at 0%.
Sensitivity	Load profile may be varied by scaling to a lower/higher annual average kWh/day; and by efficiency factors.	Multiple load profiles with different shapes provide the load sensitivity options.
Effect of Differences	HOMER uses the aggregated profile created in the decision model, so the load profiles are the same. However HOMER has more options for load variability.	

Table A10: Model validation for energy balance

Function: Energy Balance		
Components	**HOMER**	**Decision Model**
Grid Import	Energy balance calculations are done hourly, on the outcome of electric and thermal load being supplied by the chosen supply components. For grid-tied systems, this is presented by month as: Net grid purchases (total month) = Energy purchased less energy sold A negative result = net export A positive result = net import	Energy balance calculations are done on a similar hourly basis to HOMER; where load is matched against on-site supply, to identify energy flow to and from the grid. The outcome of hourly balances are presented as: Total monthly import and total monthly export.
Export Meter Options	Net metering: is an option available in HOMER, where the meter effectively 'spins' backward when energy is exported. The cost of energy is calculated on the overall balance at the end of the period (month or year). Non net-metered 'sellback' or export: if net metering is not used, the monthly/yearly cost of grid energy = Sum (energy purchased*import tariff – energy sold*export tariff)	Net metering is not legal in NZ, so the validation process must ensure net metering is not chosen. Cost of energy using dual metering (Import and export meter) follows the same process as HOMER's non net-metered sellback, with the addition of fixed lines charges. If variable costs only are used in the calculation, the outcome is the same as HOMER.
Effect of Differences	There are few differences in the process outcomes as long as net metering is not used to calculate exports. The full energy cost options in HOMER vary due to the residential energy charge differences.	

Table A11: Model validation for key output criteria

Function: Key Output Criteria Review		
Components	**HOMER**	**Decision Model**
System Performance	A key output from the modelling process for HOMER used for evaluating system configurations, is the renewable fraction. It is defined as the portion of the system's total energy production coming from renewable power. RF = $\frac{\text{renewables output}}{\text{renewables output + grid purchase}}$	System performance is defined by a set of criteria detailed in Table 13: System Performance Criteria. The 'RE Contribution to Load', delivers the same result as HOMER's renewable fraction.
Economics	Total Net Present Cost (NPC_{tot}) is a key economic measure used to evaluate and rank system configurations. It is the **present** value of all lifetime costs less revenue. $NPC_{tot} = \frac{\text{Total Annualised Costs}}{\text{Capital Recovery Factor}}$ NPC_{tot} represents the 'opposite' of NPV. Cost of Energy (COE) is the average cost per kWh of useful electrical energy produced by the system. COE as it applies to this validation process (not including thermal load) is defined as: COE = $\frac{\text{total annualised cost}}{\text{total load+ total grid sales (kWh)}}$	Alternatively, an economic measure in this model is NPV - the present value of future RE cash flows, less RE total costs less the NPC of a standard connection. It is calculated similarly to the NPC, but also includes the offset value of saved energy as part of the revenue stream. (refer Appendix C4.1) It takes the opposite economic view by assuming grid-tied systems will have a measurable 'value' over time. RE price is a key economic output that is used to compare the relative price of an alternative energy system compared to using standard tariffs. RE price = $\frac{\text{(annualised capital cost + total RE costs less export value)}}{\text{total load}}$ Translating the COE formula into the Decision Model gives the same result as the RE price.
Effect of Differences	The rationale of the output criteria is different but the outcomes are the same in terms of value. HOMER has a focus on costs, while the Decision Model looks at economic value as one of a *number* of criteria.	

C6.2 Summary of Input Data Settings for HOMER

The previous section discussed the detail of the main functions of interest to the validation. This section summarises the main input data settings used in HOMER, to ensure comparable conditions (where possible) for validation against the Decision Model. The input data settings, by function are shown in Table A12. The rationale for efficiency and derating settings are due to no system efficiency allowances in the Decision Model.

Cost and financial data were entered consistent with those used in the Decision Model, but a detailed economic comparison was not performed.

Table A12: Summary of Key Data Settings for HOMER validation

Function	System	Main Data Settings
Supply System Inputs	PV	No tracking for PV array No temperature effect Derating factor set at 90% and 100% Ground reflectance 20% PV sizes (kW) 1.7, 3.6, 5.1
	Wind	Proven P2.5 and P6 turbine power curves
	Converter	5kW Inverter efficiency set at 90% and 100%
Supply Resources	Solar	Monthly average kWh/m^2/day data, and hourly data for the year (8760 hours) imported from CLIFLO dataset. Year data adjusted BACK by 1 hour for GMT, to ensure fit with HOMER built-in extraterrestrial radiation data.
	Wind	Monthly average wind speed data imported from CLIFLO dataset. Default settings used for advanced parameters.
Load Profile		Medium demand dataset for 1 house imported for each season (annual average 22.4 kWh/day). Scaled annual average kWh/day options of 9.7 and 40.4
Energy Balance	Grid	Net metering NOT selected Rates for purchase and sellback the same ($0.23/kWh)

APPENDIX D: CHAPTER 5 SUPPORT MATERIAL

D1 Decision Model Output Graph Layout

A screen dump of the user interface showing the input area with output graphs positioned alongside is shown in Figure A18 .

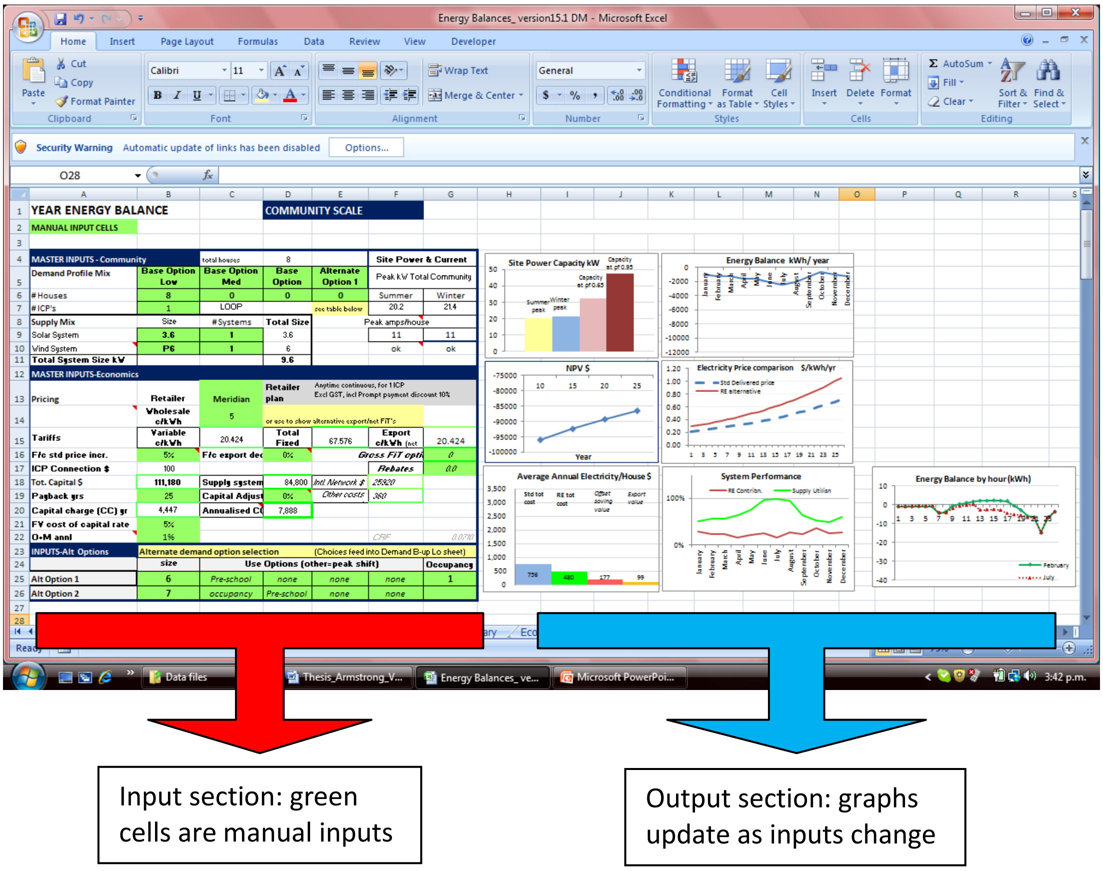


Figure A18: Example of output graph layout for user interface

D2 Scenario Analysis

This section contains detail of analysis data used to support the results shown in Section 5.2 Scenario Analysis.

<u>D2.1 Comparison of Loop vs Radial Connection</u>

Figure A19 details a range of data for short and long term economic comparison for Radial vs. Loop connected houses. Note that the NPV data is for the SITE not individual houses and uses the default settings described for previous economic analysis.

Radial vs Loop Connection			**Charges and costs**					
System			**Capital Charge**			**Annual cost/house**		
Wind	Solar	Total kW	Radial	Loop	% diff	Radial	Loop	
none	1.2	10	6525	6692	-2%	$614	$399	Annual cost difference due to fixed cost attribution of $216.
none	1.7	14	9354	9522	-2%	$465	$250	
none	2.6	21	11785	11952	-1%	$197	-$19	
none	3.6	29	16900	17067	-1%	-$101	-$317	
P2.5	1.2	30	17599	17766	-1%	$214	-$1	
P2.5	1.7	34	20394	20562	-1%	$65	-$150	
P2.5	3.6	49	27940	28107	-1%	-$501	-$717	

	Re alternative price year 25 $/kWh						**Low Demand**	
System	**Low Demand**		**High Demand**		**Average standard price**		**% difference (std)**	
Total kW	Loop	Radial	Loop	Radial	Loop	Radial	Loop	Radial
10	1.32	1.48	0.81	0.81	0.72	0.80	84%	85%
14	1.60	1.79	0.87	0.86	0.72	0.80	123%	123%
21	1.80	2.03	0.89	0.89	0.72	0.80	150%	154%
29	2.32	2.61	1.00	0.99	0.72	0.80	222%	226%
30	2.42	2.60	1.05	1.04	0.72	0.80	235%	226%
34	2.70	2.92	1.11	1.10	0.72	0.80	275%	265%
49	3.43	3.76	1.25	1.24	0.72	0.80	376%	370%

	NPV Year 25					
System	**Low Demand**		**High Demand**		**% difference**	
Total kW	Radial	Loop	Radial	Loop	low	high
10	-$108,325	-$111,640	-$52,684	-$55,998	3%	6%
14	-$167,809	-$171,124	-$88,250	-$91,564	2%	4%
21	-$200,972	-$204,287	-$85,675	-$88,989	2%	4%
29	-$312,044	-$315,358	-$162,026	-$165,340	1%	2%
30	-$337,432	-$340,746	-$234,721	-$238,035	1%	1%
34	-$399,839	-$403,153	-$276,319	-$279,633	1%	1%
49	-$549,847	-$553,162	-$363,539	-$366,854	1%	1%

Figure A19: Economic comparison for Radial vs. Loop connections

D2.2 Comparison of Loop Connection Options

The initial analysis graphs for the raw data from each of the connection scenarios are shown in Figure A20 to Figure A25. These graphs were done on the basis of overall system size (kW) to establish the nature of the relationship between the options, and to confirm if there were any significant differences. The data labels indicating 'hi' sets are for high demand; 'low' represents low demand.

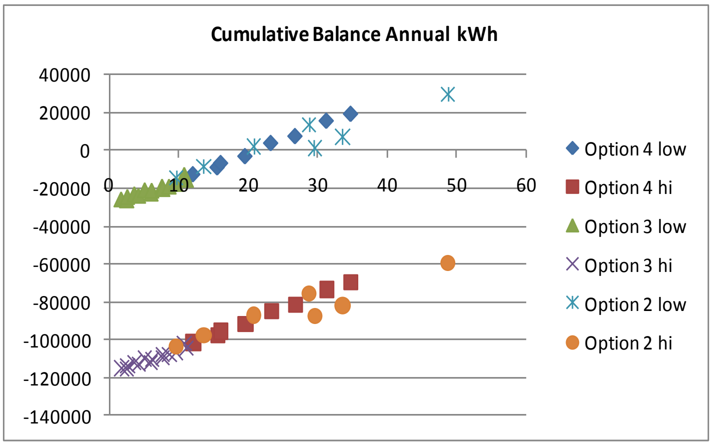


Figure A20: Cumulative Balance, annual kWh by system size, KW

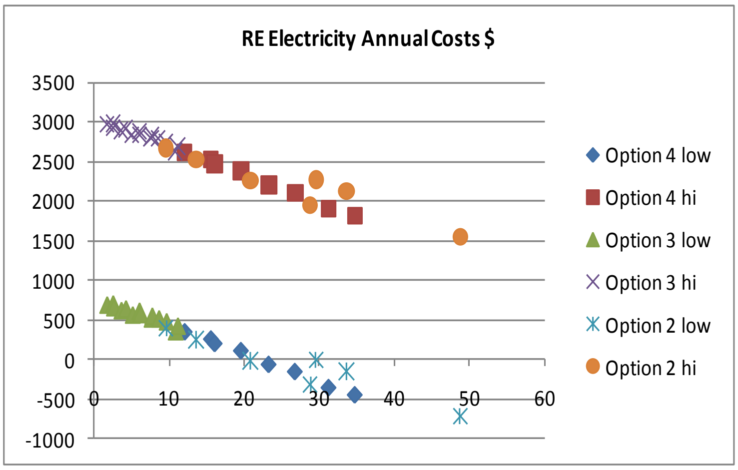


Figure A21: Annual average electricity costs for house with RE

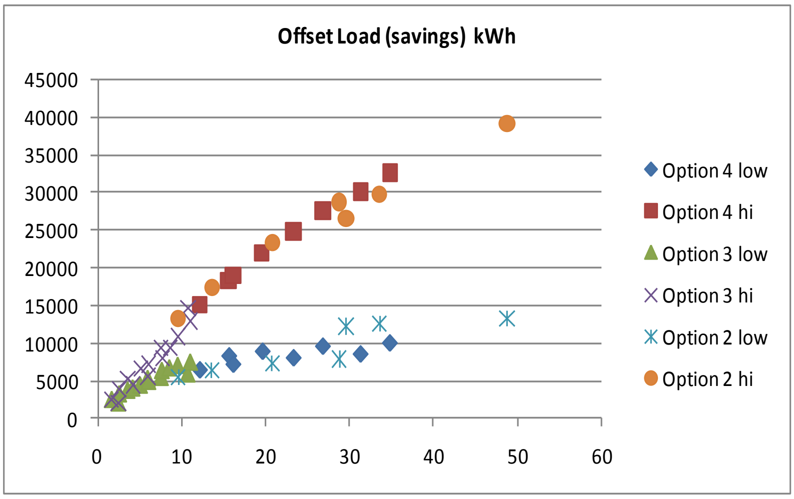


Figure A22: Annual site load savings, kWh

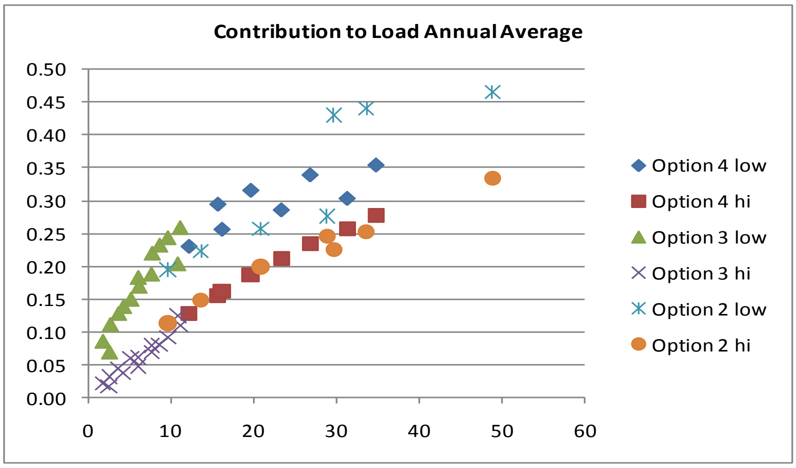


Figure A23: Average % contribution to load by RE system

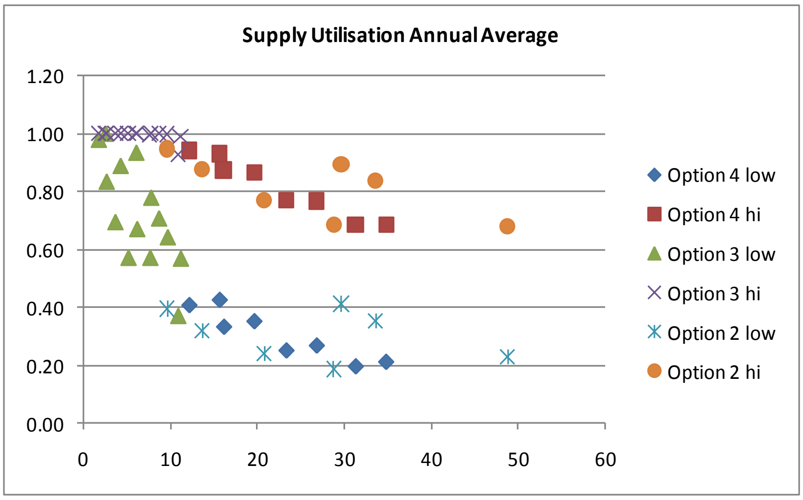


Figure A24: Average % supply utilisation of RE supply

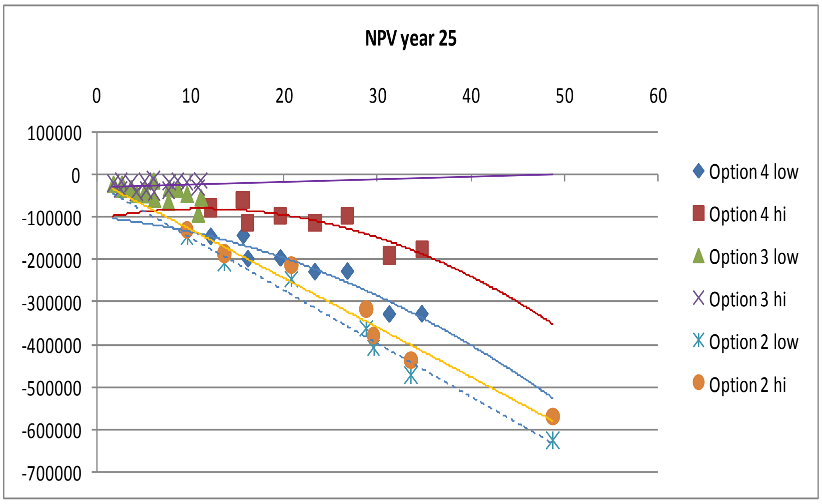


Figure A25: NPV at year 25, by connection option

D2.3 Connection Scenario Ranking by NPV

Data from the scenario connections analysis generated through the Model calculator, was ranked by site NPV at year 25. The top 50% of the data set is shown in two tables showing ranked NPV results with the corresponding economic measure data; and with system performance measures. Refer below to Figure A26: Top 50% Connection Scenario NPV Ranking, with economic measures and Figure A27: Top 50% Connection scenario NPV ranking, with system performance measures.

Scenario	Low	Medium	High	Size wind	size solar	Site kW	NPVnet 25	NPVnet 25 by house	CapChg per yr	Std price yr 10	RE Alt price yr 10	Std price yr 25	RE Alt price yr 25
Conn #3 s	0	8	0	P6	0	6.0	-$10,338	-$1,292	2386	0.34	0.35	0.70	0.73
Conn #3 s	0	0	8	P6	0	6.0	-$10,338	-$1,292	2386	0.34	0.37	0.70	0.77
Conn #3 s	8	0	0	P6	0	6.0	-$12,998	-$1,625	2386	0.35	0.42	0.72	0.88
Conn #3 s	0	8	0	P6	2.6	8.6	-$13,447	-$1,681	3808	0.34	0.36	0.70	0.75
Conn #3 s	0	0	8	P6	2.6	8.6	-$13,447	-$1,681	3808	0.34	0.39	0.70	0.80
Conn #3 s	0	0	8	P6	5.1	11.1	-$14,258	-$1,782	5080	0.34	0.37	0.70	0.77
Conn #3 s	0	8	0	P6	5.1	11.1	-$14,628	-$1,829	5080	0.34	0.40	0.70	0.83
Conn #3 s	0	8	0	none	5.1	5.1	-$15,451	-$1,931	3205	0.34	0.36	0.70	0.75
Conn #3 s	0	0	8	none	5.1	5.1	-$15,451	-$1,931	3205	0.34	0.38	0.70	0.79
Conn #3 s	0	8	0	none	2.6	2.6	-$16,214	-$2,027	1968	0.34	0.35	0.70	0.73
Conn #3 s	0	0	8	none	2.6	2.6	-$16,214	-$2,027	1968	0.34	0.37	0.70	0.77
Conn #3 s	0	0	8	P6	3.6	9.6	-$17,484	-$2,185	4447	0.34	0.37	0.70	0.76
Conn #3 s	0	8	0	P6	3.6	9.6	-$17,535	-$2,192	4447	0.34	0.39	0.70	0.82
Conn #3 s	0	8	0	P6	1.7	7.7	-$17,865	-$2,233	3504	0.34	0.36	0.70	0.75
Conn #3 s	0	0	8	P6	1.7	7.7	-$17,865	-$2,233	3504	0.34	0.38	0.70	0.80
Conn #3 s	0	8	0	none	3.6	3.6	-$20,116	-$2,515	2607	0.34	0.36	0.70	0.74
Conn #3 s	0	0	8	none	3.6	3.6	-$20,116	-$2,515	2607	0.34	0.38	0.70	0.78
Conn #3 s	0	8	0	none	1.7	1.7	-$20,632	-$2,579	1664	0.34	0.35	0.70	0.73
Conn #3 s	0	0	8	none	1.7	1.7	-$20,632	-$2,579	1664	0.34	0.37	0.70	0.76
Conn #3 s	8	0	0	none	2.6	2.6	-$20,787	-$2,598	1968	0.35	0.42	0.72	0.87
Conn #3 s	8	0	0	none	1.7	1.7	-$21,020	-$2,628	1664	0.35	0.41	0.72	0.86
Conn #3 s	0	0	8	none	10.8	10.8	-$29,809	-$3,726	6296	0.34	0.38	0.70	0.79
Conn #3 s	8	0	0	P6	1.7	7.7	-$30,713	-$3,839	3504	0.35	0.46	0.72	0.97
Conn #3 s	8	0	0	none	3.6	3.6	-$31,674	-$3,959	2607	0.35	0.44	0.72	0.93
Conn #3 s	8	0	0	P6	2.6	8.6	-$33,243	-$4,155	3808	0.35	0.47	0.72	0.99
Conn #3 s	0	8	0	none	10.8	10.8	-$33,391	-$4,174	6296	0.34	0.42	0.70	0.88
Conn #3 s	8	0	0	P2.5	0	2.5	-$33,581	-$4,198	1926	0.34	0.36	0.70	0.74
Conn #3 s	0	8	0	P2.5	0	2.5	-$33,581	-$4,198	1926	0.34	0.38	0.70	0.78
Conn #3 s	0	0	8	P2.5	0	2.5	-$33,581	-$4,198	1926	0.35	0.43	0.72	0.90
Conn #3 s	0	0	8	P2.5	5.1	7.6	-$36,145	-$4,518	4585	0.34	0.37	0.70	0.78
Conn #3 s	0	8	0	P2.5	5.1	7.6	-$36,237	-$4,530	4585	0.34	0.41	0.70	0.84
Conn #3 s	0	8	0	P2.5	2.6	5.1	-$36,691	-$4,586	3348	0.34	0.37	0.70	0.76
Conn #3 s	0	0	8	P2.5	2.6	5.1	-$36,691	-$4,586	3348	0.34	0.39	0.70	0.82
Conn #3 s	8	0	0	none	5.1	5.1	-$38,470	-$4,809	3205	0.35	0.46	0.72	0.98
Conn #3 s	0	8	0	P2.5	3.6	6.1	-$40,593	-$5,074	3987	0.34	0.37	0.70	0.77
Conn #3 s	0	0	8	P2.5	3.6	6.1	-$40,593	-$5,074	3987	0.34	0.40	0.70	0.83
Conn #3 s	0	8	0	P2.5	1.7	4.2	-$41,109	-$5,139	3044	0.34	0.37	0.70	0.76
Conn #3 s	0	0	8	P2.5	1.7	4.2	-$41,109	-$5,139	3044	0.34	0.39	0.70	0.81
Conn #3 s	8	0	0	P2.5	1.7	4.2	-$44,712	-$5,589	3044	0.35	0.47	0.72	0.98
Conn #3 s	8	0	0	P6	3.6	9.6	-$45,272	-$5,659	4447	0.35	0.49	0.72	1.05
Conn #3 s	8	0	0	P2.5	2.6	5.1	-$46,289	-$5,786	3348	0.35	0.48	0.72	1.00
Conn# 1 rad	0	0	8	none	1.2	9.6	-$52,684	-$6,585	6525	0.36	0.41	0.75	0.86
Conn #3 s	8	0	0	P6	5.1	11.1	-$53,962	-$6,745	5080	0.35	0.51	0.72	1.11
Conn# 1 rad	0	8	0	none	1.2	9.6	-$54,937	-$6,867	6525	0.38	0.47	0.79	0.99
Conn #2 h	0	0	8	none	1.2	9.6	-$55,998	-$7,000	6692	0.34	0.39	0.70	0.81
Conn #3 s	8	0	0	P2.5	3.6	6.1	-$57,718	-$7,215	3987	0.35	0.50	0.72	1.06
Conn #2 h	0	8	0	none	1.2	9.6	-$58,251	-$7,281	6692	0.34	0.44	0.70	0.91
Conn #4 h+s	0	0	8	P6	1.2	15.6	-$58,474	-$7,309	8566	0.34	0.40	0.70	0.84
Conn #4 h+s	0	8	0	P6	1.2	15.6	-$63,195	-$7,899	8566	0.34	0.46	0.70	0.95
Conn #3 s	8	0	0	P2.5	5.1	7.6	-$64,951	-$8,119	4585	0.35	0.52	0.72	1.11
Conn #4 h+s	0	0	8	P2.5	1.2	12.1	-$78,615	-$9,827	8106	0.34	0.40	0.70	0.84
Conn #4 h+s	0	8	0	P2.5	1.2	12.1	-$81,658	-$10,207	8106	0.34	0.46	0.70	0.96
Conn# 1 rad	0	0	8	none	2.6	20.8	-$85,675	-$10,709	11785	0.36	0.45	0.75	0.94
Conn# 1 rad	0	0	8	none	1.7	13.6	-$88,250	-$11,031	9354	0.36	0.44	0.75	0.91
Conn #2 h	0	0	8	none	2.6	20.8	-$88,989	-$11,124	11952	0.34	0.42	0.70	0.89
Conn #2 h	0	0	8	none	1.7	13.6	-$91,564	-$11,446	9522	0.34	0.41	0.70	0.87
Conn #3 s	8	0	0	none	10.8	10.8	-$92,970	-$11,621	6296	0.35	0.57	0.72	1.26
Conn# 1 rad	0	8	0	none	1.7	13.6	-$95,831	-$11,979	9354	0.38	0.52	0.79	1.09
Conn #4 h+s	0	0	8	P6	1.7	19.6	-$95,870	-$11,984	11362	0.34	0.43	0.70	0.89

Figure A26: Top 50% Connection Scenario NPV Ranking, with economic measures

Scenario	Low	Medium	High	Size wind	size solar	Site kW	NPVnet 25	NPVnet 25 by house	Cml Bal.	RE Contn	Supply Utn	House I-E tot	Offset house
Conn #3 s	0	8	0	P6	0	6.0	-$10,338	-$1,292	-111791	5%	100%	2885	143
Conn #3 s	0	0	8	P6	0	6.0	-$10,338	-$1,292	-60044	9%	100%	1564	143
Conn #3 s	8	0	0	P6	0	6.0	-$12,998	-$1,625	-22833	18%	93%	614	133
Conn #3 s	0	8	0	P6	2.6	8.6	-$13,447	-$1,681	-107996	8%	100%	2788	239
Conn #3 s	0	0	8	P6	2.6	8.6	-$13,447	-$1,681	-56249	14%	100%	1467	239
Conn #3 s	0	0	8	P6	5.1	11.1	-$14,258	-$1,782	-104347	11%	99%	2695	330
Conn #3 s	0	8	0	P6	5.1	11.1	-$14,628	-$1,829	-52600	20%	99%	1374	329
Conn #3 s	0	8	0	none	5.1	5.1	-$15,451	-$1,931	-109931	6%	100%	2837	190
Conn #3 s	0	0	8	none	5.1	5.1	-$15,451	-$1,931	-58184	11%	100%	1516	190
Conn #3 s	0	8	0	none	2.6	2.6	-$16,214	-$2,027	-113580	3%	100%	2931	97
Conn #3 s	0	0	8	none	2.6	2.6	-$16,214	-$2,027	-61833	6%	100%	1609	97
Conn #3 s	0	0	8	P6	3.6	9.6	-$17,484	-$2,185	-106537	9%	100%	2751	276
Conn #3 s	0	8	0	P6	3.6	9.6	-$17,535	-$2,192	-54789	16%	100%	1430	276
Conn #3 s	0	8	0	P6	1.7	7.7	-$17,865	-$2,233	-109310	7%	100%	2822	206
Conn #3 s	0	0	8	P6	1.7	7.7	-$17,865	-$2,233	-57562	12%	100%	1500	206
Conn #3 s	0	8	0	none	3.6	3.6	-$20,116	-$2,515	-112121	4%	100%	2893	134
Conn #3 s	0	0	8	none	3.6	3.6	-$20,116	-$2,515	-60373	8%	100%	1572	134
Conn #3 s	0	8	0	none	1.7	1.7	-$20,632	-$2,579	-114894	2%	100%	2964	63
Conn #3 s	0	0	8	none	1.7	1.7	-$20,632	-$2,579	-63146	4%	100%	1643	63
Conn #3 s	8	0	0	none	2.6	2.6	-$20,787	-$2,598	-24622	11%	83%	660	81
Conn #3 s	8	0	0	none	1.7	1.7	-$21,020	-$2,628	-25935	9%	98%	693	62
Conn #3 s	0	0	8	none	10.8	10.8	-$29,809	-$3,726	-101612	12%	93%	2625	373
Conn #3 s	8	0	0	P6	1.7	7.7	-$30,713	-$3,839	-20351	22%	78%	550	160
Conn #3 s	8	0	0	none	3.6	3.6	-$31,674	-$3,959	-23162	13%	69%	622	93
Conn #3 s	8	0	0	P6	2.6	8.6	-$33,243	-$4,155	-19038	23%	71%	517	169
Conn #3 s	0	8	0	none	10.8	10.8	-$33,391	-$4,174	-49864	21%	90%	1304	360
Conn #3 s	8	0	0	P2.5	0	2.5	-$33,581	-$4,198	-115417	2%	100%	2977	50
Conn #3 s	0	8	0	P2.5	0	2.5	-$33,581	-$4,198	-63669	3%	100%	1656	50
Conn #3 s	0	0	8	P2.5	0	2.5	-$33,581	-$4,198	-26458	7%	100%	706	50
Conn #3 s	0	0	8	P2.5	5.1	7.6	-$36,145	-$4,518	-107973	8%	100%	2787	239
Conn #3 s	0	8	0	P2.5	5.1	7.6	-$36,237	-$4,530	-56225	14%	100%	1466	239
Conn #3 s	0	8	0	P2.5	2.6	5.1	-$36,691	-$4,586	-111622	5%	100%	2881	147
Conn #3 s	0	0	8	P2.5	2.6	5.1	-$36,691	-$4,586	-59874	9%	100%	1559	147
Conn #3 s	8	0	0	none	5.1	5.1	-$38,470	-$4,809	-20973	15%	57%	566	108
Conn #3 s	0	8	0	P2.5	3.6	6.1	-$40,593	-$5,074	-110162	6%	100%	2843	184
Conn #3 s	0	0	8	P2.5	3.6	6.1	-$40,593	-$5,074	-58415	11%	100%	1522	184
Conn #3 s	0	8	0	P2.5	1.7	4.2	-$41,109	-$5,139	-112935	4%	100%	2914	113
Conn #3 s	0	0	8	P2.5	1.7	4.2	-$41,109	-$5,139	-61188	7%	100%	1593	113
Conn #3 s	8	0	0	P2.5	1.7	4.2	-$44,712	-$5,589	-23977	14%	89%	643	101
Conn #3 s	8	0	0	P6	3.6	9.6	-$45,272	-$5,659	-17578	24%	64%	480	177
Conn #3 s	8	0	0	P2.5	2.6	5.1	-$46,289	-$5,786	-22663	16%	77%	610	113
Conn# 1 rai	0	0	8	none	1.2	9.6	-$52,684	-$6,585	-103363	0.11	0.95	2886	339
Conn #3 s	8	0	0	P6	5.1	11.1	-$53,962	-$6,745	-15389	26%	57%	424	189
Conn# 1 rai	0	8	0	none	1.2	9.6	-$54,937	-$6,867	-51615	0.20	0.93	1564	331
Conn #2 h	0	0	8	none	1.2	9.6	-$55,998	-$7,000	-103363	11%	95%	2670	339
Conn #3 s	8	0	0	P2.5	3.6	6.1	-$57,718	-$7,215	-21204	17%	67%	572	123
Conn #2 h	0	8	0	none	1.2	9.6	-$58,251	-$7,281	-51615	20%	93%	1349	331
Conn #4 h+	0	0	8	P6	1.2	15.6	-$58,474	-$7,309	-97779	16%	93%	2527	466
Conn #4 h+	0	8	0	P6	1.2	15.6	-$63,195	-$7,899	-46031	27%	90%	1206	449
Conn #3 s	8	0	0	P2.5	5.1	7.6	-$64,951	-$8,119	-19014	19%	57%	516	137
Conn #4 h+	0	0	8	P2.5	1.2	12.1	-$78,615	-$9,827	-101405	13%	94%	2620	385
Conn #4 h+	0	8	0	P2.5	1.2	12.1	-$81,658	-$10,207	-49657	22%	92%	1299	374

Figure A27: Top 50% Connection scenario NPV ranking, with system performance measures

D2.4 Economic Sensitivity Support Data

The economic sensitivity scenario focussed mainly on economic outputs to measure the response to various economic factors. As part of the analysis, several retailers were compared using the default economic input settings. The retailer comparison of annual costs and long term economic outputs (based on the default economic inputs) is shown in Figure A28.

Standard Conditions - Retailer Comparison									
CONTACT	House std tot	House I-E tot	Offset house	Export house	Std price 25	RE Alt price	NPV 25	NPV25/h	Pricing Note
10kW mixed low	$748	$491	$173	$84	0.71	1.05	-$48,823	-$6,103	Mid-range
10kW mixed high	$2,961	$2,691	$269	$0	0.68	0.75	-$20,289	-$2,536	import tariff.
5.1 kW solar low	$748	$573	$105	$69	0.71	0.97	-$41,011	-$5,126	Export tariff
5.1 kW solar high	$2,961	$2,776	$185	$0	0.68	0.73	-$17,376	-$2,172	17c/kWh.
MERIDIAN	House std tot	House I-E tot	Offset house	Export house	Std price 25	RE Alt price 2	NPV 25	NPV25/h	Pricing Note
10kW mixed low	$756	$480	$177	$99	0.72	1.05	-$45,272	-$5,659	Lowest import
10kW mixed high	$3,027	$2,751	$276	$0	0.70	0.76	-$17,484	-$2,185	tariff.
5.1 kW solar low	$756	$566	$108	$82	0.72	0.98	-$38,470	-$4,809	Export
5.1 kW solar high	$3,027	$2,837	$190	$0	0.70	0.75	-$15,451	-$1,931	tariff=import
GENESIS	House std tot	House I-E tot	Offset house	Export house	Std price 25	RE Alt price 2	NPV 25	NPV25/h	Pricing Note
10kW mixed low	$798	$587	$187	$24	0.76	1.11	-$50,219	-$6,277	Highest import
10kW mixed high	$3,188	$2,897	$291	$0	0.74	0.80	-$11,802	-$1,475	tariff.
5.1 kW solar low	$798	$665	$114	$20	0.76	1.03	-$43,338	-$5,417	Export tariff =
5.1 kW solar high	$3,188	$2,988	$200	$0	0.74	0.78	-$11,522	-$1,440	wholesale price.

Figure A28: Retailer comparison of economic and cost results

Figure A29 demonstrates the effect on NPV breakeven time for a forecast import tariff price increase of 10% - economic benefits will be achieved earlier as import tariffs increase at a rate in excess of 6%.

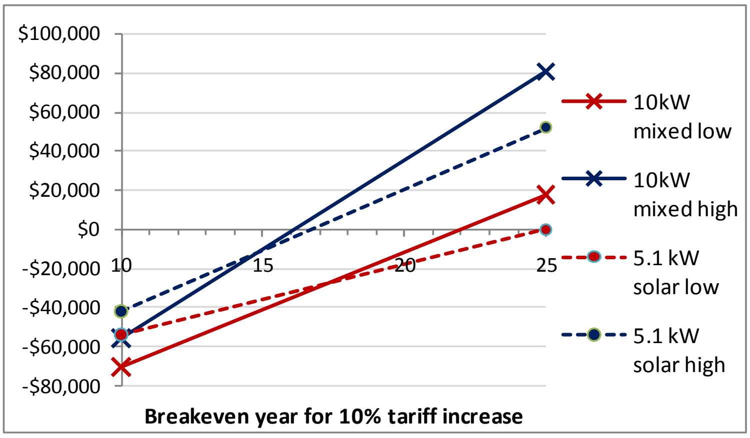


Figure A29: NPV breakeven for 10% forecast increase in import tariff

Figure A30 shows the impact of changing interest rates on RE alternative price adjustment ratio (the % adjustment of the price relative to the standard price for that system). As the adjustment ratio decreases, the RE alternative price moves closer to the standard price making the renewable system more attractive. Interest rates less than 5% are positive for switching to a renewable alternative.

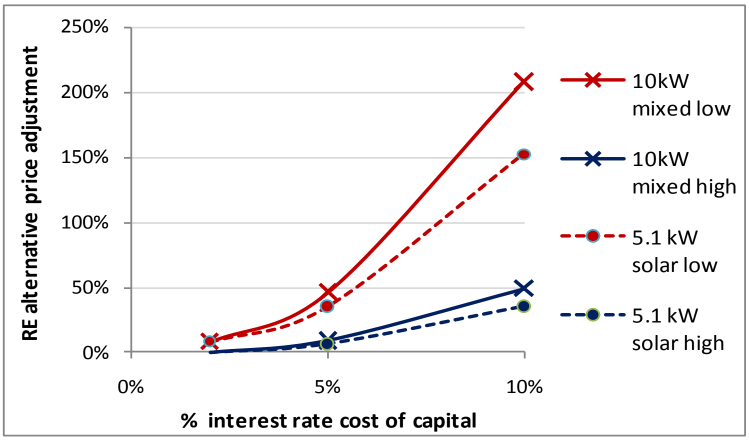


Figure A30: RE alternative price adjustment vs. % interest rate for cost of capital

Figure A31 below shows the impact on NPV of the forecast year- on-year price change for the export tariff. There is little effect at high demand levels due to the negligible export of surplus electricity. Increasing the export tariff has a positive effect on NPV, particularly if export is occurring at lower demand levels.

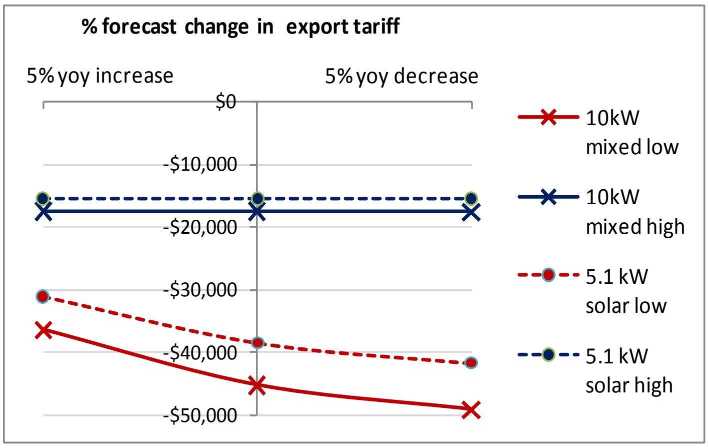


Figure A31: NPV vs. % forecast change in export tariff

Figure A32 shows how annual electricity costs decrease as Gross Feed-in tariffs increase.

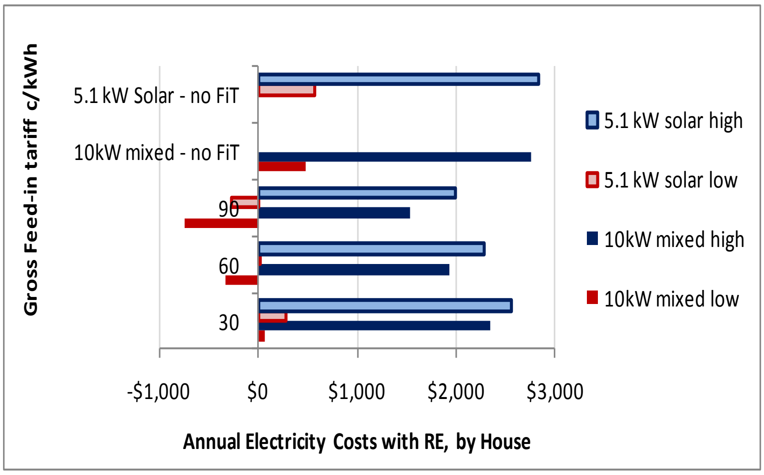


Figure A32: Gross Feed-in Tariff impact on annual electricity costs (house)

D2.5 Energy Management Support Data

Summer and winter energy balances are shown in Figure A33, and economic outcomes for NPV and RE alternative price at year 25 are shown in Figure A34.

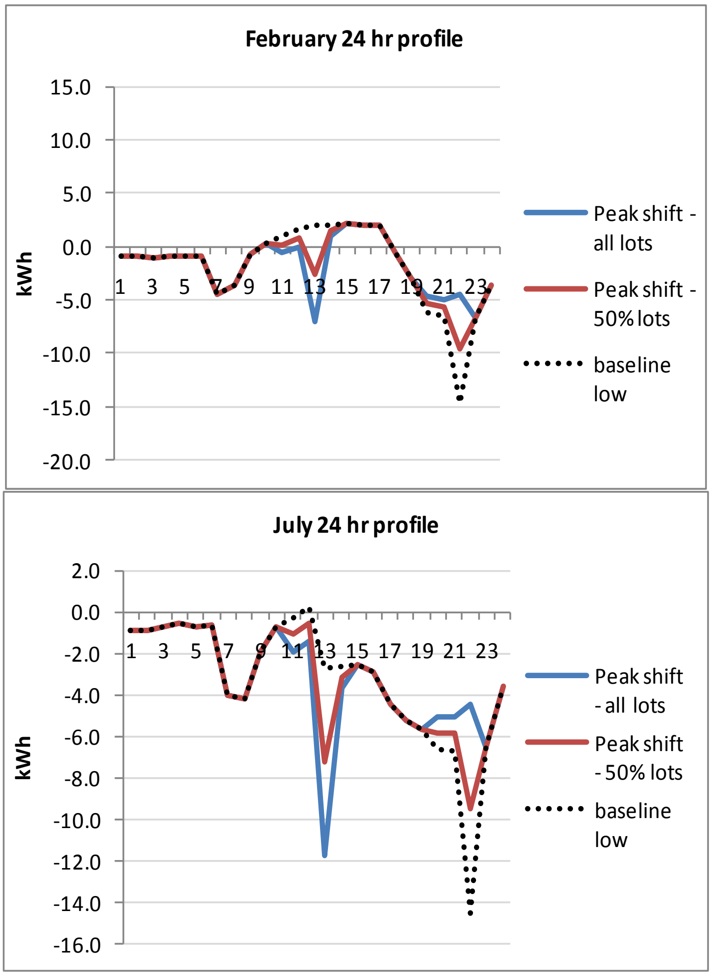


Figure A33: Summer and Winter profiles with peak shifting

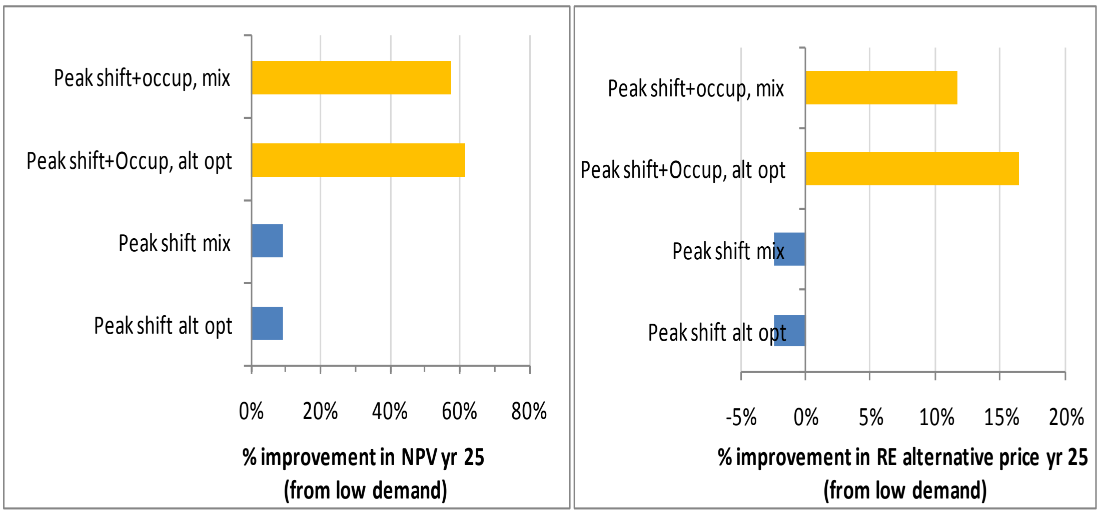


Figure A34: Economic outcomes for energy management

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