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# Residential Distributed Generation

Decision Support Software to Evaluate Opportunities in the  
Residential Market

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# Abstract

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The residential market in New Zealand consumes a significant proportion of our electricity production and is one of the fastest *growing* sectors. As a vertically integrated generator-retailer in the New Zealand electricity industry, Meridian Energy Ltd is concerned at retaining and growing their customer base. They recognise that utilisation of emerging distributed generation [DG] technologies can provide a competitive advantage in the market place.

A decision tool was developed to help Meridian identify opportunities within the residential market for applications of DG. The model compares the cost to serve a household's energy needs using a business as usual case with a DG case on an annual basis for a single household or a neighbourhood. A modular approach was used for ease of development and to enable future enhancements. The main modules were: load profile development, DG technology, operation control, costing and a calculation engine.

The load profile module estimated space heating/cooling, water heating and other electrical loads for each 30 minute period for 8 representative days of a year based on national end-use statistics and a set of 40 reference profiles. A Gamma distribution was used to simulate diversity between houses.

The calculation engine computed the amount of demand that could be met by the DG technologies and hence the residual demand or surplus for export.

The pricing module estimated the annual cost including aspects such as: capital cost, fuel cost, maintenance, value of export and cost of import.

The technology modules allowed different DG technologies, as well as a range of parameters to be selected. It included renewable energy resource modelling.

The performance module allowed different operation control of the heat engine technologies including: base load, electrical peaking, heat peaking, load following (heat-led) and load following (electricity-led).

The model was implemented using Microsoft Visual Basic for Applications, in Excel. A series of user-forms were developed to enable the model to be run with a minimum of user input.

Three case studies were undertaken. In the first, five technology types were modelled, with the heat pump and Stirling engine looking the most promising. The second case study involved these two technologies in a Christchurch urban area study. A hypothetical network analysis showed the benefit that these technologies could have in reducing peak loading on the network. The third case study examined the sensitivity of the results to the value of specific variables. Load size and capital cost had the strongest influence on NPV.

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To my friends and family. Thank-you all.

To God.

"Praise the Lord. I will extol the Lord with all my heart in the council of the upright and in the assembly. Great are the works of the Lord; they are pondered by all who delight in them. Glorious and majestic are His deeds and His righteousness endures for ever. The fear of the Lord is the beginning of all wisdom; all who follow His precepts have good understanding. To Him belongs eternal praise."

*Psalm 111*



# Acronyms

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<b>AC</b>	Alternating current
<b>APC</b>	Annual production cost
<b>BAU</b>	Business as usual
<b>BCHP</b>	Building combined heat and power
<b>BRANZ</b>	Building Research Association of New Zealand
<b>CAIDI</b>	Customer average interruption duration index
<b>CHP</b>	Combined heat and power
<b>CCGT</b>	Combined cycle gas technology
<b>CNG</b>	Compressed natural gas
<b>COP</b>	Coefficient of performance
<b>CPI-X</b>	Consumer price index
<b>DC</b>	Direct current
<b>DG</b>	Distributed generation
<b>DN</b>	Distribution network
<b>DHW</b>	Domestic hot water
<b>DPS</b>	Dispersed power source
<b>DSM</b>	Demand side management
<b>ECNZ</b>	Electricity Corporation of New Zealand
<b>EGB</b>	Electricity Governance Board
<b>EIRA</b>	Electricity Industry Reform Act
<b>EPRI</b>	Electric Power Research Institute
<b>GIP</b>	Grid import point
<b>GRI</b>	Gas Research Institute
<b>GXP</b>	Grid exit point
<b>HEEP</b>	Household End-use Energy Project
<b>HVAC</b>	Heating, ventilation and air-conditioning
<b>HVDC</b>	High voltage direct current
<b>IPO</b>	Independent power operator
<b>IRL</b>	Industrial Research Limited
<b>kW</b>	kilo Watts (Joule per second)
<b>LHV</b>	Lower heating value

<b>LNG</b>	Liquefied natural gas
<b>LPG</b>	Liquefied petroleum gas
<b>MACQS</b>	Multilateral Agreement on Common Quality Standards
<b>MARIA</b>	Metering and Reconciliation Information Agreement
<b>MCFC</b>	Molten carbonate fuel cell
<b>MED</b>	Ministry of Economic Development
<b>MEL</b>	Meridian Energy Limited
<b>NZEM</b>	NZ Electricity Market
<b>NPAT</b>	Net profit after tax
<b>NPV</b>	Net present value
<b>OECD</b>	Organisation for Economic Development & Co-operation
<b>ODV</b>	Optimal deprival value
<b>O&amp;M</b>	Operating and maintenance
<b>PAFC</b>	Phosphoric acid fuel cell
<b>PEM</b>	Proton exchange membrane
<b>PV</b>	Photovoltaic
<b>RAPS</b>	Remote area power systems
<b>RMA</b>	Resource Management Act
<b>ROC</b>	Renewable obligation certificate
<b>ROI</b>	Return on investment
<b>RPM</b>	Revolutions per minute
<b>RTP</b>	Real time pricing
<b>SAIDI</b>	System average interruption duration index
<b>SC</b>	Space cooling
<b>SEF</b>	Sustainable Energy Forum
<b>SHWH</b>	Solar hot water heating
<b>SH</b>	Space heating
<b>SME</b>	Small medium enterprise
<b>SOE</b>	State Owned Enterprise
<b>SOFC</b>	Solid oxide fuel cell
<b>SNZ</b>	Statistics New Zealand
<b>SPD</b>	Scheduling Pricing and Dispatch
<b>T&amp;D</b>	Transmission and distribution
<b>TOU</b>	Time of use
<b>TN</b>	Transmission network
<b>TSM</b>	Traditional supply mechanism
<b>VAR</b>	Voltage amps reactive
<b>WTG</b>	Wind turbine generators

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# Chapter 1

## Introduction

*This Chapter gives some perspective of where the Thesis sits in relation to distributed generation as a whole. It provides an overview of the Chapters contained in the Thesis, highlighting their main objectives.*

---

### **1.1 Electricity in New Zealand**

The electricity industry in New Zealand has recently undergone significant change. It has moved from state-owned, regulated and vertically integrated utilities (Electricity Corporation of New Zealand [ECNZ] plus regional distribution companies) into a competitive market where the monopoly activities (lines businesses) have been separated out from the competitive services of generation and transmission. After 12 years of almost continual reform, there still exists the possibility of further changes, as proposed by the recent Ministerial Inquiry into the Electricity Industry (MED 2000<sub>a</sub>).

In parallel with these reforms, the concept of distributed generation [DG] has re-emerged. A new term, replete with many new technologies that describes an old method of delivering power to end users. DG consists of small energy converting devices such as fuel cells, micro-turbines and Stirling engines that can be located close to the load source and often deliver not only electricity but also thermal energy (heat, cold). Meridian Energy, the largest of the 3 state owned utility companies and the privately owned Contact Energy that were created after

the split of ECNZ, wants to investigate how to take advantage of this new way of providing energy to its customers.

## **1.2 Objectives**

The overall objective of this thesis is to provide Meridian Energy with a decision tool to assist them in their process of identifying DG opportunities, particularly in the residential market. This thesis had two aspects. Firstly, a model<sup>1</sup> to quantitatively assess various DG technologies under multiple scenarios and secondly, a qualitative description of the issues involved with the application of DG in the residential sector.

## **1.3 Scope**

This thesis concentrates on assessing how the energy requirements for residential buildings are provided. Therefore it examines both technologies and demand-side issues that are relevant to domestic<sup>2</sup> applications. However, it is envisaged that the analysis would also be applicable to the study of other sectors in the economy (i.e. the commercial sector and in particular small, medium enterprises [SME]) with minor modifications. Since Meridian Energy is a generator, trader and retailer market participant, issues are viewed by the effect they have on this type of company and not from the transmission and distribution company perspective. Importantly, the scope is future focused to allow the decision tool to address issues likely to change as the electricity industry evolves, but are not yet apparent.

## **1.4 Thesis Structure**

### **Chapter II Literature Review**

Describes the overall drivers that are creating an environment of change in the electricity industry both world wide and in New Zealand, particularly those that affect the introduction of DG. The intention of this chapter was to provide a basis on which to assess the factors affecting DG.

---

<sup>1</sup> The terms decision tool and model are used interchangeably

<sup>2</sup> The terms domestic and residential are used interchangeably

- Chapter III      DG and Meridian Energy  
An overview of the New Zealand electricity industry and the role that Meridian Energy plays in it. This Chapter also explores how a DG business case may be developed by Meridian Energy.
- Chapter IV      Residential Distributed Generation  
This Chapter looks specifically at the market for residential DG in New Zealand. It examines the characteristics of this market as well as the likely technologies to be deployed in it.
- Chapter V      Model Charter  
The model charter clarifies the objectives and purposes of the Thesis in terms of the decision tool that was developed. The model charter is a reflection of the results of the literature study as well as the commercial goals of Meridian Energy.
- Chapter VI      Conceptual Model Development  
The basic premise on which the analysis was conducted on (i.e. the value proposition) is identified and the framework on which this analysis will be carried out is described. It outlines the specific modules (Chapters VII to X) and their position in the model framework.
- Chapter VII     Load Profile Development  
This Chapter describes the concept of load profiling and represents the demand side aspects of the model. It shows the importance, yet difficulty in achieving accurate load profiles that reflect socio-economic factors.
- Chapter VIII    DG Selection  
Describes the technical aspects of the different DG technologies that are modelled. This module highlights the variables that are included in the analysis, the reasons why they were chosen, the assumptions made about them and their impact on the model.
- Chapter IX      Operational Control  
This Chapter shows what different operating regimes could be employed for DG and how this control is achieved.

- Chapter X      Costing  
The mechanism used to cost the supply of energy to a residential consumer, both via the traditional supply means and also with the use of DG technologies is described.
- Chapter XI     Model Implementation  
This Chapter shows how, using a computer programme the formulation developed in the preceding Chapters is implemented. It addresses the practical issues of the system architecture as well as providing a description of the calculation sequence.
- Chapter XII    Case Studies  
Three case studies are conducted showing the model's ability to analyse real market scenarios. The model's functionality is demonstrated and used to discover a range of important insights into the current use of DG.
- Chapter XIII   Conclusions and Recommendations  
This Chapter provides a summary of the model's capabilities. In addition it reflects on the original objectives of the Thesis and provides a commentary on areas that warrant further analysis.

## Chapter 2

# Literature Review

*This Chapter addresses the historical use of DG for energy supply and attempts to put into perspective why the application of DG is again an option for the electricity industry*

---

### 2.1 Structure

The purpose of the literature review is to give an understanding of how DG sits in the electricity industry landscape and in particular what the scenarios are for the residential application of DG from Meridian's [MEL] point-of-view (Figure 2-1).

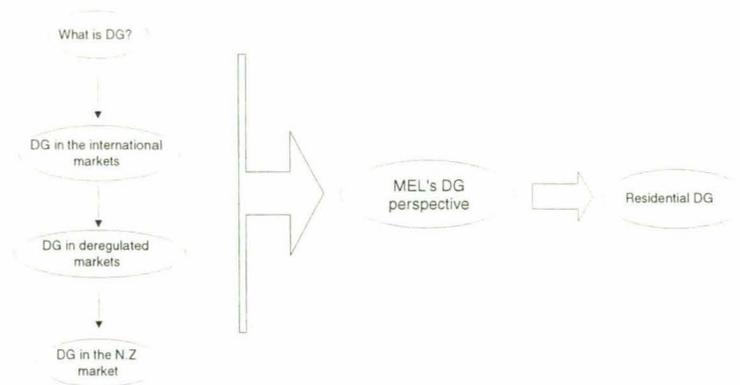


Figure 2-1: Literature Review Progression

## 2.2 What is DG?

In reviewing the literature, there are a number of definitions used for DG. Factors that can affect the classification of a generating entity as *distributed generation* include:

- Purpose
- Location
- Power rating
- Power delivery area
- Technology
- Environmental impact
- Mode of operation
- Ownership

A contemporary definition of DG (Ackermann et al, 1999<sup>3</sup>) states:

*‘Distributed generation is an electric power source connected to the distribution network<sup>3</sup>  
or on the customer side of the meter.’*

However, this definition does not cover the full application intended in this Thesis. By defining DG technologies as “distributed energy converting mechanisms<sup>4</sup>”, it includes more diverse technologies such as solar water heaters and heat pumps, even though they do not produce electric power in their own right but reduce the consumption of it. In addition many existing and emerging DG technologies can run in combined heat and power [CHP] mode, where the 'waste' heat can be utilised as a valuable energy resource.

Therefore the definition of DG in this thesis is:

*‘Distributed generation is an energy source, or conversion mechanism which provides useful energy, that is located in the distribution network or on the customer side of the meter.’*

It is an essential aspect in building a DG model for the purposes of Meridian Energy that the definition used is compatible with the company’s interests. However, because of the dynamic nature of the trends in DG it is probable that the application of DG in the market place will be

---

<sup>3</sup> The distribution network is distinct from the transmission network.

<sup>4</sup> No device can create energy according to the 1<sup>st</sup> Law of Thermodynamics.

subject to change, not only explicitly, with new technologies being developed that fit into this class but also implicitly i.e. with a change in definition of DG<sup>5</sup>.

Figure 2-2 illustrates the positioning of DG in the network. It was felt that this aspect, its location, was the most important criteria in its definition.

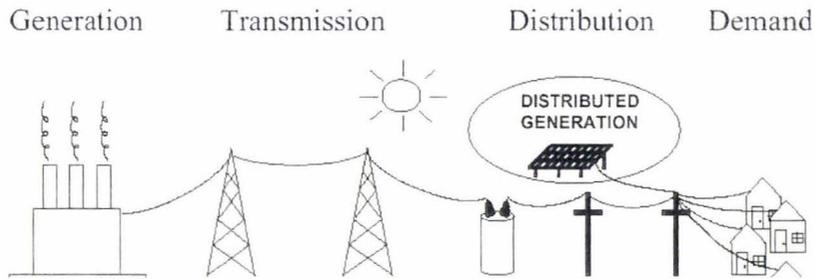


Figure 2-2: Spatial Representation of DG in the Network

Figure 2-3 gives an overview of the size, cost and technology types that may suit the criteria for DG. There is also a time factor (moving from left to right) indicating the drop the dollars per kW cost as technologies mature between 2000 and 2015. If the residential market appears to be suited to by only a narrow band of technologies (below 200 kW) which also happen to be the more expensive.

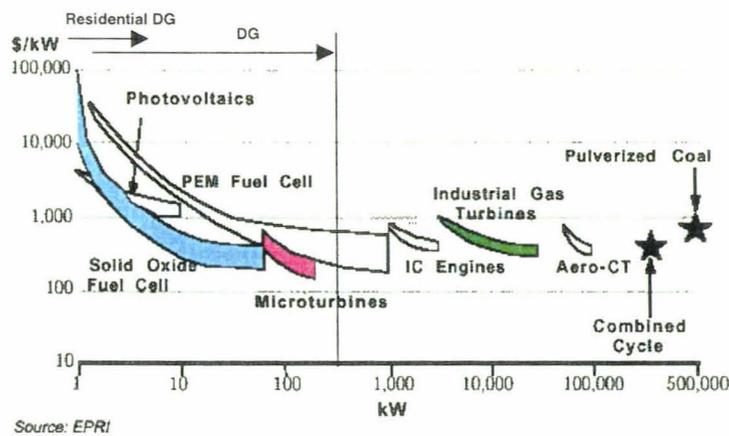


Figure 2-3: Size, Cost and Various Technologies for Power Generation

<sup>5</sup> DG is not to be confused with embedded generation. All embedded generation is DG (as it is located in the distribution network). However if it is located on the utility side of the meter, it would more accurately be classified as 'fully embedded'.

## 2.3 DG in International Markets

### 2.3.1 Historical Trends

DG is not new. The idea to install and operate a power system was first utilised by Thomas Edison in the 1880s. Subsequently a trend developed with generating units being sited close to loads. Because the low-voltage direct current [DC] systems had high losses, thus limiting the distance between load and source. But the advent of transformers and higher voltage alternating current [AC] with lower associated line losses, allowed large generators to be located far from loads. Over the years as transmission line technology increased and economies of scale (due to higher thermal efficiency) became a factor, fewer but larger power stations were built, often connected by high voltage transmission systems. Technological developments were not the only drivers. Institutional and organisational structures such as government owned utilities favoured long term investment and large scale power generation.

Figure 2-4 shows the progression of power production as a function of delivered cost over time. Clearly, economies of scale are evident with costs decreasing with increasing size of plants. However this trend has begun to reverse. The oil price crises in the 1970's showed that many countries depended on imported fossil fuel from abroad to keep their economies alive. This prompted the development of non-fossil fuel technologies including nuclear and renewables<sup>6</sup> to provide a hedge against future oil price rises. This interest in new technologies allowed a shift away from the traditional 'bigger is better' mentality to consider alternatives which were previously thought to be uneconomical. Combined cycle gas technology [CCGT<sup>7</sup>] development in the 1980s led to an optimal plant size of around 100MW, which significantly lowered investment costs and lead times. The late 1990s have seen new technologies such as fuel cells, micro-turbines and Stirling engines in the size range of a few kW to a few hundred kW appear on the market. These technologies, partly because of their small capacity, make them an option for DG in the residential market, though at present they make expensive options.

---

<sup>6</sup> Using the power of nature i.e. wind, solar, biomass, geothermal and tidal as sources of 'clean, sustainable fuel'

<sup>7</sup> Combined cycle refers to the sequential production of electricity, initially by a gas turbine and secondly with a heat recovery steam turbine

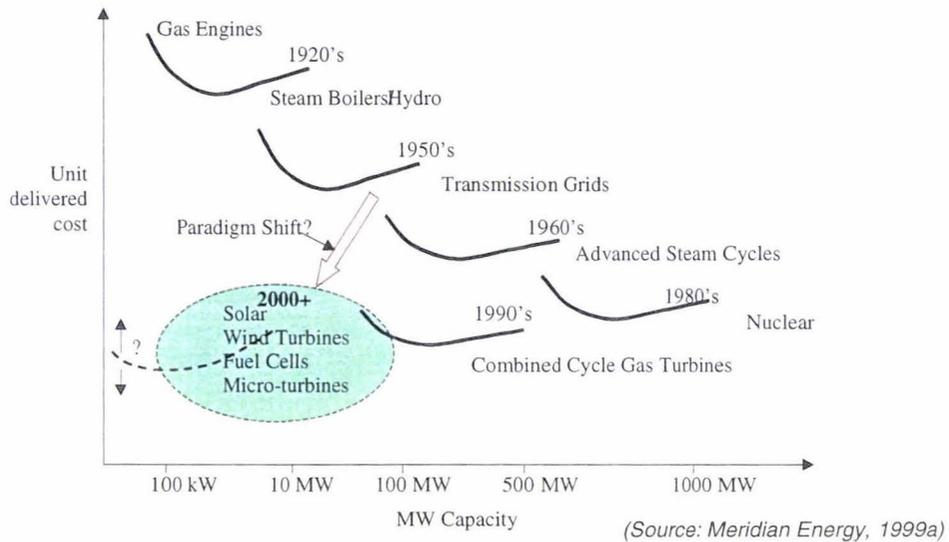


Figure 2-4: Evolution of Electricity Power Production

## 2.4 Drivers

There are a number of factors affecting the application of DG. Many literature sources convey the common theme outlined below (Willis & Scott, 2000):

### 2.4.1 Environmental Issues

There is a perception that 'green' power is better. Policies driven by public awareness place restrictions on the impact on the environment. Reduced emissions for example, has forced the development of cleaner technologies. Large power projects, requiring resource consents which are becoming more difficult to obtain, are becoming less feasible as the lead time increases. The Kyoto Protocol is broadening the scope for renewable energy developments, which often lend themselves to DG applications (e.g. solar and wind based). In California they have a million roofs programme which aims to install PV panels on a million residential roofs. On the retail side customers are becoming educated as to how 'green' their electricity they consume is. For example in Victoria, Australia it is proposed that a CO<sub>2</sub> metric be included on customer's bills. Carbon tax and cash subsidies for 'green' projects are becoming important issues when assessing project feasibility. Environmental and economic policy shifts are moving towards fully costing externalities, which in some cases favour (e.g. solar water heating) but in others decrease (e.g. large scale hydro electric) the value of renewable projects.

#### **2.4.2 Privatisation and Deregulation**

The electricity industry world-wide is evolving, led by a trend towards privatisation and deregulation. Large investment of venture capital into new generation technologies is occurring. This phenomena has been previously observed in the telecommunications industry when it was de-regulated and the resultant growth that occurred in technology development and ultimately in customer use and market capture. Large multinationals such as Shell and BP are entering the market and raising the profiles of new technologies. Deregulation of the electricity market lowers entry barriers for new and smaller specialist energy companies that are looking to deploy DG. This however is not always the case. For example some lines companies may be reluctant to allow third parties to connect DG units to their networks by imposing stringent interconnection standards. The presence or absence of such barriers often depends on who receives the benefit of any particular installation of DG as these more competitive markets are focussed on satisfying specific customer needs and capturing the 'added value' benefits. Further deregulation and competition is moving investment risk and incentives nearer to customers.

#### **2.4.3 Increased Electricity Demand**

World wide electricity demand is increasing. This is especially apparent in the developing world, where not only is the demand increasing the fastest but established transmission and distribution systems do not exist. This is providing growth opportunities for DG technologies as an alternative to large high voltage transmission systems. In the U.S. alone the Electric Power Research Institute (EPRI, 2001) estimates that the market for distributed resources would grow between 2,500 to 5,100 MW annually by 2010, which will account for about 25% of new generation. In addition, world wide electricity forecast shows electricity consumption increasing from 12 trillion kWh in 1996 to 22 trillion kWh in 2020 (U.S. DOE, 1999). It can be seen that there is an obvious need for new electricity generation capacity. It is proposed that DG will provide a portion of the increase without having to replace existing large scale power plants.

#### **2.4.4 Increased Need for Power Quality**

The 'new' economy industries that provide the nerve centres for the 'information age' we live in, such as network servers, telecommunication exchanges, data processing facilities for banks and governments, all require high quality power. In addition, many manufacturing and process industries are reliant on computer controlled critical manufacturing processes. The widely quoted example of silicon-wafer manufacturing, incurs losses in the millions of dollars for momentary power fluctuations. The cost justification for installing DG at a particular site is often not based on the cost of the electricity provided but on the cost of not having

electricity or electricity of sufficient quality. Different DG technologies allows a customised solution that meets the power requirements for its host. The 'solution' is defined in terms of the response speed and sensitivity to voltage fluctuations and the duration that the load can be sustained.

#### **2.4.5 New Technologies**

Whether technology development drives market reform or the other way round is open for debate. However the reality is that the long awaited commercialisation of some technologies such as fuel cells, external combustion engines and micro-turbines is happening. It is no longer a question of if, but when technology will meet the increasing demand for cleaner, more efficient small scale power systems. Further, the huge advances in information and communication technologies are both enabling networked systems approaches and overcoming earlier barriers to the widespread application of DG. Recent performances of micro-turbine manufacturers Capstone and Plugpower in the USA, and the increasing flows of venture capital into development companies, signal investors' near term expectations of significant industry change (Little, 2000).

#### **2.4.6 Natural Gas**

Gas is fast becoming the premium fuel for power and heat generation, which many DG technologies utilise. Its cleaner burning characteristics (compared with coal) often lower price and suitability for state-of-the-art CCGT power plants have heightened the awareness of gas as a fuel choice in the market place. Further the gas networks that are often quite extensive with high levels of penetration, are in many cases operating below their maximum capacity. The opportunity to exploit this marginal gas line capacity in highly reticulated urban areas warrants further exploration. However it must be cautioned that as gas demand increases so inevitably does the price. In fact in the past 14 months natural gas prices have quadrupled in the USA, a fact now ironically quoted by nuclear industry proponents.

#### **2.4.7 NZ Situation**

The drivers above are operating at global levels. Technology that is being developed as a result of them may not find application at all national or regional levels. In other words what is economically the best option in Asia, where established large-scale generation and transmission systems don't exist and there is a massive shortfall in generating capacity, will not necessarily apply in New Zealand where there is currently a generation surplus (wet year) and electric power is cheap and reasonably reliable by comparison with other countries. Concerning natural gas in NZ, the anticipated demise of the Maui field by 2007 has placed

greater emphasis on the discovering and bringing into production of additional fields, with an associated rise in gas price to facilitate further exploration expected.

## **2.5 Benefits**

The benefits of DG are numerous, however it is important to address them in correct context, which some proponents of DG have failed to do. Moreover the benefits experienced may be specific to the type of 'player' in the market; be it generator, retailer, lines company, transmission company or end-user. The difficulty in performing a cost-benefit analysis is that DG resources produce benefits that typically flow to more than one entity. This produces a split incentive where no single entity sees all the benefits, meaning their desire to introduce DG is likewise affected.

### **2.5.1 Avoided Transmission and Distribution Costs**

The defining characteristic of DG is its location, close to the load. The electricity therefore has to travel a relatively short distance, consequently avoiding transmission and distribution [T&D] line losses which in NZ typically account for 8% of the electricity produced. The line losses are a result of the heat dissipation that occurs in cables transporting electricity as well as in transformers which convert the voltage level. Avoiding these losses and consequent recovery costs mean cheaper electricity. Another consequence is the avoidance of use of system charges of the T&D networks. For example, if the DG unit was embedded in the distribution network the total power drawn from the relevant grid exit point [GXP] could be lower, meaning lower charges paid to the transmission company. Deferral or avoidance of system capital investment by way of transformer, substation or line capacity upgrade is an option open to network companies by employing DG technologies in constrained areas of their network. These points of constraint (an imbalance of supply and demand) can either be due to the market (competitive) or lack of line carrying capacity (physical) which result in volatile and high prices.

Depending on whether the load is connected to the grid will determine the extent to which T&D costs can be avoided. If the grid is used as back-up, a connection fee will be incurred, whereas if the lines are cut, all costs associated with the grid can be eliminated. However, this last option appears unlikely for the mass residential market where frequent load variations, the low likelihood of customers investing in multiple redundancy and cost of storage devices often mean staying grid connected is likely to make economic sense in the foreseeable future.

There may be another set of T&D costs to consider; those of the gas network. If, as many anticipate, natural gas is used to provide the fuel for many of the DG technologies like fuel cells and Stirling engines, the gas network costs may become a constraining factor to consider. At present in New Zealand the gas network is only at 50% capacity factor in places but this could change with the advent of wide spread deployment of gas fuelled DG.

### **2.5.2 Bundle the Customers' On-site and Market Needs**

Locating a DG unit on the customer's premises allows for greater flexibility in meeting the energy requirements. Customers can specify what their needs are in terms of power quality, reliability and cost. A number of solutions can be designed which may include various DG technologies and different configurations. An example of this is the Bank of Omaha, USA , which required a reliability of 99.999997% for its Data Technology Centre. This equates to less than one second of predicted downtime each year because a one hour outage is estimated to cost around US\$ 6 million (HDR, 2001). A four fuel cell configuration (2 being adequate to completely supply the critical base load) was used. The utilisation of waste heat can lead to a more complete 'energy package' being offered which not only includes electricity but water heating, space heating, space cooling and even refrigeration.

### **2.5.3 Increased Efficiencies with Combined Heat and Power**

Most electricity production has associated heat generation with it. The utilisation of this heat for process or heating needs for example can lead to lower heating value [LHV] efficiencies of between 75-85%. This compares to efficiencies of some non-CHP configurations of 25-35% for some DG units (Meridian 1999<sub>a</sub>). CHP is achieved only where the heat load is in close proximity to the DG source and where efficient heat transport mechanisms exist.

Figure 2-5 gives a numeric example of this: 696 units of energy to provide 400 units of delivered energy via the traditional supply chain versus 500 units needed for a CHP system.

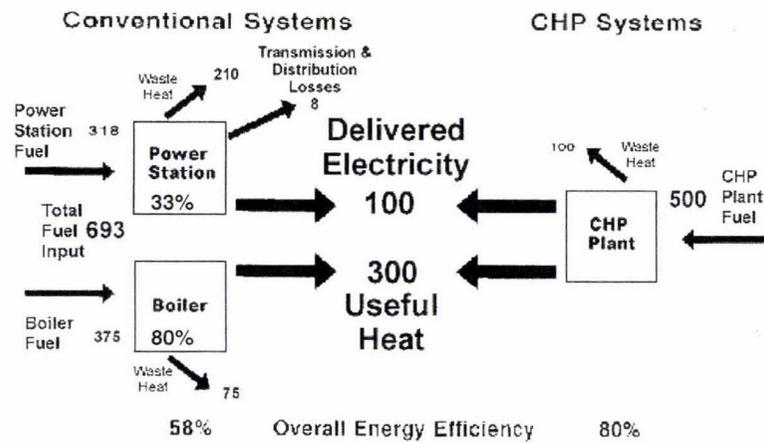


Figure 2-5: An Example of CHP Efficiency Compared with Conventional Supply Systems

Not only can the 'waste' heat be used as a thermal source, in some instances it can be used to generate additional electricity in a co-generation configuration. An example of this is the solid oxide fuel cell [SOFC], which operate at temperatures of around 1000°C where hybrid fuel cell-steam generator systems are used (Lee & Sudhoff, 2001). However, this normally requires high grade heat (high temperature and pressure steam) which is normally outside the domain of units sized for domestic applications.

#### 2.5.4 Utilise Low Cost Process Waste Fuels

Industries that have suitable waste streams such as forestry, dairy and petrochemical can transform a possibly costly waste management issue into a low cost fuel (e.g. timber waste). It would however be unlikely that residential use of such fuels could occur in New Zealand. Industrial DG applications of this variety have occurred in NZ recently. For example Meridian Solutions (a subsidiary of Meridian Energy) is actively pursuing such opportunities and Biogrid (a subsidiary of Carter Holt Harvey) is currently working with Golden Bay Cement to use wood waste to replace some of the coal used at their cement works.

#### 2.5.5 Short Lead Time

The 'off the shelf' availability of many DG technologies minimises lead times and reduces design costs. In addition, their modularity can minimise large capital expenditure by avoiding the need to invest in redundant capacity. By incrementally purchasing additional capacity the risk of uncertain demand can be decreased. Importantly the difficulty in obtaining resource consents in countries like NZ, under the Resource Management Act [RMA], can be eased e.g. avoid having to secure right-of-way access for power lines and consents for large, high impact plants.

## 2.6 Modes of Application

The different modes of applications of DG are widely known (Table 2-1). In reality the best mode might be a combination of these. For residential applications, the continuous power, CHP and peak shaving modes may be best at different times and locations.

Application Mode	Description
Continuous Power	Unit runs continuously either as: <i>Back-up</i> - running in parallel with the grid  <i>Uninterrupted</i> - running independent of the grid
CHP	Utilising waste heat as a useful thermal output
Peak shaving	Operating when demand and/or charges are high
Standby/emergency generation	Periodic use to provide power whenever grid fails
Mechanical drive	Units drive shaft-driven equipment
Grid support	Applications may use DG to defer T&D system upgrade or to provide ancillary services
Emerging applications	Premium or green power

(Source: Distributed power, 2000)

Table 2-1: DG Application Modes

## 2.7 DG in Deregulated Markets

Various countries world-wide have and still are undergoing market deregulation. A number are reviewed here (Ackermann et al, 1999<sub>a</sub>)

### 2.7.1 England and Wales

An important issue in these countries was the development and commissioning of the Non Fossil Fuel Obligation (NFFO) bidding system. The implementation of NFFO contracts was slower than anticipated due to difficulties with planning mechanisms and has been replaced by a new Renewable Obligations arrangement (suppliers have to include a specified 3% of electricity generated from renewable sources). In addition Renewable Obligation Certificates (ROC's) will be generated and traded.

- Introduction of green pricing mechanisms are expected to lead to a greater number of smaller projects, which may be classified as DG due to their size and/or location.

- In December 1997 the Labour government introduced a moratorium on planning consents for new gas fired power stations, which may slow down new large-scale gas turbines and CHP units.
- A country wide target to achieve 10% electricity generation from CHP plants by 2010 has been introduced. Installed capacity of CHP grew by 62% (1439 MW) from 1991 to 1997.

### **2.7.2 California**

- The state of California has been the subject of much interest due to their second consecutive summer of rolling blackouts in 2001. As one of the pioneers of deregulation in the United States it is interesting to note the small role that DG has played in the power crises.
- The two regulatory issues that are influencing how DG is applied are the funding by the California State Energy Commission and green pricing schemes. The funding for projects which have wind, geothermal, small hydro, landfill gas and biomass technologies. The green pricing schemes include a commitment to build new renewable generation plant when a sufficient amount of customers have signed their commitment to purchase 'green' electricity.
- California has 11% non hydro renewable generating capacity which suggests a significant share of DG. Wind may be an obvious exception as it often feeds into the transmission network and hence cannot be classified as DG.
- It should also be noted that there are other states that have begun to reform their electricity industries such as New York and Texas.

### **2.7.3 Norway and Sweden**

- In Norway the nature of the population distribution has led to a large number of power companies which in the past developed their own networks and power generation, resulting in wide use of DG. In late 1998, financial support for projects such as wind were introduced which led to a total of 600 MW of wind power now being in the planning stage (Ackermann, 1999). In 1999 the government announced restrictions on CO<sub>2</sub> emissions from new gas plants making them less economically viable. No special regulations for small scale DG exist.
- In Sweden there are a large number of small and micro-hydro stations, some of which are owned by distribution companies. Renewable technologies including wind, that have received special support in the past are now under review making their future uncertain. Biomass as a fuel for DG units has great potential, particularly within the paper industry which includes applications for CHP with electricity being fed into the grid in some cases. Sweden has a CO<sub>2</sub> energy tax for which renewables and DG producing less than 1.5 MW

will be reimbursed for CO<sub>2</sub> tax paid. There are also concessions for small scale generation (up to 1.5 MW), in which the concession holder is required to buy all the power supplied by these small DG units at a tariff that represents the avoided costs of the concession holder.

#### **2.7.4 New South Wales and Victoria**

- For the period 1995 to 2000, 1470 MW of new grid connected DG was added in New South Wales, increasing its share to 13.7%. A pollution levy is proposed to be the main driver for DG.
- In Victoria over the same period, 247 MW of DG was added resulting in a 7% share of total generating capacity. A special government program promoting CHP was responsible for about a third of all new DG systems, however with no pollution levy DG has less incentive to be developed.
- A green pricing scheme introduced has led to approximately 19MW of new distributed renewable energy [RE] being employed since 1997 in both states. In addition the nation wide quota for renewable energy which requires retailers 2% of generation to come from RE by 2010 is expected to lead to further installations of renewable distributed energy technologies.

It has been noted during the review of other electricity industries, that they do differ markedly, not only in their physical makeup of generation type and transmission systems but even more so in their restructuring. The 'life' of DG in NZ is difficult therefore to predict from overseas experience.

## **2.8 DG in the New Zealand Market**

### **2.8.1 Historical**

DG in New Zealand is not a new phenomenon. Following the historical overseas trend, electricity was produced at or near the load site, until centralisation of the industry began in the 1930s. Since then, the government and power boards have developed a backbone of high voltage transmission lines, distribution infrastructure, and generation plants using fossil fuels, hydropower and geothermal energy to bring networked electricity to almost every part of the country. New Zealand's reliable T&D system and comparatively low electricity prices as well as its highly reticulated electricity network has led to a low impact of DG on the market.

Figure 2-6 illustrates how the percentage of DG has fallen from 100% in the early 1900s to a low in the 1970s. At this point, following overseas trends, DG (particularly industrial DG) began to be used for more electricity generation. However, it is only from recent times that the percentage of DG has significantly increased mainly due to industrial co-generation plants and the Tararua wind farm.

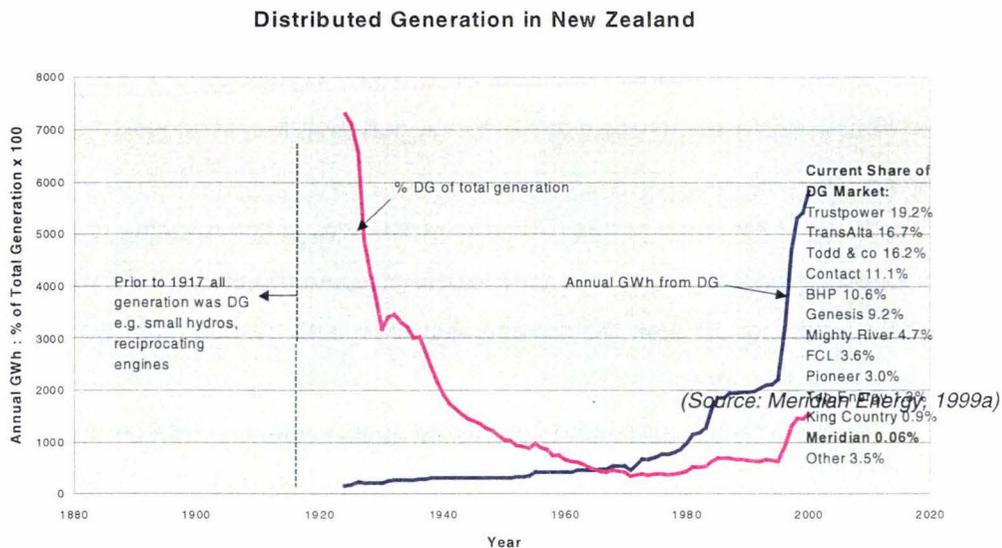


Figure 2-6: DG Development in NZ

### 2.8.2 Reforms

There have been a progression of reforms in the New Zealand electricity industry. The more recent significant developments are shown in Figure 2-7.

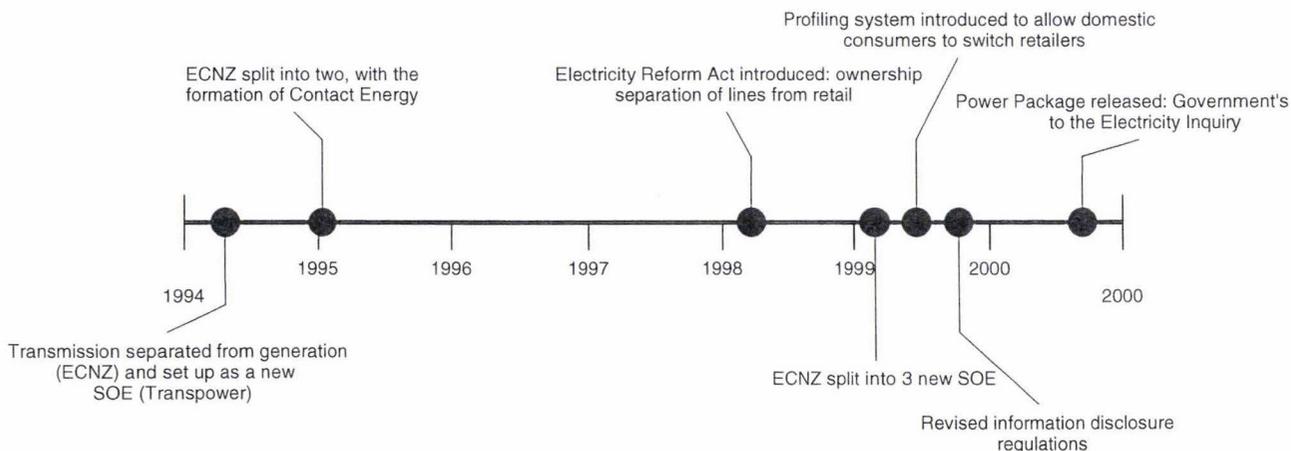


Figure 2-7: Evolution of Electricity Reform in NZ since 1994

In essence the reforms were designed to give smaller consumers a choice of power suppliers and lower prices; lower electricity costs for business and industry; guard against privatisation; and be better for the environment. As indicated above a major component of the reforms was

the Electricity Industry Reform Act [EIRA] 1998, which required the separation of vertically integrated companies into distinct line businesses or generator/retailer businesses. This was to prevent integrated companies from using their monopoly lines position to prevent competition in their area by restricting access to customers, cross subsidising some customers and also by cross subsidising their generation from their monopoly line position. Before the onset of competition wholesale prices averaged 3.35 c/kWh, in a wet year. For the later half of 1999 after the reforms came into play prices dropped to 2.58 c/kWh indicating that, at least at the wholesale level, the government's objective of lower prices was being achieved.

It is vital for any study on DG that the proposed reforms are understood because changes in the regulatory framework can have significant impact on who the players are in the DG market and to what extent that will be mandated.

### **2.8.3 Ministerial Inquiry into the Electricity Industry**

The purpose of this inquiry in 2001 was to "evaluate whether the current regulatory regime (EIRA) meets the government's objective of ensuring electricity is delivered in an efficient, reliable and environmentally sustainable manner". It was undertaken in response to the perception that the previous reforms had not delivered sufficient benefit to consumers. Importantly the discussion on how DG is to be treated is very significant as the economics and therefore application of DG can be greatly enhanced by a favourable regulatory regime.

### **2.8.4 Power Package**

A number of issues were identified in the Inquiry and responded to by the Government in the Power Package (released in 2001), that related to DG. They include:

#### *Ownership of DG*

DG should be allowed to be utilised where it is most economically efficient. Lines companies, although having strong drivers to use DG were currently prohibited from owning DG. The government believed that this restriction should be removed to allow lines companies to own DG up to 2 percent of the network's maximum demand or a maximum of 5 MW, provided that the source of such generation is a new renewable and that the generation activity is carried out in a separate company. They believe that this would not endanger the underlying objectives of the EIRA. However some industry participants have questioned whether this will be possible. New legislation enabling this change in ownership has recently been passed.

### *Construction and implementation of DG plant*

Obviously line companies are in a good position to identify opportunities for the implementation of DG within their network. Therefore provision will be made to require that line companies publicise their intentions to construct DG 30 days prior to entering binding contracts. It must be questioned though whether this will allow competitors sufficient time to respond.

### *Connectivity with the network*

It is proposed that the Electricity Governance Board<sup>8</sup> develop generic terms and conditions for the connection of DG to distribution networks.

However not all points highlighted by the Inquiry with respect to DG were addressed by the Government's response. These include:

*Functionality of DG* - DG should be allowed to participate in the provision of ancillary services such as demand shedding or frequency support.

*Transpower's stand-by charges* - Customers utilising on-site generation are required to pay for their off-take based on peaks during the preceding 12 months, even if they only utilise Transpower's services for a fraction of that time. A differential standby facility charge is proposed.

### **2.8.5 National Energy Efficiency and Conservation Strategy**

As Figure 2-8 indicates the National Energy Efficiency and Conservation Strategy (NEECS) is another aspect of the government's energy policy.

Its goals are to (EECA, 2001<sub>a</sub>):

- Reduce CO<sub>2</sub> emissions
- Reduce local environmental impacts
- Improve economic productivity
- Promote industry development
- Improve economic resilience
- Reduce energy deprivation

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<sup>8</sup> The Electricity Governance Board [EGB] is the amalgamation of the NZEM, MARIA and MACQS

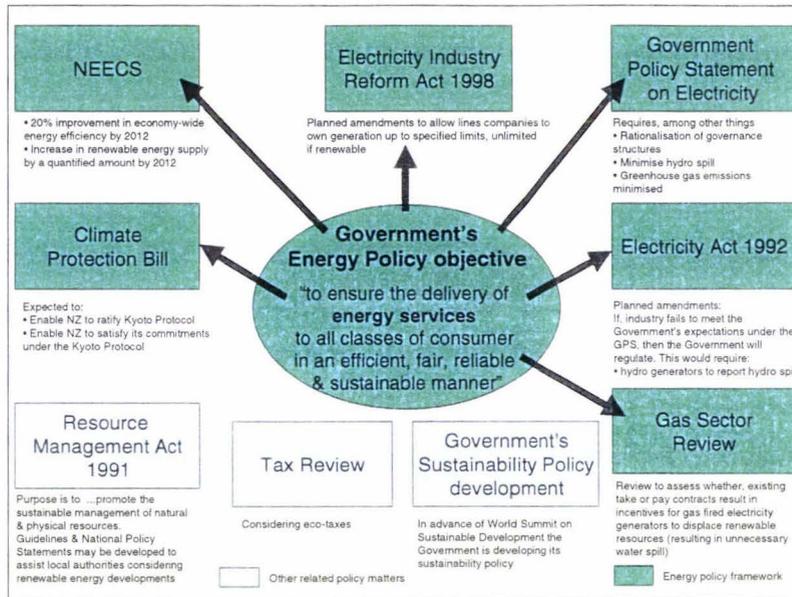


Figure 2-8: Government's Energy Approach (Source: Meridian Energy, 2001)

Its targets which are required to be measurable, reasonable and practical include:

- Energy efficiency: At least 20% improvement in economy-wide energy efficiency by 2012
- Renewable energy: Increase renewable energy supply by 30PJ by 2012.

What is of interest to DG proponents and Meridian Energy is how technologies, including renewables that lend themselves to DG applications are going to be supported as a result of the government policy? Some of the possible measures that may be employed are:

<b>Energy Supply</b>	<b>Renewables</b>	<ul style="list-style-type: none"> <li>• Facilitate use of wood waste in forestry processing sector</li> <li>• Evaluate mechanisms to increase proportion of electricity from renewables</li> </ul>
	<b>Electricity sector</b>	<ul style="list-style-type: none"> <li>• Improve understanding of DG and Demand Side Management [DSM]</li> <li>• Introducing pricing to facilitate energy efficiency</li> </ul>
	<b>Industry development</b>	Develop support mechanism for solar water heating industry
<b>Buildings</b>		Home energy rating scheme
<b>Industry</b>		Direct grants to carry out energy audits

### 2.8.6 Current Environment

The current environment provides both encouragement and uncertainty to DG proponents. As shown earlier, proposed changes to legislation, particularly relating to lines companies are addressing some of the issues facing DG. Ironically as the name suggests 'distributed' generation has significant benefits for the distribution network in terms of system capital deferment for line upgrade. But with restricted DG<sup>9</sup> ownership, lines companies are reluctant to give over control of potentially hundreds of units to third parties. High entry and membership fees into the market have put small companies wanting to specialise in DG at a disadvantage and the lack of common interconnection standards have meant that unforeseen expense and delay can reduce the feasibility of a DG applications.

In the New Zealand market, DG has made an impact. Growth in energy demand over the last five years has averaged around 2% per year i.e. a total of around 500 MW. Approximately half of this has been DG. Table 2-2 (Meridian Energy, 1999<sub>b</sub>) summarised the DG installations that have occurred in New Zealand.

Plant	Type	Size (Electric)	Market
Te Rapa	Gas Turbine	60 MW	Dairy Co-gen.
Te Awamutu	Gas Turbine	80MW	Dairy Co-gen.
Bay Milk	Gas Turbine	65 MW	Dairy Co-gen.
Haunui	Wind	3.5 MW	Distribution support
Brooklyn WTG	Wind	225 kW	Embedded generation
Tararua	Wind	32 MW	Embedded generation, distribution support
Blue Mountains Lumber	Biomass Steam	1.5 MW	Industrial co-gen.
Kinleith Pulp and Paper	Biomass Steam	40 MW	Industrial co-gen.

Table 2-2: Recent DG Installations in NZ

The installations fall into two categories: a) Large industrial applications, primarily in the dairy and wood processing industries and network support such as voltage regulation using wind turbine generators. This initial uptake was expected, particularly in the industrial sector where the most profitable sites are 'cherry-picked'. These sites are typically viable because they can utilise low cost fuel and/or the heat produced in a co-generation configuration.

<sup>9</sup> DG for the use of network reinforcement and peak demand management would probably be dominated by non-renewable generating technologies because of their higher availability.

b) Network support has been provided by WTG, able to supply both active and reactive power. The large increase in units produced, particularly overseas, has resulted in WTG becoming more cost-effective and hence a growing application. Apart from these two categories, DG applications have been minimal, the challenge, if DG is to gain widespread application in New Zealand, is to explore the smaller end user i.e. the small commercial and residential user.

Table 2-3 shows a study conducted by ECNZ's Technology Research Strategic Development Group that shows the number of potential sites in relation to their energy requirements that may be serviced by DG. The domestic market sector represents the greatest potential in terms of the number of sites but the smallest on an energy per site basis.

Market Sector	Annual Growth Total GWh	Average Site Usage GWh	Average Site Load kW	Est. Annual Potential Sites
Industrial	265	10	1,000-3,000	5
Commercial	265	2	50-1000	30
Domestic	265	0.008	3-5	1250

(Source: TRSDG 1998<sub>b</sub>)

Table 2-3: ECNZ Study on the Potential Market for DG in NZ

## 2.9 Previous NZ Distributed Generation studies

The main published studies into the NZ market for DG are reviewed below. Presumably there been more but given the relatively recent interest in DG applications and the previous limited number of interested parties (with a single ECNZ and past prohibition on lines company ownership) the scarcity of work is not surprising.

### 2.9.1 Industrial Research Limited (IRL)

Numerous studies have been conducted by IRL into different aspects of DG (Table 2-4).

Area	Scope	Detail	Result
Dispersed Power Source (DPS) model	Regional across all of NZ and concentrating on residential market	NZ divided into regional: <ul style="list-style-type: none"> <li>▪ Resource data</li> <li>▪ Energy consumption</li> <li>▪ Electricity price</li> </ul>	Which regions in NZ best support which technologies, based on financial return. They are:

Area	Scope	Detail	Result
<i>Gardiner &amp; Sanders (1999).</i>		<p>Compared different pricing mechanisms:</p> <ul style="list-style-type: none"> <li>▪ Tariff</li> <li>▪ Line replacement costs</li> <li>▪ GXP</li> </ul>	<p>New Plymouth - Photovoltaics</p> <p>Wellington - Wind</p> <p>Palmerston North - Biomass</p>
<i>Sanders &amp; Gardiner (2000).</i>	<p>Two case studies done in the Wellington region:</p> <ul style="list-style-type: none"> <li>▪ Commercial site</li> <li>▪ Cluster of small businesses</li> </ul>	<p>Demand profiles simulated against single generating profile</p> <p>Excess power sold to grid</p>	<p>Comparison of different turbine sizes with ROI and payback years. Optimum turbine size of 230 kW with payback periods of between 12 and 20 years, depending on price of electricity saved.</p>
<i>Sanders. (2000).</i>	Regional	Uses retail cost to compare payback time for different regions and technologies.	<p>Provide 'hot spot' map of network areas where renewables are most economical. They are:</p> <p>Marlborough Lines- Solar thermal, Solar PV &amp; Biomass</p> <p>United Networks (Waitemata) Wind energy</p>
<i>Ackermann, et al. (1999<sub>b</sub>)</i>	11kV distribution network	<p>2 step process:</p> <ol style="list-style-type: none"> <li>1) Overall system optimisation model</li> <li>2) Electrical system simulation</li> </ol>	<p>Embedded WTGs, capable of supplying reactive and active power can improve power quality in low voltage distribution systems. (It is shown that a 280 kW WTG has a similar influence to two 900 kVAR capacitor banks)</p>

Table 2-4: Summary of IRL's Work on DG

It is interesting to note the differences between Sanders (2000) and Sanders & Gardiner (2000) in terms of the optimal regions for various technologies.

The work involved in producing the DPS model appeared to be the most relevant to this thesis. It was designed to simulate and compare the use of various DG technologies in residential applications by considering a number of factors:

- Operating conditions
- Operating capacity
- Import/export of electricity
- Storage and heat recovery
- Demand
- Weather patterns
- Fuel prices
- Technology and fuel types

Significant factors found to impact the feasibility of DPS technologies were:

- geographic availability and cost of renewable energy
- equivalent cost of grid purchase
- comparative cost of network upgrade

The model highlighted the sensitivity of simple economic indicators like payback period to these factors.

Weaknesses in the DPS model include:

- The load profiles are limited in scope and flexibility i.e. they are not linked to any socio-demographic factors and are not sensitive to varying individual end uses i.e. the IRL's model is limited in its ability to reflect demand side changes.
- Economic analysis is simple discounted cash flow and may not take account of other factors e.g. CO<sub>2</sub> tax, and avoided network reinforcement.
- Some of the DG technology descriptions are quite simplistic and the model cannot consider combinations of DG technologies.
- Does not provide an estimate of effect on network in terms of net power flows.
- Does not model diversity between houses.
- Does not offer the capability to perform a network analysis, with a number of houses, each having a DG unit installed.

## 2.9.2 ECNZ

Before the ECNZ was split into three SOE's a number of investigations into DG were carried out:

Area	Scope	Detail	Result
<b>Ceramic Fuel Cell Ltd</b>  <i>ECNZ (TRSDG 1998<sub>a</sub>)</i>	ECNZ's fuel cell investment strategy	Comparison of different fuel cells & SOFC in various operating modes	Detailed mass, steam and energy balance on plant
<b>ONSI Power Plant</b>  <i>Center for Technology. (1997)<sup>10</sup>.</i>	Fuel cell application in NZ	Comparing different applications of: <ul style="list-style-type: none"> <li>▪ On-site energy</li> <li>▪ Continuous power</li> <li>▪ Independent power</li> <li>▪ Power quality</li> </ul> with and without the application of the waste heat	Output of 20yr life giving NPV and IRR. E.g. Fuel cell serving a computer centre as a continuous uninterruptible power supply:  NPV \$265 <sup>11</sup>  IRR 29.5%
<b>Rutherford House: Case Study</b>  <b>Meridian 2000<sub>b</sub></b>	Fuel Cell Application Case Study	Explores different fuel cell types for different sectors of the economy	Suitability of fuel cell type for commercial building and industrial facilities in rank are: <ol style="list-style-type: none"> <li>1. PAFC</li> <li>2. PEM</li> <li>3. SOFC</li> <li>4. MCFC</li> </ol>

Table 2-5: Previous DG Studies by ECNZ

The work carried out by ECNZ centred around their investment in fuel cells. The studies investigated different types of fuel cells, under different operating configurations and for different applications. The study on Rutherford House, a commercial building (10,043 m<sup>2</sup> floor area), appears to be the most relevant as it analysed how the daily power and thermal component of the load profile could be met with micro-turbine or fuel cell technologies.

<sup>10</sup> Conducted on behalf of ECNZ by the University of Waikato

<sup>11</sup> Interest rate of 9%

### 2.9.3 Transpower

A recently completed study gave a general overview of DG and how it may impact New Zealand's transmission system (Table 2-6).

Area	Scope	Detail	Result
Impact of DG  <i>Fuge et al. (2000)</i>	Transpower and the transmission network	High level review of DG	DG impact will be less than growth in demand and most applications will be grid connected

Table 2-6: Transpower's Recent Study on DG

An important aspect considered was the interconnection issues faced by DG, particularly since most applications will be grid connected. The report describes interconnection standards and market mechanisms to determine but the optimal siting of DG within the network.

### 2.9.4 Other Studies

Numerous works have been carried out in the area of remote area power supply [RAPS] (Irving 2001). These involved rural loads where the significant cost of line upgrades make DG a more viable option. Given that these applications are typically not grid connected and electrical storage facilities are employed, this type of application is a significantly different proposition to urban residences, which this thesis considers.

Overall it was noted that there had been relatively few studies into DG, particularly at the residential level. The studies were either at a high level-general overview or concentrated on a particular technology type. For example, Appendix A.3.3 contains results from a solar hot water heater study (EECA, 2001<sub>a</sub>). IRL have done the most wide ranging in-depth studies and have created a model for the assessment of DG economics, unfortunately the DPS model was not available to Meridian Energy.

There are also a number of commercial software models that have been developed to assess DG (Table 2-7). They are primarily sourced from overseas and have a broad range both in the depth of analysis of a particular technology type as well as the number of scenarios and variables examined (E source, 2001).

<b>Model name</b>	<b>Producer</b>
DG Argus	Apogee Interactive
D-Gen Pro	Architectural Energy Corp.
Cogeneration Ready Reckoner	Australian Department of Industry, Science and Resources
Disgenie	e2thermax
Spreadsheet Screening Tool	Energy and Environmental Economics
SOAPP-CT.25	EPRI
DIRECT	Kreider and Associates
RETScreen International	Natural Resources Canada
Quickscreen	Sandia national Laboratories

*Table 2-7: Commercially Available Tools to Evaluate DG*

These models, whilst providing useful information, did not address the integration of the supply and demand side in the residential marketing sufficient depth and as such could not be used further in this study.

## Chapter 3

# DG and Meridian Energy

*This Chapter provides a description of Meridian Energy and its role in the NZ electricity industry. It explores the drivers for Meridian Energy in developing a DG strategy and what the strategy might entail.*

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The following material has been sourced from general discussions with staff at Meridian Energy plus 'in-house' documentation.

### 3.1 Introduction

Meridian Energy is both a generator and retailer in the NZ electricity market. Its main generation capacity is located in the South Island in the Waitaki hydro systems and the Manapouri power station. It has around 228,000 customers with a significant portion, excluding Comalco<sup>12</sup>, remote from its generating base and at the other end of the Transpower operated High Voltage Direct Current [HVDC] link to the North Island, a major transmission constraint. This, combined with predicted load growth being mainly in the North Island, means that Meridian is exposed to significant transmission and distribution costs and runs the risk of becoming a 'stranded generator'. Although Project Aqua (in the lower Waitaki Valley) is aiming to service the growing South Island electricity demand in dairying and

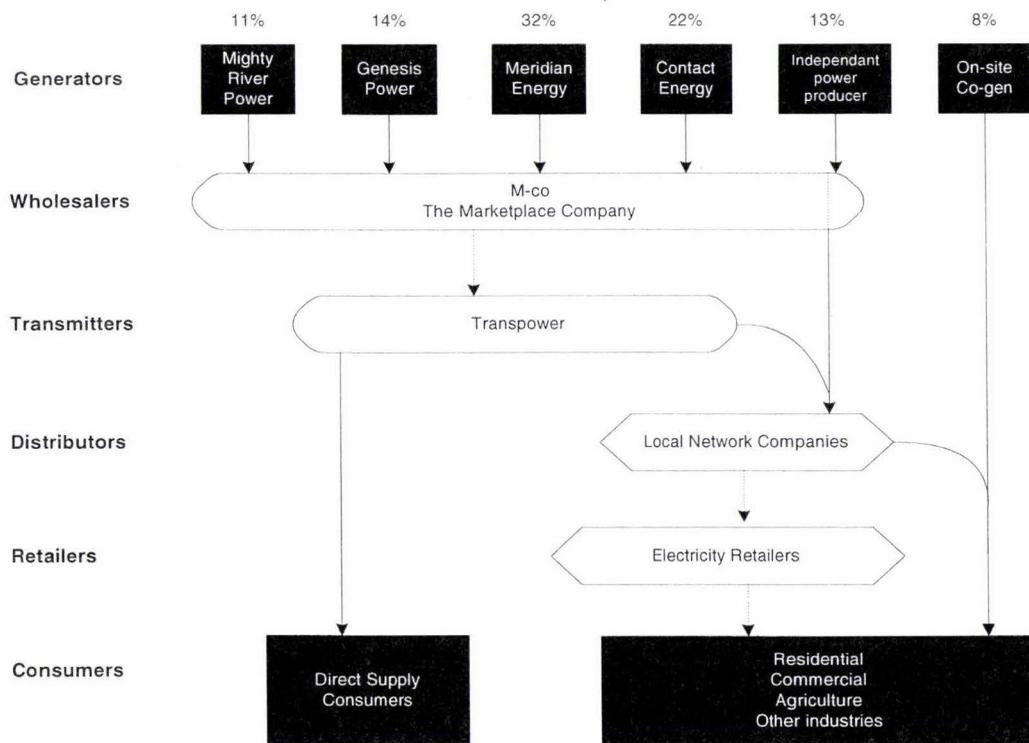
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<sup>12</sup> Comalco owns and operates an aluminium smelter at Tiwai Point which consumes the majority of the output from Manapouri power station

irrigation. Meridian's customers are primarily price-driven and DG technologies offer Meridian an innovative way to minimise future transmission and distribution costs and hence offer lower prices to their customers. Strategic placement of generation capacity can overcome cost penalties incurred in supplying energy to specific locations within local electricity grids. It could allow Meridian to decrease costs associated with the delivery of electricity to customers through expensive transmission and distribution networks thus giving Meridian a greater capacity to both retain its present customers and acquire new customers. In addition, DG may provide a hedge against high electricity prices driven by low inflows into the hydro storage lakes. The recent crisis in 2001 highlights the risks associated with predominant use of hydropower with small storage capacities.

### 3.2 NZ Electricity Overview

The current structure of the NZ electricity industry and the relationship between the various sectors as power is moved from generator to consumer is summarised in Figure 3-1. A qualitative description of each sector in the industry follows. Section 4.6 gives a more detailed analysis of the network aspects as they relate to DG.



(Source: MED, 2000<sub>b</sub>)

- ▶ Contractual agreements between generators and retailers via M-co to purchase and supply power to electricity end users through Transpower and local network companies
- Conveyance of power from generators to end users through distribution companies

Figure 3-1: NZ Electricity Industry Structure

### 3.2.1 Generation

As of November 2000 there was 8,300 MW of installed generating capacity in NZ, which generated around 37,500 GWh of electricity annually. The two main sources of this generation were hydro and gas at 62% and 25% respectively. Geothermal, wind and biomass provided most of the remaining generation. Two thirds of the hydro generation is located in the South Island (MED, 2000<sub>b</sub>). An important feature of the NZ scene is the small amount of hydro storage - around 13% of annual demand, in comparison to over 2 years storage in Norway. This can have significant impact on the spot price, when inflows are small and demand is high as evidenced by the high market price in the winter of 2001. In terms of new thermal generating capacity Contact Energy's Otahuhu B plant (390 MW) was commissioned during 1999. Significantly, it is located, near the major load and growth centre of Auckland. There has also been a number of renewable energy and energy supply efficiency projects under construction. Notably an increase in wind generation to 64 GWh per annum and the completion of the second Manapouri tailrace tunnel which will provide an additional 640 GWh per annum of renewable energy (Meridian, 2000<sub>a</sub>).

### 3.2.2 Wholesale market

The NZ Electricity Market [NZEM] is a transparent, voluntary and self regulating market. It was established in 1996 by market participants to foster a robust, enforceable, efficient and competitive market for electricity. The NZEM is operated by three organisations:

The Market Administrator and Pricing & Clearing Manager	M-Co
Scheduler, Dispatcher and Grid operator	Transpower
Reconciliation Manager	d-Cypha

The NZEM is itself undergoing change, with the Government Inquiry recommending that the three governance boards of NZEM, MACQS (Multilateral Agreement on Common Quality Standards) and MARIA (Metering and Reconciliation Information Agreement) be replaced by a single Electricity Governance Board (MED 2000<sub>c</sub>).

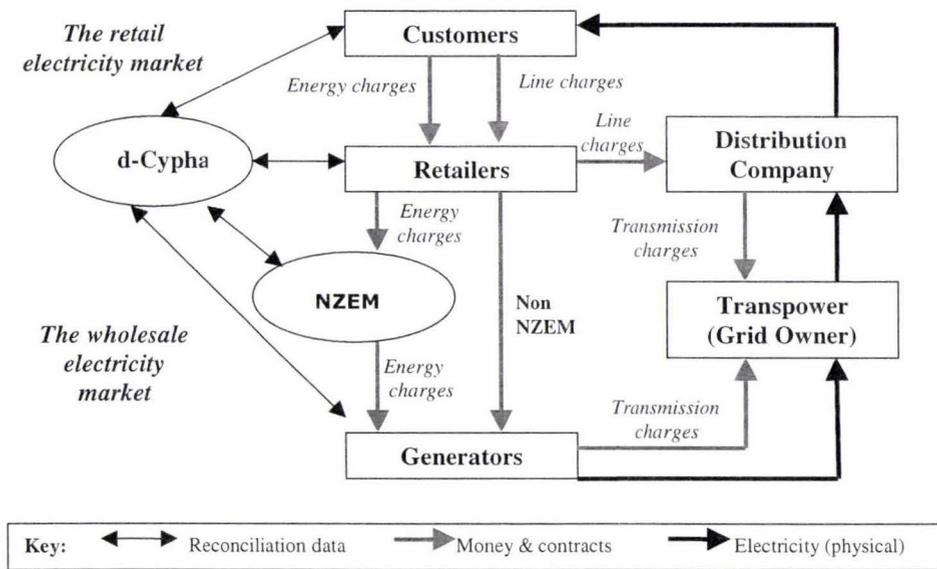
The market trades around 75% of the wholesale electricity produced with the rest traded on a bilateral 'off-market' basis. Basically the NZEM operates to a daily cycle where generators offer in bids of supply and purchasers bid to take supply. It is a 'blind' market in which offers and bids are made each day before 1:00pm for each of the following 48 half-hour period.

### 3.2.3 Grid operation, scheduling and dispatch

Transpower uses its scheduling, pricing & dispatch [SPD] model and the offers and bids from the market to calculate a schedule of production from power stations to meet expected demand from each purchaser. It also produces a forecast of the price generated at 244 Grid Exit Points [GXP] around the country for every 48 trading periods of every day. The spatial price differences are represented by the nodal price factor and are designed to send messages to market participants about constraints in the grid, the direction of energy flows and losses, i.e. the relationship between supply and demand. Generators are dispatched in real time to meet electricity demand. It is one of the unique characteristic of this industry that supply and demand has to be balanced for practically every second of the day, every day of the year in order to avoid voltage fluctuations.

### 3.2.4 Clearing, Settlement and Reconciliation

Figure 3-2 shows the how the payments are organised for all purchases from, and sales to, the NZEM. Data from Transpower and sales and purchase data from generators and retailers are sent to d-Cypha, the Reconciliation Manager. Reconciled volumes are calculated and sent to M-Co the Clearing Manager. M-Co then applies the final prices and calculates the dollar amounts to be assigned to the various parties.



Source: GSP Industry Primer

Figure 3-2: Pricing of Electricity in NZ

### 3.2.5 Transmission

The national grid or transmission system acts as the physical hub of the market. Power from the generators is injected into the grid at a possible 92 Grid Injection Points [GIP] and power is drawn from around 182 GXP (McKee, 2002)<sup>13</sup>. Transpower, the grid operator, is responsible for the security of the short-term electricity supply in NZ using ancillary services such as spinning reserve. The cost of reserve can have an impact of the wholesale price of electricity by impacting on the investment cycle of new generation and there impacts the competitiveness of DG.

### 3.2.6 Distribution

As at September 2001 there were 31 lines or 'wires' companies operating in the market, created by the Electricity Industry Reform Act, all having divested their retail operations. They range in size from less than 6,000 connections to around 500,000 for United Networks. The 11 largest are shown in Figure 3-3. These distribution companies have varying ownership structures including trusts, local councils and public listings. Their business is the conveyance of electricity from the grid to the end user within their network on-behalf of the retail companies. They may play a pivotal role to the uptake of DG as it is there network that will be connected to the DG units.

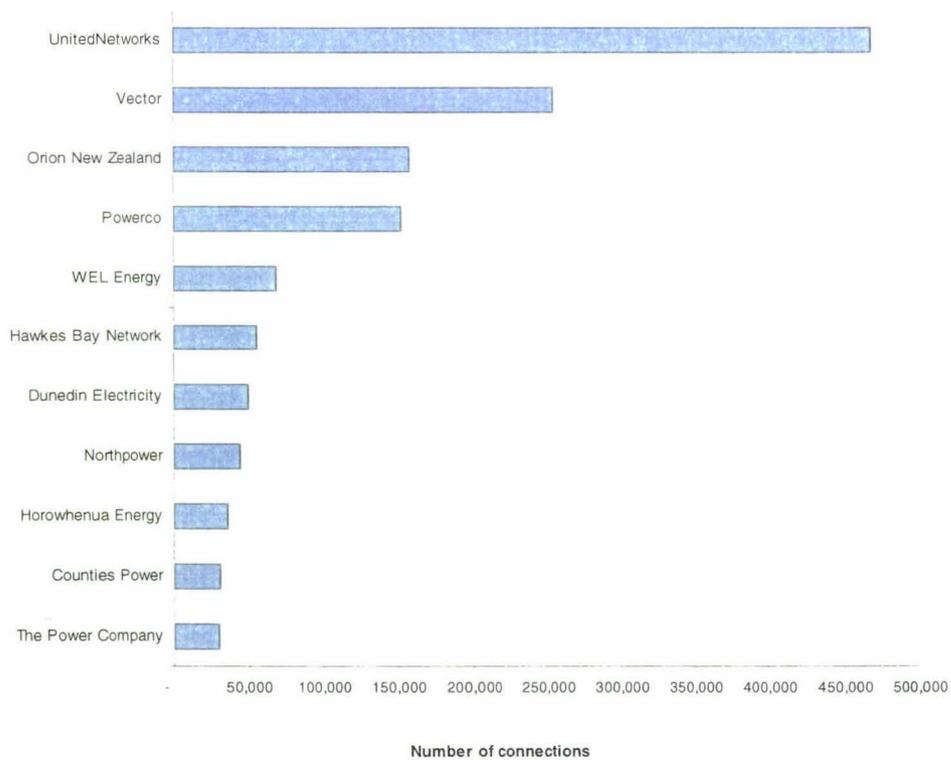


Figure 3-3: Line Company Size by Customer Connections

<sup>13</sup> The total number of grid points is changing with a number of being decommissioned. The ratio between input and export varies depending on the net power flow at each grid point.

### 3.2.7 Retailing

As at September 2001 there were 9 retailers competing in the market, purchasing electricity from the market and on-selling to its customers. The introduction of load profiling in 1999 meant that small consumers (without time of use [TOU] metering), could switch to another retailer servicing that area, i.e. a company that is not necessarily the incumbent<sup>14</sup> retailer. Most of the generators are retailers. Again there is a wide spread of customer numbers from less than 20,000 for Marlborough Lines Company to the 450,000 for Genesis. The 5 largest retailers are shown in Figure 3-4. Despite the drop in wholesale price, small domestic customers have experienced an increase of 3.4% in their power bills since the introduction of EIRA in 1998 (MED, 2000<sub>c</sub>).

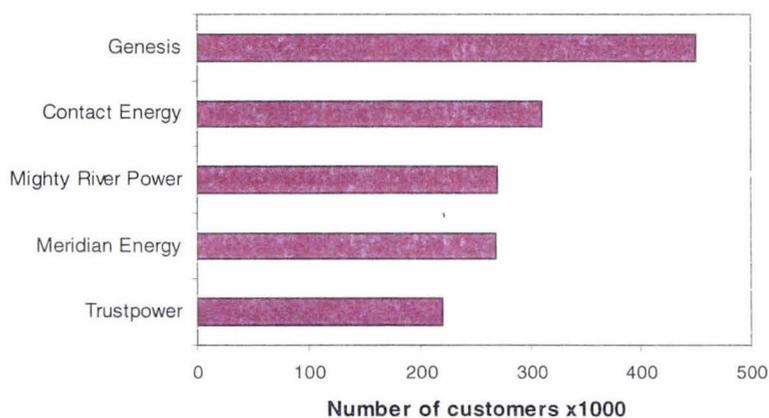


Figure 3-4: Retailer Company Size by Customer Connection

### 3.2.8 Consumption

Electricity accounted for 115.3 PJ or about 44 % of NZ's (non-transport) consumer energy in 2000. The major sectors had the following electricity consumption (MED, 2000<sub>b</sub>).

Sector	% of National Consumption
Residential	35
Commercial	43
Industrial	22

<sup>14</sup> Incumbent retailer: The retailer originally taking over the retail business from the lines company when distribution and retail were split

The residential sector is a significant market and warrants studies into ways to both capture more customer share and to increase the profitability of present customers to Meridian Energy.

### **3.3 Overview of Meridian Energy**

Meridian Energy Limited is the largest (in terms of generation) of the three companies formed following the split of the ECNZ in December 1998. Being an SOE, it follows that its Statement of Corporate Intent 1999 says, "its primary objective is to operate as a successful business which is profitable and efficient as comparable businesses not owned by the Crown. Further its core business is primarily the generation, marketing, trading and retailing of energy and wider complementary products and solutions which meet customer needs" (Meridian 1999<sub>b</sub>). Meridian employs around 170 staff in offices in Wellington, Christchurch and Twizel.

Meridian's generation is predominantly in the South Island. It owns eight hydro stations on the Waitaki River and New Zealand's largest hydro station (720 MW) at Manapouri. They generate on average 12,500 GWh annually or about a third of electricity generated nationally. In addition, the company owns the 225 kW Brooklyn wind turbine in Wellington and a 10 MW<sub>e</sub> biomass cogeneration plant in Tapanui. Clearly Meridian are true to their 'power of nature' identity, generating all its electricity from renewable energy resources. On the retail side, Meridian currently has around 210,000 domestic customers (after the purchase of On-energy South Island customers), being the incumbent retailer in the Northpower, Central Hawkes Bay, Scanpower and Waitaki areas.

Meridian are actively involved in generation improvement. Turbine refurbishment at Aviemore has led to a gain of 45 GWh and the ongoing work on the second Manapouri tailrace tunnel. They are looking to expand their hydro business both via Project Aqua, a joint hydro-irrigation scheme in the lower Waitaki that would generate 3,200 GWh of electricity and irrigate up-to 39,000 hectares, and in Australia where Meridian has recently acquired 62 MW of hydro investments.

### **3.4 Meridian's Overall Strategy**

Meridian Energy's overall goal is "to become the Number One sustainable energy company in Australasia" achieved by "using creative solutions within the power of nature". Key

milestones have been set for 2005 of [deleted due to commercial sensitivity]. As such DG is explicitly recognised in Meridian's planning and strategic direction. Meridian is able to leverage off its unique position in N.Z of being 100% renewable in addition to being a SOE with a shareholder committed to the global trend towards sustainability.

### 3.5 Meridian DG Strategy

At the time of writing Meridian was in the process of developing its DG strategy. It was important when developing the model (Section 1.2) to be aware of the general direction in which the company is moving in order to produce something that is of benefit longer term. Figure 3-5 shows the broad steps that may be involved in developing this strategy.

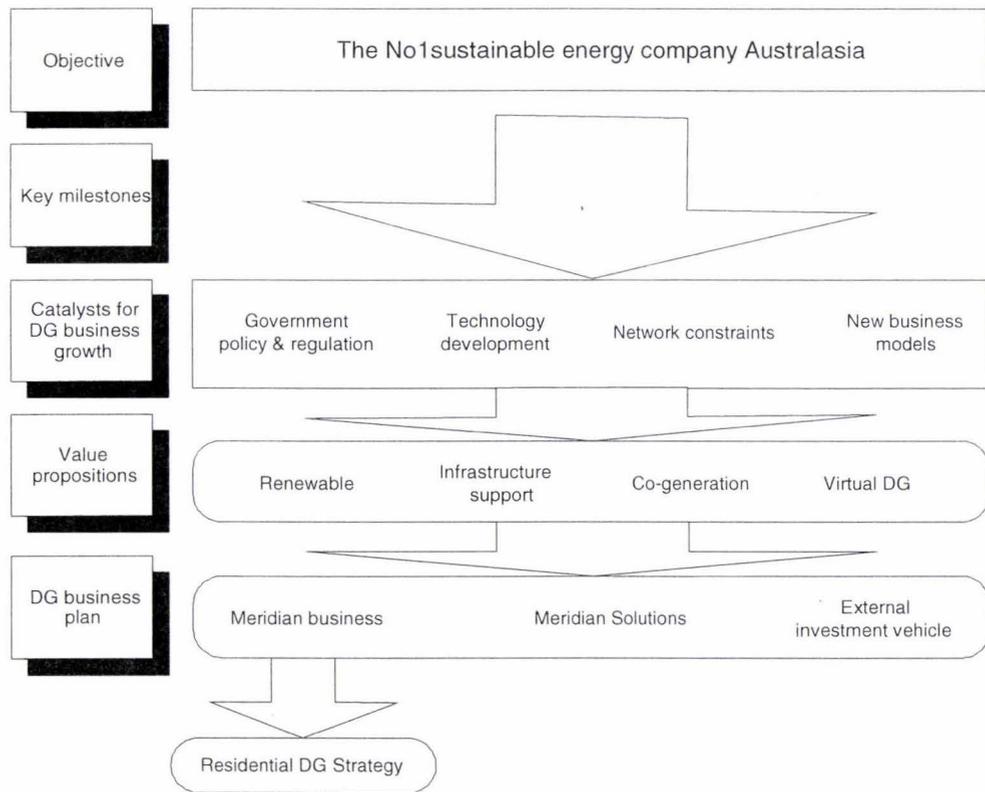


Figure 3-5: DG Strategy Development within Meridian

#### 3.5.1 Value Propositions

The 4 main types of value propositions that Meridian was considering for DG are described below.

### *Renewable Energy*

DG technologies that are based on renewable energy supplies cover a wide range of sizes and technology types. Green energy provides a market advantage via a 'feel good' factor for interested customers, immediate compliance for generator-retailer if the government introduces environmental/climate change regulations or mechanisms to encourage renewable energy plus it lowers the risk for the generator. The Meridian brand is strongly associated with "power of nature" – renewable DG would be in keeping with this.

### *Power plant – for infrastructure support*

This consists of stand alone power plants that produce electricity for a variety of purposes including on-site prime mover, power quality, peak shaving and simple energy reduction reasons. In addition, network related services could include peak capacity, voltage support and capital investment deferral. This proposition is characterised by providing these services with a technology that is not necessarily renewable or using co-generation, i.e. it is technology based.

### *Co-generation*

A co-generation system simultaneously providing power and heat (or cooling) aimed at users who will be able to use these 'products' on site. This proposition would invariably include renewable energy, as often fuels for such applications are renewable e.g. wood waste in the wood processing industry.

### *Virtual DG*

Heat pumps and solar hot water heaters are often termed 'virtual DG' as they generate no electricity in its own right. Instead they reduce the need for grid electricity by reducing the demand required to supply the same amount of thermal energy. These proven technologies and established distribution channels may provide a platform into the residential market where initial acceptance of DG may otherwise be muted.

In reality the value of DG is diverse and fits into a number of classification systems which invariably overlap with each other. The choice of which value proposition or combination is affected by:

- overall strategic implications with respect to Meridian Energy's sustainability policy;
- business fit with industrial and retail sectors and new business initiatives;
- competencies required to deliver the business model envisaged;
- market alliances or out-source partnerships that might compliment a DG business strategy

- change in national and international regulations and obligations; and
- being able to capture as much of the value chain derived from DG as possible.

### 3.5.2 Business Plan

According to a recent briefing paper (Meridian Energy, 2000) possible DG business opportunities could be:

- continued investments in global DG technologies through venture capital investment companies such as N<sup>th</sup> Power;
- marketing and distribution of DG plant and systems in Australasia. For example using mobile diesel generators in South Australia to take advantage of seasonal short falls in generating capacity;
- development of DG based products and services suitable for Meridian Solutions' industrial and commercial market applications and involving the provision of all energy needs, inclusive of electricity, heating and possibly cooling; and
- financing and packaging of DG products and services directly to retail customers via existing and new mass marketing channels, e.g. "green" energy and home services.

The last opportunity is particularly relevant to the area that this study is investigating i.e. the residential sized DG technologies.

### 3.6 Strategic Fit

Figure 3-6 illustrates how some of the various DG technologies were considered to compare in terms of new business fit and investment risk for Meridian in 1999. It would seem that the two most suited to residential applications, solar and micro CHP, were currently not perceived to be promising. However, the dynamic nature of the electricity industry means that, care must be taken to not put too much emphasis on past predictions.

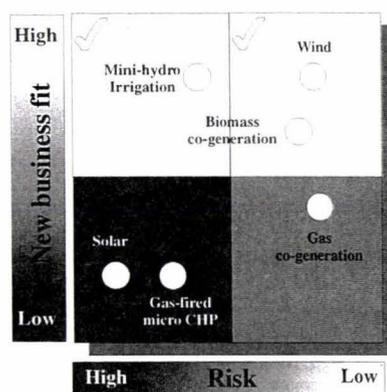


Figure 3-6: New Venture Risk Assessment Matrix for Meridian in 1999

### 3.7 Meridian's DG Portfolio

There are number of drivers that have maintained and increased Meridian's involvement in DG. Firstly, DG is not a new concept in Meridian Energy. ECNZ had earlier investigated DG, particularly through their investment in fuel cells. This innovative and forward approach was carried through to Meridian Energy.

Figure 3-7 shows there are a number of distinct projects that involve DG. These projects are looked after by different units within the business i.e. Strategic Growth, Risk Portfolio, Meridian Solutions and Knowledge and Enterprise.

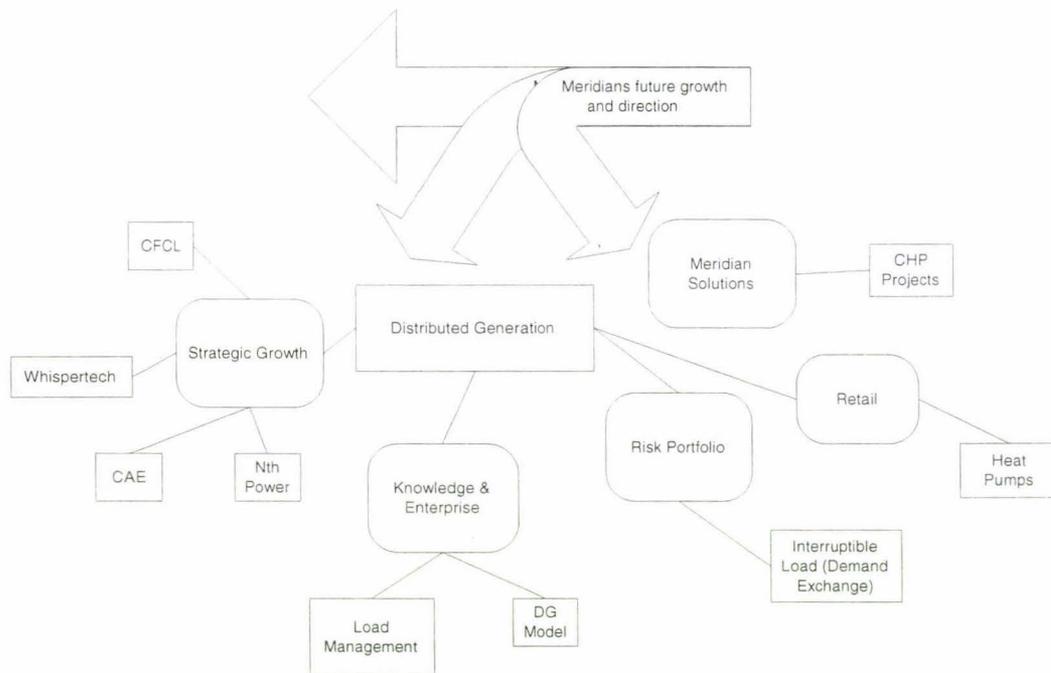


Figure 3-7: Meridian's Business Unit Involvement with DG



## Chapter 4

# Residential Distributed Generation

*This Chapter provides an in-depth analysis of the residential sector energy market. It highlights the characteristics of the NZ residential market, the drivers and obstacles which face the implementation of DG, and which technologies are available to affect this change.*

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### 4.1 Definition

This thesis on 'residential' DG concentrates on homes<sup>15</sup> that are either a singular or an aggregated dwelling unit in an urban setting. Therefore, apartment blocks, flats and other multiple units were considered, where as homes that are in a rural areas, were not.<sup>16</sup>

### 4.2 The NZ Residential Market

#### 4.2.1 Housing Stock Characteristics

Table 4-1 gives an indication of the size of the residential market and its possible growth over the next twenty years (EECA, 2000).

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<sup>15</sup> A home is differentiated from a dwelling, in that it is occupied for the majority of the year. Therefore, holiday houses for example are not included, which must be noted when reviewing housing statistics.

<sup>16</sup> Urban areas are defined where the population density is >10 dwellings/hectare (Christchurch City Council, 2001<sub>h</sub>).

Characteristics	Number
Number of private dwellings in March 2000	1,354,000
Increase in the number of dwellings occupied and under construction from 1991 to 1996	7.6%
Percentage that were owned with or without a mortgage	68%
Number of new dwellings authorised for construction between 1997 and 2000	74,000
Average number of occupants per dwelling	2.7
Estimated number of households in 2001	1,377,000
Estimated number of households in 2021	1,676,000
Average size of the New Zealand home (m <sup>2</sup> ) <sup>17</sup>	111
Average size of new home being built (m <sup>2</sup> )	172
Approximate number of main residence demolitions	4,000

Table 4-1: New Zealand Housing Statistics

Source: (EECA 2000)

#### 4.2.2 Studies into the NZ Residential Energy Market

There have been a number of studies done in New Zealand examining energy use, provision and trends of the domestic sector. All of them provide useful data and are examined in detail below. Industrial Research Limited [IRL] and the Building Association of NZ [BRANZ], both government organisations, have investigated energy use in homes. The Ministry of Economic Development [MED] and the Energy Efficiency Conservation Authority [EECA] have published reports on the use and future projections of energy consumption in this sector. Statistics New Zealand have also contributed results from the census and other statistical exercises.

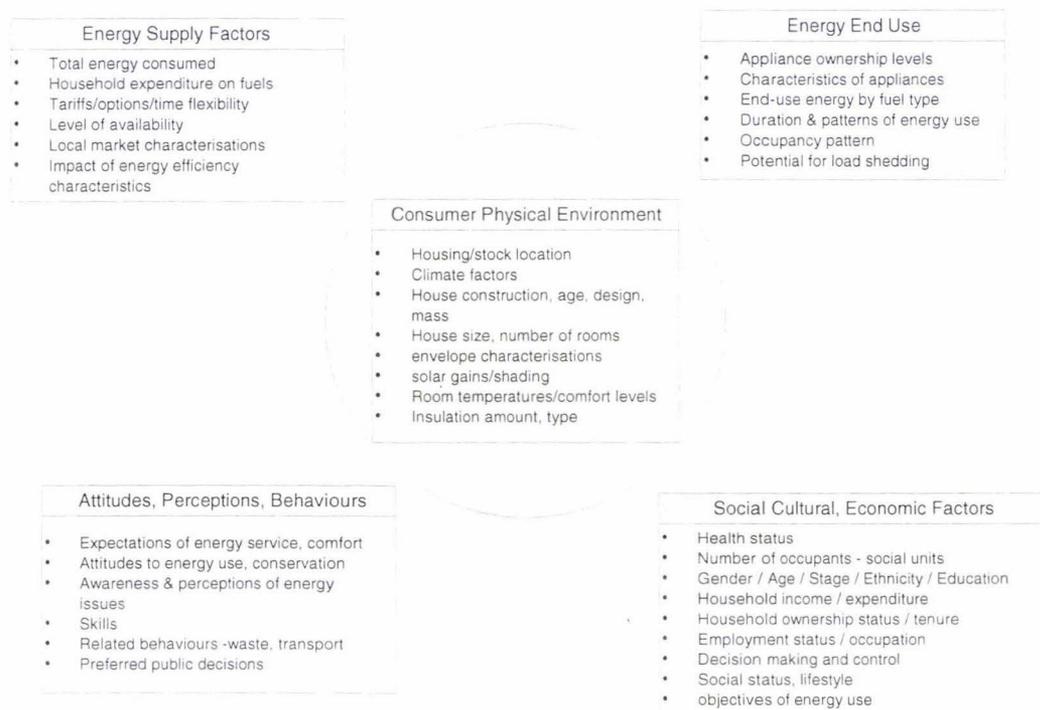
A number of questions have been addressed by these studies, including:

- What factors affect electricity consumption?
- What are the significant factors that affect electricity consumption?
- What is the best way to determine the significant factors? Is their relationship to electricity consumption linear or non-linear?
- Is there a cross correlation between these variables and how do combinations of them affect electricity consumption?
- What is the relationship between electricity consumption and energy consumption?

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<sup>17</sup> New homes built replace approximately 0.3% of existing stock. Since new houses tend to be larger in size than those replaced, a gradual increase of average house size is expected over time

Figure 4-1 provides a summary of the factors that affect electricity consumption. Whilst simple to list, quantifying their magnitude and inter-relationships is a complex task. This figure divided these factors into generic categories.



Source: (EECA 1997<sub>b</sub>)

Figure 4-1: Factors Affecting Electricity Use

#### HEEP

The Household Energy End Use Project [HEEP] was established in 1995 by EECA and BRANZ plus a number of other sponsors. The main source of results are the four annual reports (EECA: 1997<sub>b</sub>; 1998; 1999<sub>a</sub>; 2001<sub>d</sub>). Raw data from the studies are not publicly available.

The HEEP objectives are to establish :

"How much *energy* is used by which domestic *appliance* at what *time* periods, when used by which type of *households*, with which type of occupant *behaviour* in order to deliver what level of *energy service*."

Table 4-2 shows a preliminary analysis on factors affecting different end uses categorised into generic classes of demand, technology and pattern of electricity use.

Appliance group	Demand Factor (behaviour & attitude)	Technology Factor (appliance ownership)	Pattern of Electricity Use
Cooking	% using microwaves	% with microwaves	Time at home
Lighting	Unnecessary use of lighting	% with efficient lighting sensors	Time at home, time awake
Washing, drying	% of using dryers	% with efficient appliances, dryers	Time of year, temperature, technology (timers)
Water heating	Temperature setting, washing habits	% with efficient water heaters, insulation wraps etc.	Time of year, temperature, technology (night rate)
Space heating	Comfort level, knowledge of heating losses	% with central heating, physical envelope	Time of year, temperature, technology

Source: (EECA 1997<sub>b</sub>)

Table 4-2: End Use Analysis

HEEP studies used regression analysis to identify the significant factors influencing demand and to derive linear equations linking social and physical factors to electricity usage. There is a cautionary note with the HEEP data: statistically, to date only a fraction of the number of houses required for reliable results have been studied, meaning their results are inconclusive. Water heating was found to be the most variable and thus requires the largest sample size (around 150) to generate statistically valid results. Findings that may prove to be significant are an apparent poor correlation between night store heater ownership and high electricity use between the hours of 11:00pm and 5:00am, questioning initiatives to shift usage by the promotion of night store heaters; a base-load of around 300W in the houses studied; heated towel rails consume around 500kWh/yr and microwaves use 43% of their energy in stand-by mode.

#### EECA

Energy consumption in the residential sector increased approximately 30% from 42 PJ in 1975 to 54 PJ in 1998 or an annual increase of 1.2%. The residential sector currently accounts for 13.3% of the total consumer energy in NZ. The increase in energy consumption during this period is due to a number of factors:

- The New Zealand population increased 21% from 3.14 million to 3.82 million.
- The housing stock increased by 47% from 0.98 million to 1.44 million as a result.

- Ownership of household appliances increased.

The residential sector's *share* of overall national energy actually decreased over the period 1975 to 1999 by 19% (mainly due to a rise in transport related energy use). However, as Table 4-3 shows, since 1991 the residential sector's energy increase of 7.3% outpaced that of the commercial and industrial sectors.

Sector	Energy increase '91 to '99	PJ
Residential	7.30%	4.0
Industrial	-2.90%	5.0
Commercial	-0.50%	0.2

Table 4-3: Energy Sector Usage

Figure 4-2 shows how individual household usage compares with that of the entire residential sector. The average household power usage follows the overall residential consumption. The individual average started and finished the period at around 7,800 kWh whereas the total shows a consistent upward trend due to population increase. Poignantly, the only periods of energy use *decrease* both corresponded to 'power crises' where low water inflows into hydro storage lakes and high heating demands from severe winters forced the electricity price up.

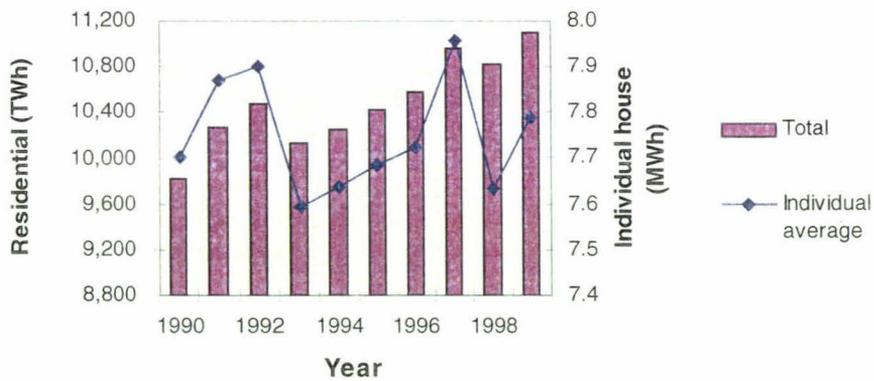
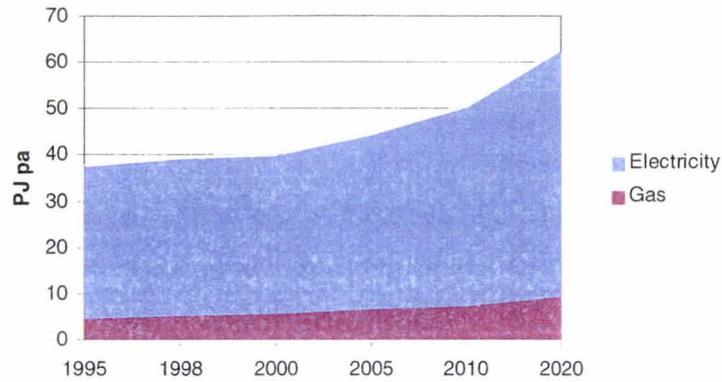


Figure 4-2: Electricity Consumption by the Residential Sector

Recent estimates suggest that the residential energy demand will grow by 54% from 44 PJ in 1995 to 67 PJ in 2020 or an average of 1.7% per annum<sup>18</sup> (EECA, 2000). Other studies suggest that this could be as high as 2.1% (MED 2000<sub>a</sub>), particularly for electricity and gas, the two fastest growing sources of energy (Figure 4-3). The residential market is therefore significant both in current capacity and projected growth.

<sup>18</sup> Excluding geothermal and wood sources of energy



Source: (EECA 1997<sub>b</sub>)

Figure 4-3: Projected Residential Consumer Energy by Fuel

According to EECA (2000), there are three generic factors that affect the energy intensity of a house: the design, the appliances used within the house and the occupancy behaviour. These factors can be broken down into those that increase energy intensity and those that decrease it.

*Increase in household energy intensity:*

- Average house size increased from an average floor area of 103 m<sup>2</sup> in 1975 to 111 m<sup>2</sup> in 1995. This led to an increase in space heating.
- Over the same period the size of new houses increased from 107 m<sup>2</sup> to 172 m<sup>2</sup>).
- Increase in number of domestic appliances and equipment e.g. heated towel rail.
- The use of more energy intensive lighting.
- Increase in the number of single dwellings, energy intensity being greater per capita than in shared accommodation.
- Change in habits and lifestyle expectations e.g. increase in comfort levels.

*Decrease in household energy intensity:*

- Higher proportion of newer homes in the housing stock. These houses are generally built using construction techniques that involve energy efficiency measures such as draught avoidance and moisture control and through the use of materials with higher insulating properties.
- Steady replacement of less energy efficient appliances with those that meet the new minimum energy efficiency performance standards [MEPS]. These include high efficiency compact fluorescent light bulbs.
- The increase in microwave ownership. SNZ estimated that from 1985 to 1995 the percentage of households owning microwaves increased from 12% to 72% with commensurate reduction in cooling energy use.

- A northward drift of population to the warmer climatic regions in the top half of the North Island, particularly Auckland and Tauranga. This is shown by the share in the national population living in these areas increasing from 30.5% to 33.1% over the period 1986 to 1996. A warmer climate means a decreased need for space heating and domestic hot water heating<sup>19</sup>.
- Increase in the average domestic electricity price from 8.24 - 11.72 c/kWh between 1991 and 1999. The recent reforms to the electricity industry, envisaged that this trend would not continue, although evidence to date, does not support this happening.
- Increased awareness of energy efficiency practices, brought about by continued education but also experiences that highlight the reliability of supply and demand of this seemingly invisible energy, e.g. the recent Auckland power crisis.

A review of data collected between 1974 and 1994 identified 4 factors that correlate with energy use per dwelling (EECA, 1997<sub>a</sub>). They are:

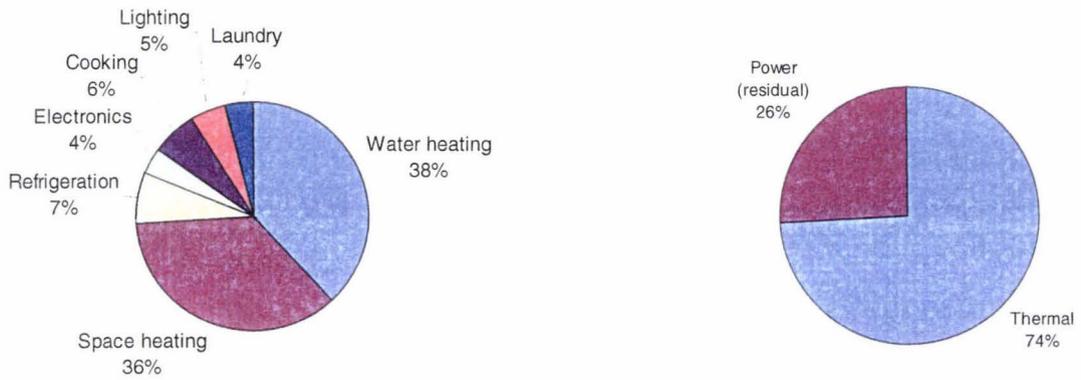
Factor	Correlation
Number of occupants	A 1% increase in the average number of household occupants results in a 1.1% increase in the energy use per dwelling.
Per capita income	A 1% increase in the per capita income of the household results in a 0.77% increase in energy use per dwelling.
Electricity price	A 1% increase in the price of electricity results in a 0.47% decrease in energy use per dwelling.
Ratio of non-electricity to electricity use	A 1% increase in this ratio results in a 0.1% increase in energy use per dwelling.

The above variables accounted for 54% of the variation in energy consumption between households.

The dominant components of domestic *end use* are water heating and space heating (thermal load of a house) which, take make up approximately 74% of energy usage (Figure 4-4). There is considerable difference in energy use across socio-demographic and geographic sectors of the population as well as seasonal variation. For example in Dunedin, a higher proportion of space and water heating would be expected than in Auckland where the climate is milder.

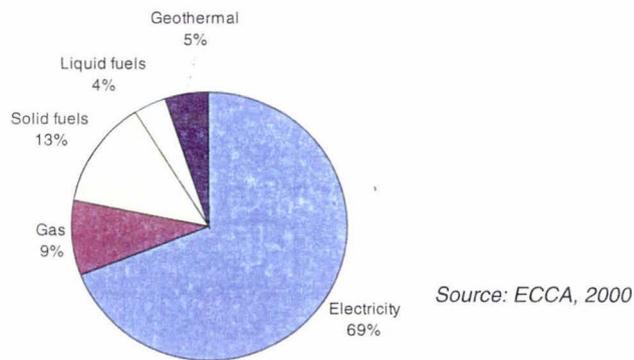
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<sup>19</sup> The heating required for DHW is affected by the ground temperature, which in turn is closely related to the air temperature.



Source: ECCA, 2000

Figure 4-4: Residential Energy End Use



Source: ECCA, 2000

Figure 4-5: Residential Sector Energy Use Mix

The sources of energy used in NZ homes is dominated by electricity (Figure 4-5).

Table 4-4 provides a break-down of domestic energy use in terms of how those end uses are provided for.

Energy Use	1996	Electricity		Gas		Fuel wood		Coal		Fuel Oil		Geothermal
		PJ	%	PJ	%	PJ	%	PJ	%	PJ	%	PJ
Water heating	38%	18	46%	2	45%	0.2	4%	0.2	6%			
Space heating	36%	7	19%	2	41%	4	95%	4	93%	0.8	100%	
Refrigeration	7%	4	10%	1	14%							
Cooking	6%	3	7%			0.04	1%	0.04	1%			
Lighting	5%	3	7%									
Electronics	4%	2	6%									
Laundry	4%	2	4%									
<b>Total PJ</b>	<b>54</b>	<b>38.1</b>	<b>71%</b>	<b>4.5</b>	<b>8%</b>	<b>8.0</b>	<b>14%</b>	<b>0.8</b>	<b>1.6%</b>	<b>2.7</b>	<b>5%</b>	

Source: MED, 2000

Table 4-4: End Use Energy Break-Down

Electricity is also the major source for each of the end-uses. Only the thermal loads of space heating [SH] and domestic hot water [DHW] have significant supplies of non-electricity sources, mainly natural gas and wood.

The trends in domestic sector energy sources since 1980 are shown in Figure 4-6. Electricity's share of the domestic sector has been increasing at an annual rate of 1.25% whilst that of gas has been increasing at 5.8% until 1991 and at 5.1% since 1991. Liquid fuels have increased at around 21.7% since 1991. The share of solid fuels (wood and coal), in the residential sector dropped by 23.1% over the same period.

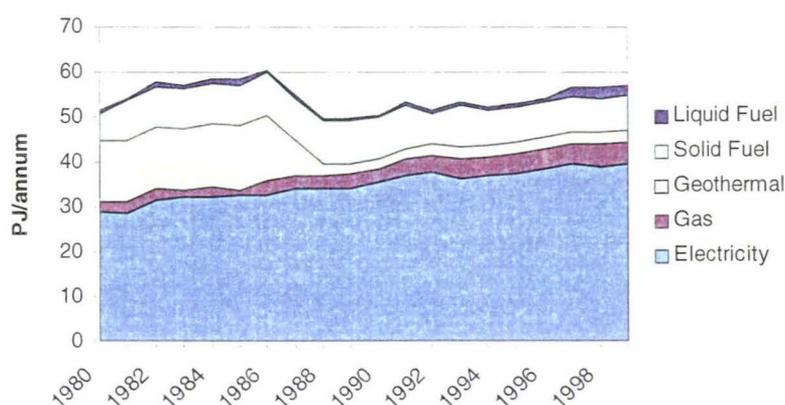


Figure 4-6: Trends of Energy Sources used in the NZ Residential Market

#### *The Energy Efficiency Resource Assessment Project (EECA, 2000<sub>b</sub>)*

The EERA Project was designed to quantify, formulate and evaluate the energy savings potential from the implementation of technical and behavioural energy efficiency measures. It provides data for appliance stock levels on a national basis. Appliance information includes energy source, type, regional distribution and annual energy consumption. EERA contains projections up to the year 2020 of appliance stock that will be used to model future trends in energy demand. In addition, it contains a break-down of the housing stock by region and insulation level.

#### *BRANZ*

A previous study to HEEP by BRANZ (Pollard & Stoecklein, 1998) investigated the relationship between indoor temperature (a key driver affecting space heating) and environmental, building and socio-economic factors. It was found that the only correlation with indoor house (lounge) temperature was the number of heaters used and that the only factor correlating with total energy use of the household was the total income of the household. Surprisingly, the floor area and the number of inhabitants were not identified as significant factors.

### *IRL*

IRL have studied factors affecting electricity consumption domestically (Fitzgerald & Ryan, 1996). The biggest drawback of the work is that it was limited to only 13 houses, presumably all in Christchurch. A multiple regression procedure was used to identify which independent variable (factors) account for the observed levels of different types of consumption (the dependent variable). The factors that were most significant for the following end uses were as follows:

<b>End use</b>	<b>Factors affecting electricity consumption</b>
Water heating	Number of minutes people spend in the shower Number of teenagers Proportion of people home during the day Income level Water tariff
Cooking	Number of electrical and non-electrical cooking appliances available
Space heating	Average bedtime Presence of ceiling insulation Number of electrical heating appliances
Washing	No clear result, variability too great to be accounted for by household characteristics
Lighting	Income
Total consumption	Income Number of appliances usually plugged into the range Presence of ceiling insulation Number of teenagers

### *Supply Curves for Conserved Energy*

Baines and Wright (1986) provided excellent back-round qualitative analysis on domestic energy use in New Zealand. It focused on the building stock in 1986 which is largely still around today given the low turnover rate of houses. It also provided qualitative descriptions of the main end uses, their predicted values in the year 2000, and how predicted variations in energy consumption varied between the main urban centres.

In conclusion, most of the studies lack credibility due to their small sample sizes (number of houses measured). In addition, some work focuses on energy consumption and makes no mention of how the energy is provided and no relationship between energy use and electricity consumption is outlined. The various studies also do not test the same variables, so comparison between them is difficult. However variables that were commonly identified (in the BRANZ and IRL studies) to be major factors contributing to energy use were:

1. Income level.
2. Number of occupants, especially teenagers.

#### **4.2.3 Overseas Comparison**

How NZ energy use compares with overseas countries is addressed in a study by the International Energy Association (IEA, 2000). An international comparison is useful as it provides a possible future outlook on how energy use might change in NZ. Typically the more developed countries of Europe, North America and Japan have higher living standards compared to New Zealand. The significant findings of the report were:

- Energy use in this sector (residential) is very low by international standards (in 1995 it was found to be the lowest of all the countries studied). This is predominately due to the low space heating [SH] component.
- Electricity shows a much higher share of energy provision than other countries. New Zealand has the second highest rate of electricity use for SH and DHW.
- New Zealand had the lowest SH intensity of all the countries studied, even though data is temperature adjusted to remove the differences in climatic conditions between the countries (measured as energy per square meter per degree day). However, inaccurate data for wood use could have biased this result.

#### **4.3 Residential Drivers for DG**

There are many drivers for DG in the power supply market. However those that pertain to the residential sector are not as strong as in other sectors such as commercial and industrial and involve the complex issue of consumerism.

A homeowner is unlikely to be concerned or even want to know how their electricity is supplied, but only that they are getting a good deal. Grid supply to the average household in urban NZ is of good reliability. Even though the home owner is concerned if the lights go out, a momentary power fluctuation or even failure will probably only be a matter of minor inconvenience. The cost of residential electricity is not high, around 12 c/kWh and it

compares favourably with international prices. So there is little incentive for someone to install a DG unit such as a Stirling engine, that could cost as much as \$5,000 up-front and pay for a natural gas connection and usage fee as well.

Residential DG is a mid to long term prospect. It is not expected that the residential market in its current state is ready to receive DG to a significant level. Drivers for DG can be separated into two categories, those that are physical and those that are marketing or service driven. Some of the major drivers are not yet significant because the marketing of DG to domestic consumers has not commenced.

An additional aspect is who benefits from DG being installed. This is closely related to how the DG unit is operated, the cumulative impact of multiple DG units and the capacity of the lines in a growth area.

#### **4.3.1 Total Energy Provision**

Products that provide the household with its total energy needs i.e. electricity as well as thermal requirements will be favoured. A home package might include all the electric needs, central heating requirements, DHW and space cooling. In the future refrigeration and freezing could conceivably be offered as well. A single bill for multiple utilities such as power, heating and possibly telecommunications is seen as an incentive to customers.

#### **4.3.2 Cost**

Cost is a major determining factor. DG will only be used if it provides an economic benefit to the householder in terms of either or both of the initial and running costs. The cost benefits of a building based DG is dependent on the amount of power and thermal load that can be displaced. For example, CHP units could provide lower energy costs than the grid, and this is essential if it is to recuperate its high initial costs.

#### **4.3.3 Net Metering (Grid Export)**

Many DG technologies will generate more power than the household needs at some times of the day. This surplus can be exported into the grid for use by other households. Net metering is where the household is only billed for the difference between import and export (i.e. the meter is allowed to run backwards when exporting). Net metering is a key both to the economic viability of the DG unit and also the practicality of its operations as it relates to the interconnection with the grid as it is very simple to implement. Net metering implies that the cost of export is the same as import. If not used then a separate meter or register for import

and export must be used which adds to the implementation costs and could reduce the value of exporting from the household.

The value of export into the network is thus a critical issue concerning DG. However, there are examples where this has occurred in N.Z, albeit without industry wide regulations. (e.g. the Greenpeace building in Auckland exports electricity generated from solar panels).

#### **4.3.4 Green and Premium Power**

The growing public awareness of environmental issues may led to an increase in the market for green power in which people are willing to pay a premium for the electricity if it is guaranteed to come from a 'green' source. In addition, "green" power may receive carbon credits or be spared carbon tax schemes, making them more feasible. Some DG technologies are "green". Trustpower which currently is the leading DG company in NZ, offered customers a \$2 per week premium in order to receive renewable energy from their proposed Tararua wind farm extension. However, they failed to achieve their target numbers – the apparent problem being that 70% of electricity is already "green" (hydro) so consumers were reluctant to pay anything extra.

#### **4.3.5 Increased Comfort Levels**

Heating levels in New Zealand homes are considerably lower than those of other OECD countries. Kiwi homes are frequently colder than the 16°C recommended by the World Health Organisation (ECCA 1999). Over time it would be reasonable to assume that these levels in NZ will rise to match those of other OECD countries. DG technologies could offer ways to meet this increase in expectations and this could provide a larger market for SH technologies. Improved insulation may also contribute to warming homes in NZ.

#### **4.3.6 Network Related Benefits**

DG offers many benefits to the distribution network including voltage regulation, peak demand reduction and hence deferred network investment, higher system capacity utilisation and reduced losses. Network benefits are related to the size and number of DG units and thus their cumulative impact on the distribution network. As stated in Section 2.4 who receives this benefit (i.e. who has the incentive to invest, operate and own the units is a likely point of contention). Lines companies who are best suited to operating the units, are restricted in their ownership of generating assets (particularly non renewables). A further disincentive is that they stand to loose use-of-system revenue if load is removed from their network. Therefore,

any device that removes load from the network and decreases the amount of electricity conveyed through it is a potential competitor to the lines companies.

#### 4.4 Obstacles to DG

E-source (1999) highlighted some of the obstacles that could face the introduction of residential DG.

Critical Issue	Background
<b>A poor marketing plan</b>	Failure to capture the attention of the public who are unfamiliar with the new technology and the concept of on-site generation of energy.
<b>A lack of service outlets</b>	Sufficient outlets to provide adequate back-up to customers is needed. With new and unfamiliar technology and unproven performance records, the 'service man' should be an integral part of the campaign.
<b>A small distribution structure limited the sales volume</b>	Lines company policy that may resist the introduction of these new products means that customers may fail to hear about the product, or if they do may be reluctant to take the plunge without their lines companies support
<b>Long payback periods</b>	Resulting from high initial cost, in comparison to traditional systems, and high operating costs. Residential customers would generally not accept payback periods longer than 2-3 years.
<b>Low value for export</b>	Meant that a potentially substantial revenue stream was minimised.
<b>Connection problems</b>	Lack of interconnection standards and required safety protection equipment (to prevent back feeding into network during an outage) further increases costs.
<b>Loss of revenue by network</b>	Fearful of decreasing usage of the networks lines companies are reluctant to support DG in some instances.
<b>No capability for stand alone generation.</b>	Synchronous generators which rely on excitation from the grid and thus can not operate during a grid outage.

*Table 4-5: Obstacles Facing Residential DG*

#### 4.5 Overseas Experience

There have been failures by two companies attempting to enter the North American residential market. Firstly, Kohler and the Gas Research Institute [GRI] in 1989 developed a natural gas fired 5 kW co-generation unit. However, given its limited market potential and their inability to reach a price point of 750 US\$/kW, they decided not to proceed with commercialisation.

In 1994 Intelligen Energy Systems developed a 5 kW<sub>e</sub> and 20 kW<sub>th</sub> oil fired co-generation system aimed at replacing fuel oil furnaces. The unit was heat led and excess electricity was injected back into the grid. However it had no cooling capabilities and could not provide power during a grid outage. With a price tag of US\$11,000 installed, it could not compete with traditional HVAC (costing around US\$4,500) and had around three times the maintenance cost as well.

On a more positive side, there are at present numerous companies all over the world that have either introduced new DG technologies into the residential market or have announced plans to do so. These include technologies such as fuel cells and Stirling engines. For example a NZ company based in Christchurch, Whispertech, are looking at selling their Stirling engine in the European domestic and marine markets. Plug Power and H-Power were projecting shipping their fuel cell units in 2002 and Ecopower Energy Solutions have launched their micro-CHP unit based on the Marathon engine in several European countries.

#### 4.6 Technologies

Practically all DG technologies have applications within the industrial and commercial sectors. The emphasis here is the residential market so only those technologies with capacities appropriate for domestic loads will be considered. Figure 4-7 shows the relative importance of heat in domestic DG applications. In NZ it accounts for 74% of the energy use in a home.

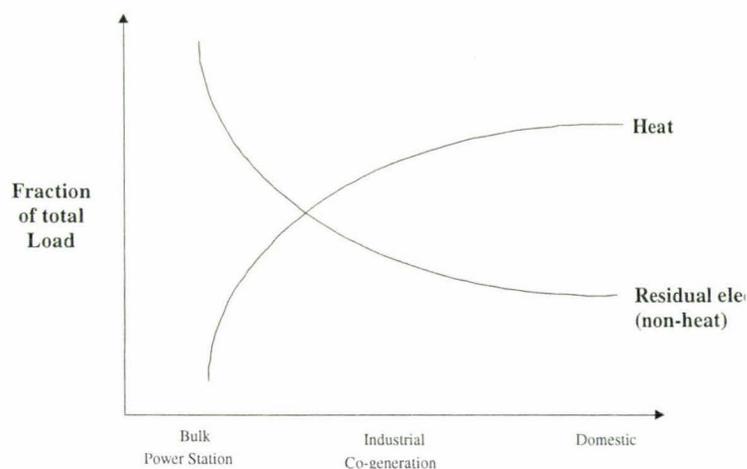


Figure 4-7: Importance Of Energy Conversion Efficiency in Domestic DG Appliances

The economics of fuel based DG technologies are closely related to the ability of the supply to closely match the heat and power load. In a grid-connected case, power can usually be exported, but heat must generally be consumed on site, stored or wasted.

Figure 4-8 provides a summary of heat and power outputs from various DG technologies. The scales on the axes are relative and can be interpreted as either actual or normalised values. As can be seen, apart from PV, wind and fuel cells, the ratio of heat to power is greater than one. This bodes well for residential applications where the ratio of thermal to residual electricity load is around 2.5:1.

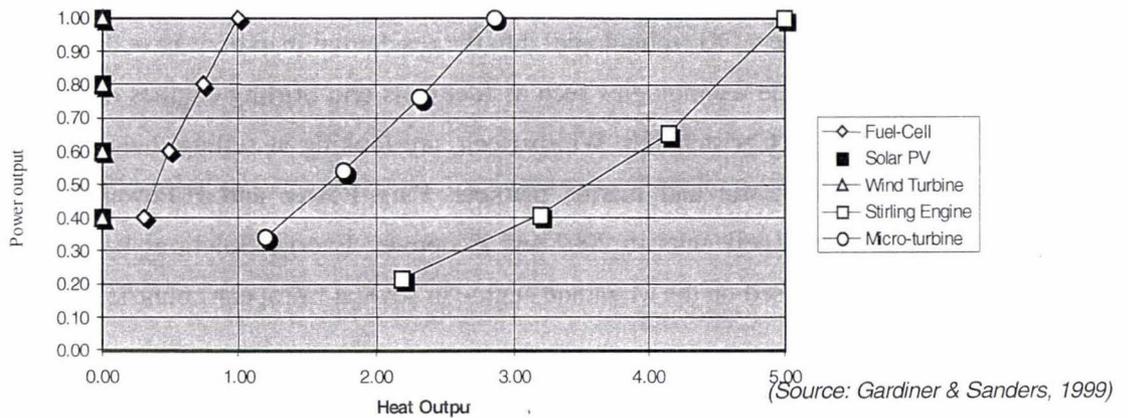


Figure 4-8: Heat & Power Outputs for DG technologies Operating at 40%, 60%, 80% & 100% of Full Load Capacity

Table 4-6 lists the main DG technologies, their typical current performance characteristics and prices.

#### 4.6.1 Reciprocating Engines

Reciprocating internal combustion engines have dominated the DG market for decades and are currently the only proven commercially available technology for providing on demand electricity at the domestic level. Technological advancements have meant an improved efficiency, lower emission levels, less maintenance, higher reliability and ability to run on natural gas. However the residential market has very high standards in these areas and considerable improvement is still needed. This has not stopped many companies from introducing units into the marketplace such as Honda Motor Company, Kohler, Intelligen and Senertec Heiz-Krafr-Anlagen (E-Source, 1999).

One significant advantage that reciprocating engines will have over newer technologies is their established distribution and service networks. Reliable historical records of their operating performance are known as well as maintenance and service intervals. This will have an impact on the public's perception but also that of line companies which may view a

traditional technology with less apprehension than unproven ones, especially when concerned with grid security and reliability. However, long held beliefs that 'generators' are noisy and dirty may prove a difficult barrier to overcome especially when considering siting issues in residential neighbourhoods.

Reciprocating engines can be divided into either *compression* ignition diesel or *spark* ignition gas/petrol fired engines. Compression ignition requires higher compression ratios of between 12 and 16 : 1, whereas spark ignition engines have compression ratios of only 7 or 8:1. This leads to a slower response time for compression ignited engines, which has implications for its load following ability. However, diesel engines have better reliability and require lower maintenance.

Performance can be improved by converting a diesel engine to one using a dual fuel, i.e. utilising diesel or natural gas as a fuel supply. There are significant advantages which are inherent with dual fuel operation. Firstly, reduced emissions. Typical NO<sub>x</sub> reduction percentages compared to full diesel operation can reach 75% (E-source, 2000). Secondly, in island mode you need on site fuel storage if you require full backup. For dual fuel engines, diesel can be stored on site and NG is available through a pipe connection.

#### **4.6.2 Stirling Engines**

Stirling engines use an external heat source i.e. they are an external combustion engine. They can use virtually any energy source capable of producing heat over 537 °C (E-source, 1997). They typically produce 2 to 6 kW of heat for every kW of electricity produced.

Their characteristics are well suited to residential applications. Burners and filters have low maintenance with intervals of between 5,000 and 10,000 hours. Free piston Stirling engines are hermetically sealed, so no maintenance is required on the engine itself. Their efficiencies range from 12% to 20% lower heating value [LHV<sup>20</sup>], however running in CHP mode, over 90% of the chemical potential energy of the fuel can be utilised (WhisperGen, 2001). Low emissions levels are also realised with NO<sub>x</sub> levels of less than 0.1 g/kWh. Noise levels are significantly less than reciprocating engines.

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<sup>20</sup> The potential energy available in a fuel as received, taking into account the energy used in evaporating and superheating the water in the fuel and any water produced during combustion from the H<sub>2</sub> present.

### 4.6.3 Fuel Cells

Fuel cells use an electro-chemical reaction to produce both electricity and heat. A hydrogen rich fuel such as natural gas [NG] is reformed, thereby separating out the H<sub>2</sub> gas. This is then combined with oxygen from the incoming air (Figure 4-9). The oxidation of the H<sub>2</sub> produces water and free electrons, which flow out as electricity. Since this is an exothermic reaction the water is heated and depending of the stack type and operating conditions steam can be produced.

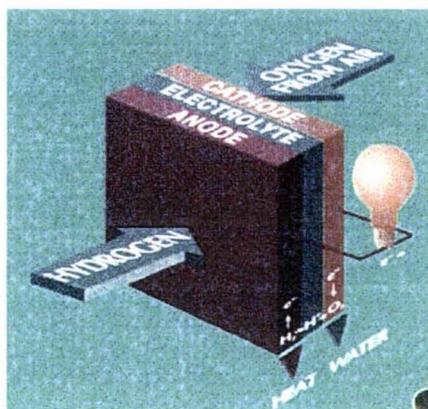


Figure 4-9: Fuel Cell Operation

There are a number of varieties of fuel cells that are aimed at the stationary market, some of which may be suitable to residential applications. They include phosphoric acid [PAFC's], proton exchange membrane [PEM's], molten carbonate fuel cells [MCFC's] and solid oxide fuel cells [SOFC's]. The different types relate to the material of the stack which dictates the operating pressure and temperature of the cell and its operating efficiency. For residential conditions lower temperature technologies such as PAFC and PEM with 40% LHV electrical conversion efficiencies seem most promising (E-Source, 1997). The overall efficiency that can be achieved in CHP mode with these types of fuel cells can be as high as 80% with hot water recovery at between 190°C and 250°C. For fuel cells that have higher operating temperatures and pressures such as SOFC high quality heat can be recovered and used in a steam turbine generator.

Since fuel cells do not use a combustion process, their atmospheric emissions are low. With NG as the fuel NO<sub>x</sub> levels are at 0.01 g/kWh or 1 part per million volume (ppm<sub>v</sub>). This is possibly one of the biggest advantages of fuel cells given potentially long operating hours in densely populated residential areas. The O&M costs as reported by ONSI (now called International Fuel Cells), are around 2 USc/kWh but were expected to drop to 0.75 USc/kWh.

Likewise, capital costs of around 3,000 US\$/kW<sup>21</sup> were expected to drop by 50% in the three years after 1997 (E-source, 1997). However in a more recent report (E-source, 2002) the US Department of Energy suggests that costs will remain above 3,000 US\$/kW until 2005. Contrary to this though is ZeTek's projected costs for their alkaline fuel cell to be less than 300 US\$/kW by 2005 (E-Source, 2001<sub>b</sub>).

#### 4.6.4 Micro-turbines

Micro-turbines are the small cousins of the much larger aero-derivative gas turbines [GT] that are currently the central power plant of choice. They present a "lower-tech GT" solution but with more complex ancillary plant integration. A single shaft, supported by air bearings spins at between 60,000 and 120,000 rpm and with the use of power electronics, the high frequency voltage can be converted to the conventional 50Hz. Micro-turbines are reputed to be the favoured entry technology to replace internal combustion technologies. However they have generally been developed in the 25-35 kW range and thus would be unsuitable for a single dwelling. However, neighbourhood, apartment block and semi-detached housing schemes, open up the possibility of micro-turbines being used for these applications. Their characteristics as described below are well suited to the residential environment.

Again, as with many of the emerging technologies, performance data is limited. According to E-Source (1997), electrical efficiencies of 32% and 17% LHV with and without recuperators<sup>22</sup> respectively can be achieved. With the waste heat being used for heating purposes overall system efficiency is likely to be much higher. Their emissions levels are characteristically low with NO<sub>x</sub> levels at about 5-11 ppm and are projected to go below 1 ppm. Noise is also low at 60 dBA at 3 m. Operations and maintenance costs are in the range of 0.4 USc/kWh and 1.0 USc/kWh due to the small number of moving parts.

Manufacturers such as Allied Signal, Capstone and Elliot Energy / GE Power systems are among the many who have commercialised their products. The capital costs vary widely, not only between manufacturers but also through experience as past predictions give way to reality and commercial units are priced much higher than once touted. Recent estimates are 800-825 US\$/kW from Honeywell Power Systems and 350 US\$/kW for Allied Signal Power Systems (Lenssen, 2001).

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<sup>21</sup> This is for the 200 kW PC25 at US\$600,000

<sup>22</sup> A heat exchange device that utilises the hot exhaust gases from the turbine to pre-heat the incoming air into the combustion chamber, thus improving efficiency.

#### **4.6.5 Heat Pumps**

Heat pumps have been available to the home heating market for the last 50 years. However high capital cost and unreliable performance in the past has hampered their widespread use (E-Source, 1996). In recent times though, technological advances have allowed their high efficiencies to be felt in nearly 22% of all new homes built in the US (E-Source, 1996).

Essentially a heat pump is a device that is able to redistribute solar heat. It uses solar heat stored in either the ground (ground-source), water (water-source) or ambient air (air-source) and delivers the 'free' heat to the load. Thus the only energy input is that to the compressor to 'move' heat and upgrade heat from low temperatures to higher temperatures. Coefficient of performances (COP<sup>23</sup>) are between 1.7 to 5, i.e. they are between 170% to 500% efficient. A heat pump is often reversible and can function to provide both cooling in the summer and heating in the winter. Around 80%-85% of heat pumps are air-source units (E-Source, 1996).

Heat pumps can also be used for water heating and there are commercial units available.

#### **4.6.6 Wind Turbine Generators**

Wind is one of the fastest growing sources of energy in the world today, with some 3,500 MW of utility sized capacity being installed during 2000 (AWEA, 2000), creating a total of 17,000 MW mostly in Europe, particularly Germany. Reasons for the promising uptake of wind turbine generators [WTG] include the maturation of the technology and significant reduction in production costs. In the US some new projects have been contracted at less than 3 USc/kWh, making it competitive with some grid supply electricity (AWEA, 2000).

WTG are not ideally suited to the mass residential market. Their significant height requirements even for small ratings (e.g. around 6 m for a 1 kW Soma 1000) would make getting consents unlikely in urban settings. However, given their applicability for rural dwellings and the current and potential interest in them, they are considered in this thesis. As with other renewable sources of energy, storage devices play an important role in fully utilising this resource. NZ has some of the highest rated wind sites in the world due to its location in the "roaring forties" and exposed topography.

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<sup>23</sup> The amount of heat/cooling produced in kWh for each kWh of electricity needed to run the heat pump

#### 4.6.7 Photovoltaics

Each day, more energy falls onto the earth from the sun than the total amount of energy that the entire population would consume in 27 years (BP Solar, 2001). Despite the high cost of photovoltaics [PV], it has become a US\$1 billion dollar business world-wide, with about 152 MW worth of PV modules shipped in 1998 (E-Source,1999) and 600 MW of installed capacity by 2000. Of this 28 MW have already been sold to grid-connected houses, via the development of micro-inverters and building integrated PV roof shingles. Substantial government subsidies have been incorporated in many of the schemes designed to introduce PV into the market. However the manufactured cost that once hovered around 4,000 US\$/kW, is now down to around 2,000 US\$/kW as larger production facilities come on-line (E-Source, 1999). (It is important to note, that the modules comprise only a third to a half of the total system cost (Able Solar, 2001).)

PV arrays can come in virtually any size and their extremely low maintenance makes them ideally suited for residential applications. Modern, mass produced solar *cells* have efficiencies of between 18% and 20% whereas the *panels* are typically 8% to 18% efficient. Since the fuel is free and there is generally enough area to place a collector, the initial cost is more of a limiting factor than their low efficiencies.

#### 4.6.8 Solar-Thermal

Solar thermal involves the use of the sun's energy for either water or space heating requirements. In this study solar thermal is limited to domestic water heating as solar space heating is related to building design rather than a separate technology that can be retrofitted. Solar hot water heaters [SHWH] can fall into the categories of active or passive and closed or open loop. Figure 4-10 shows a typical configuration of an active closed-loop system. Closed refers to the working fluid in the collectors being separate from that consumed by the household. Its active in the sense that it requires the use of pumps and controllers for operation whereas a passive system relies on thermosyphon driven system.

Since SHWH are pollution free in their operation and utilise a renewable energy source they are often candidates for 'green' subsidies, making them more cost effective in comparison to their all-electric counterparts. Overseas analysis suggests that the initial installed cost of a SHWH (US\$1,500 to US\$3,000) is significantly higher than that of a gas water heater (US\$350 to US\$450) or an electric water heater (US\$150 to US\$350). However SHWH save as much as 50% to 85% on annual electricity bills compared with electric water heating (EREN, 2001). The emissions are practically zero and efficiencies are of secondary importance in comparison to the cost of the system.

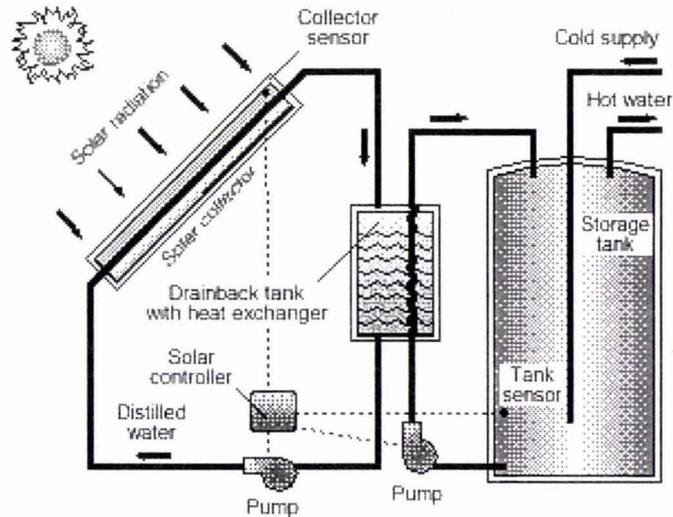


Figure 4-10: Closed Loop, Active SHWH System

#### 4.6.9 Storage Devices

Storage devices can be grouped into two generic categories; electrical or thermal. Electrical storage most often takes the form of batteries, although new technologies such as flywheels and superconductors are being developed. The battery types that are most likely to be used in residential applications are the deep cycle lead-acid and Nickel Cadmium (Ni-Cd) varieties. However given the scope of this study, i.e. the urban residential market, it is unlikely that electrical storage will be widely used. The reason is one of practicability and economics. The vast majority, if not all houses will be connected to the grid by default, allowing the grid itself to perform a storage and balancing role, so that power can be imported or exported.

Therefore unless there were large variation in the TOU charges for exporting and importing, storage is unlikely to be feasible. Such variation is unlikely as export price would probably follow import prices. Further, the additional capital cost and added maintenance would make this option even less appealing to the home owner.

Thermal storage devices can be either direct (storing waste heat) or indirect (storing excess electricity in the form of a thermal mass such as in hot water). Whether electricity is stored as a thermal mass or exported directly depends on the practical ability to export power as well as its value. Given that waste heat is largely free (apart from the heat recovery system), direct thermal storage which is technically easier than electrical storage is a viable option. For example, a generator may run during the night, utilising low gas prices, and accumulate heat for the peak load in the morning.

Type	Size kW	Thermal kW	Efficiency % <sub>e</sub> LHV % <sub>th</sub>	Heat recovery temperature °C	O & M cost (excl. fuel) c/kW (hrs of operation)	Current cost \$/kW	Commercialisation (for residential market)
Reciprocating Engine	1.8-5	4.7-11.7	25 90	427-538 (exhaust) 93 (water jacket)		500-1,500	current
Stirling Engines	0.3-25	1.8-3.5	12-20	71-93		10,000	current
Fuel Cells	1 – 5		20-50 80	190-250	2	3,000	3 years
PV panels	1 – 100	n/a	13	n/a	negligible	2,000-10,000	current
Wind turbine	1-5	n/a	n/a	n/a		8,500	current
SHWH	1-5	1-5	35	65-95	negligible	1,500-3,000	current
Heat Pump	1-7	1-7	170-500			500	current
Micro turbines	25 – 100	42-170	26 – 30	205-260	0.4 to 1 (10,000 to 60,000)	310-800	current

Table 4-6: Residential DG Technologies: Critical Data

## **4.6 DG and the Electricity Network**

### **4.6.1 Transmission Network**

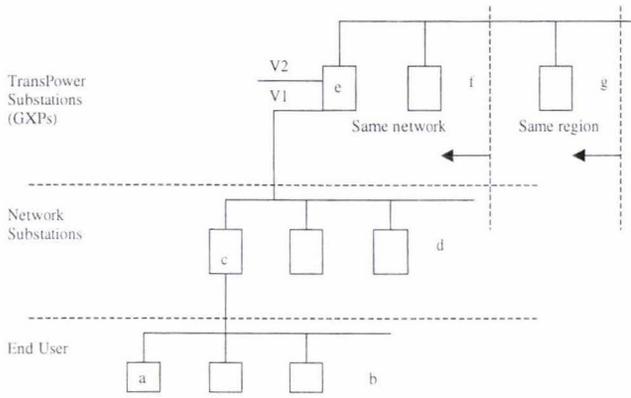
The transmission network [TN] is owned and operated by Transpower. The backbone is a HVDC link between the 220kV networks in both the North and South Islands. Transmission lines of 110kV, 66kV, 50kV, 33kV and 11kV also form part of the Transpower's network. However, in general anything less than 66kV is regarded as part of the distribution network (Ewers, 2001). An additional criteria that is often used is anything downstream of the GXP is considered distribution rather than transmission, i.e. that which is owned and operated by the distribution or lines companies.

By its definition DG is physically separate from the TN, however its affects may not be. Widespread use of DG may have the potential to impact the load profile of the TN. Typically this would mean a flatter, more consistent demand throughout the day and possibly the year, as well as an overall decrease in demand. This would be driven by the change in the demand through the GXPs (which itself is a reflection of a change in the supply/demand profile of the distribution networks connected to that GXP). This has implications for Transpower in terms of how system peaks and constraints are handled. Typically these two characteristics are drivers for capital investment. However, it is proposed that given the on-going increase in electricity demand, uptake of DG may slow down or delay the need for system upgrade, but is unlikely to render any parts of the TN stranded.

A detailed analysis of the TN and its relationship with DG is beyond the scope of this thesis (However Transpower have completed a DG impact study which is covered in Section 2.9.3).

### **4.6.2 Distribution Network**

The distribution network [DN] is by default all of the electricity network that is not part of the transmission network. DG may be placed at different levels in the network (Figure 4-11). Their impact on the network is in part due to their location as well as how they're operated. If DG is widely deployed in the future, the role of the DN may fundamentally be altered. Currently the primary function is to deliver power from the grid to the end user (from high voltage levels to low voltages) in a unidirectional manner. Widespread DG may require the DN to act as a giant transfer, buffer and storage mechanism, receiving electricity not from 1 or 2 GXPs but hundreds and possibly thousands of DG units in a dynamic and changing manner. Hence there are significant technical issues that become apparent if a network is to support DG.



- a Small generation on a specific site with no export from the site
  - b Small generation with some export into the local neighbourhood, (possibly fully bypassing the local network company),
  - c Small generation that is totally absorbed within a network company area through a network company zone substation,
  - d Generation that is exported to adjacent network substations but not fed back through the adjacent TransPower substation,
  - e Generation connected to a TransPower substation but fully absorbed by Grid Exit Points (GXPs) at a range of voltages at the substation,
  - f Generation connected to a TransPower substation with some export to adjacent GXPs within the same network company boundary, and
  - g Generation connected to a TransPower substation that is exported regionally but not extra-regionally.
- (Source: MEL, 2001<sub>a</sub>)

Figure 4-11: Levels of Network Embedded DG

The network at the residential level (suburban) comprise of 400V primary feeders. A typical pole at this level carries three phases, an earth line as well as lines for street lighting. The three main lines are typically rated at 60 Amps. This is an important quantity as it gives a measure of the amount of export that could be transmitted. Apartment blocks, found in the inner city are often connected to higher voltage feeders (11kV) therefore potentially supporting larger export.

Figure 4-12 is an example of the normalised (to 10,000 kWh/day) consumption profile for a primary feeder. Variation is shown between consecutive days. Currently it is through this profile that non-incumbent retailers are charged for their cumulative, but non-TOU, electricity consumption (i.e. non-incumbents are assumed to have the same average profile as incumbent customers).

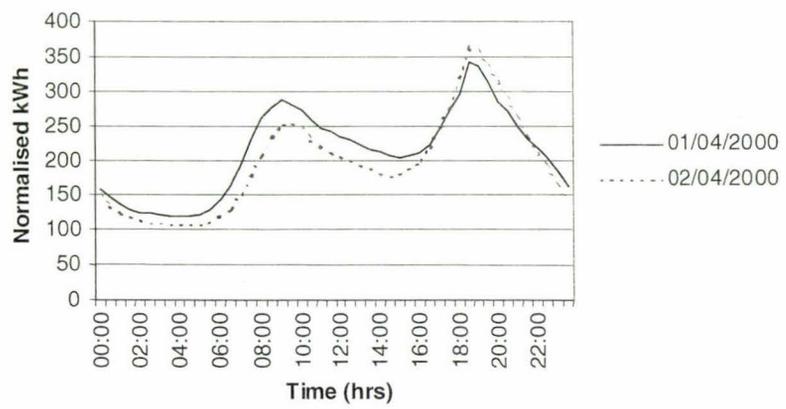


Figure 4-12: GXP Normalised Profile for a Week-End Day in April

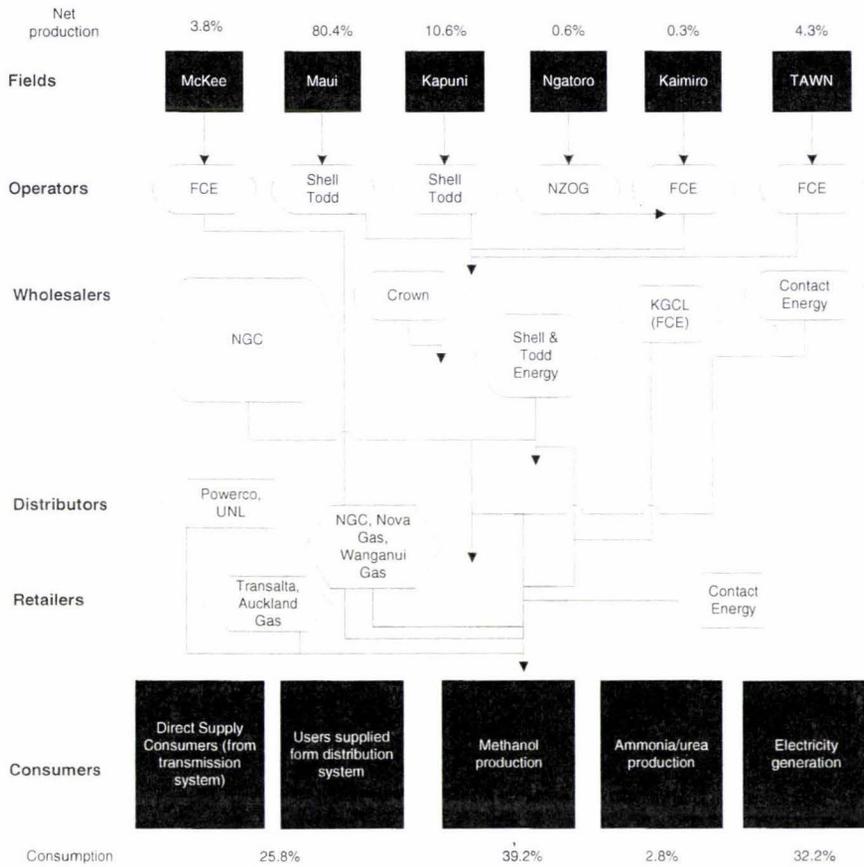
If significant amounts of DG are used within a particular DN, the profile may change substantially, probably with a reduction in the peaks and a general lowering in demand. Since the lines companies pass through demand charges onto retailers (who pass it through to consumers, Figure 3.2) significant savings can be achieved in this area. As with the TN the upgrading of the DN is dependent on system peak demand. Sections 12.4 provides a more detailed review of this issue.

A distinction needs to be made between the physical impact of DG on a network and how this impact is then quantified into revenue streams. Determining the network benefits of DG and who receives them is a separate issue. (Section 7.7)

## **4.7 Gas Industry**

### **4.7.1 NZ Overview**

Figure 4-13 shows the physical and ownership flow of gas from its field production to consumption by consumers. There is obvious similarity to the electricity industry structure with the gas being produced at a few locations, transmitted along a high pressure transmission system and then sold to consumers through low pressure distribution networks. The gas industry has also undergone deregulation with the removal of gas franchise areas and price controls by 1993.



Source: Energy Data File, 2001

Figure 4-13: Gas Industry Relationships

#### 4.7.2 Production

Gas production is dominated by the Maui and Kapuni fields, which operated by Shell Todd Oil, provide over 90% of production. Currently there are seven producing fields all in the Taranaki region. In 2000, production was 233 PJ which accounted for 29% of New Zealand's primary energy supply.

#### 4.7.3 Transmission

Figure 4-14 shows where the gas transmission network and distribution network (NGC owned) are located. The Wairarapa is the only major urban area in the North Island where reticulation is not present. There is no significant reticulated gas network in the South Island except for the remains of the coal-gas reticulation systems in Christchurch and Dunedin.

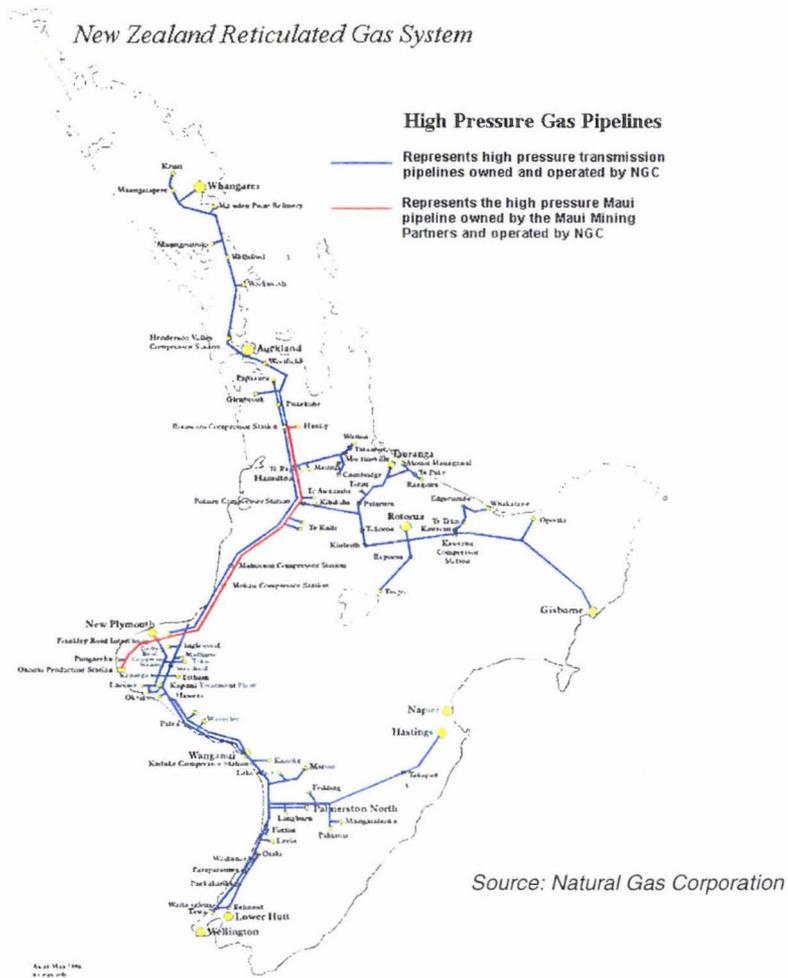


Figure 4-14: NGC Transmission and Distribution Network

The transmission system is operated and majority owned by NGC. It consists of 2,600 km of high pressure gas pipeline which conveyed 100 PJ during 2000. Methanex and Petrochem, both based in Taranaki, are the main direct supply customers. Load factors for the following main trunks of the transmission network are shown in Table 4-7 (Garr, 2001). The excess capacity of the transmission system is difficult to define due to the dynamic nature of demand and the ability to increase capacity limits by increasing compression.

Zone	Load factor
North and Central	91%
BOP	83%
Frankley Rd- Kapuni	76%
South	68%

Table 4-7: Zone Load Factors of the Transmission Network

#### 4.7.4 Distribution

The distribution networks comprise 11,363 km of low pressure pipelines operating at an industry wide average load factor of 79%. There are over 220,398 customer connections receiving 29.7 PJ of gas. Around 2.5% of total annual gas production goes into the residential market. Areas in central Christchurch may still have the old coal-gas network, which may prove suitable for retrofitting with modern gas piping to provide a convenient way to distribute gas throughout the area.

#### 4.7.5 Market

Residential DG technologies such as fuel cells and Stirling engines would rely on reasonably priced gas to ensure it could compete with the electricity grid and other energy sources. Companies like Contact Energy and NGC are able to gain low ex-field gas prices (due to Maui gas take-or-pay contracts). However as with electricity a large proportion of the delivered cost is due to the transportation of gas to the end-use location.

### 4.8 Optimal Sitting of Residential DG

Figure 4-15 shows three critical factors affecting where best to site residential DG. If a electricity network is constrained it should be reflected in the nodal price factor, which means higher spot prices and inevitably higher electricity bills.

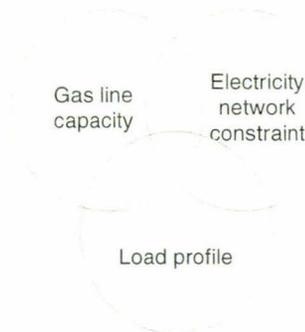


Figure 4-15: Crucial Factors in Determining Economics of Residential DG

This would mean a more competitive environment for a DG unit to operate in. If the DG unit is gas fired, an obvious requirement is for available capacity within the existing network to serve the increase in demand from possibly thousands of units. The third category is the demand side. The load to be served must be, or could be made to be well suited to the output of the DG unit. This is obviously dependent on the type of DG technology deployed.



## Chapter 5

# Model Charter

*This Chapter clarifies the main objective: "to provide Meridian with a decision tool to assist them in their process of identifying DG opportunities, particularly in the residential market" in the light of the preceding chapters.*

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### 5.1 Situation Description

- DG is an energy source/conversion unit that is located close to the load, either in the distribution network or on the customer side of the meter. As such it can take advantage of savings from avoiding transmission and distribution [T&D] costs and deliver these to the end user.
- A significant end user in the New Zealand market is the residential household. It is the fastest growing sector of our economy (EECA 2000) in terms of energy use and has experienced electricity price increases despite the reforms and subsequent drop in the wholesale price of electricity.
- The residential market has a high (although seasonal) thermal component to its load profile, making it well suited to CHP type DG technologies.
- The market is unique in its large variability of energy use between regions, seasons and occupancy characteristics. The complexity is further increased by variability in the heating to power ratio in homes and the various sources of energy currently used to supply these needs. Identifying profitable customers who are suitable to use DG is thus a complex task.

- As an integrated generator-retailer, Meridian has a significant number of residential customers, generation that is situated at some distance from major load centres, and is exposed to a number of transmission constraints and has no North Island gas presence. DG offers a potential solution to these challenges.
- The application of residential DG is envisaged as helping Meridian maintain a profitable residential customer base. This would be not only in terms of quantity but importantly quality, where homes that are suitable for DG may also prove to be candidates for value enhancing home automation products.

## 5.2 Purpose

There are a number of purposes which this thesis and ultimately the decision tool should provide:

- *an aid* in assessing the business opportunity for residential DG;
- *greater understanding* of the residential market and the factors that affect domestic energy use;
- *awareness of new and emerging technologies* that may be used in this market and
- *a base* on which further and more detailed analysis can be carried out.

## 5.3 Objectives

Specifically, the objectives for the model were to:

- develop *a framework of analysis* which incorporated the key factors affecting DG in the residential market;
- develop *a methodology* that provided a quantifiable description of the effect of these factors;
- develop the *formulation* for these relationships;
- construct a *calculation engine* that is complete with an user-friendly interface;
- use *a modular approach* that enabled the incorporation of additional modules and or the expansion of existing ones in order to increase the accuracy and expand the range of applicability of the model;
- perform *case studies* of a DG opportunities in which different scenarios were analysed and the functionality of the model was demonstrated and
- prepare *a users guide* that provided instruction of how the basic functionality of the model could be accessed.

## 5.4 Scope

Many aspects of the impact of DG are the result of multiple instances of DG units and the cascading effect of DG through the distribution network. However, these effects feed back to the individual houses. Therefore a complete analysis even at a single household level requires the broader impact of DG uptake to be accounted for. Figure 5-1 shows the effect of synergy between multiple DG units (i.e. the extra benefit obtained from multiple units working together) and indicates the degree of focus given in this work.

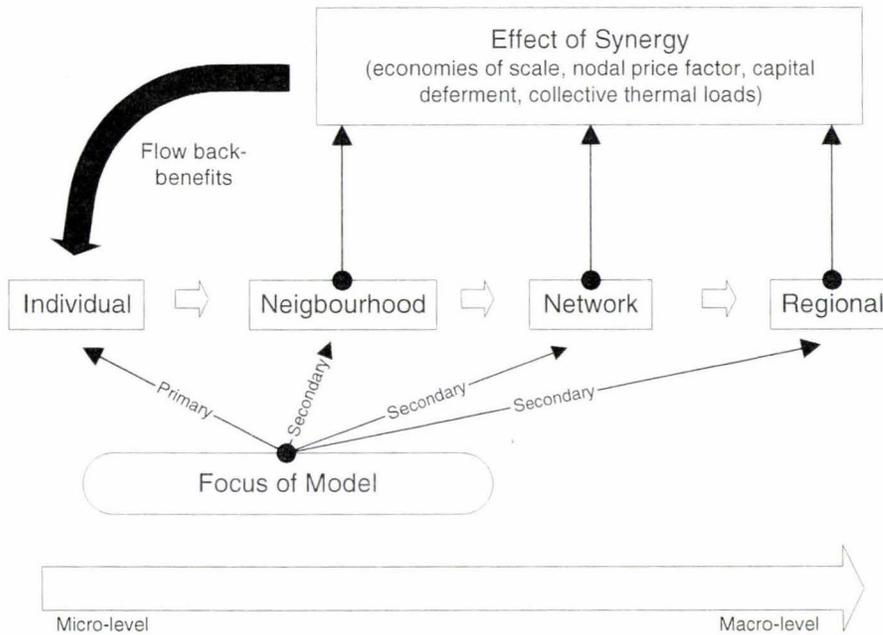


Figure 5-1: Scope of Model Development

The development of the model was restricted to:

### *Residential market*

- A focus primarily on the New Zealand residential market. This market is represented by a collection of single or attached urban dwellings. Overseas, commercial, industrial and rural applications were not explicitly examined, although in many cases the same analysis methodology could be applied.
- The model looked at applications of DG into single urban dwelling. A single DG unit serving multiple end users such as a suburb (e.g. district heating schemes), or multiple housing units was not considered.

### *On-site applications*

- DG that is embedded on the customer side of the meter (DG within the distribution network generally was not considered).

- The effect on the distribution network from multiple single DG units was quantified but how these effects impact the operation of the distribution network was not considered.

### *Technologies<sup>24</sup>*

The following technologies were considered:

- |                          |                        |
|--------------------------|------------------------|
| 1. Reciprocating Engines | 6. Photovoltaics       |
| 2. Stirling Engine       | 7. Heat Pump           |
| 3. Fuel Cell             | 8. Solar water heating |
| 4. Microturbine          | 9. Storage             |
| 5. Wind                  |                        |

The technologies examined were chosen because of their suitability to the residential environment either now or after further development or because they represented a benchmark technology from which comparisons to the newer technologies could be made.

### *Functionality*

Figure 5-2 illustrates the dilemma of designing a decision tool that was useful and could perform and produce required results, but the exact nature of these results, for different users, were unknown. The approach used was to create a generic platform which could be used to produce a wide range of specific results after further definition downstream.

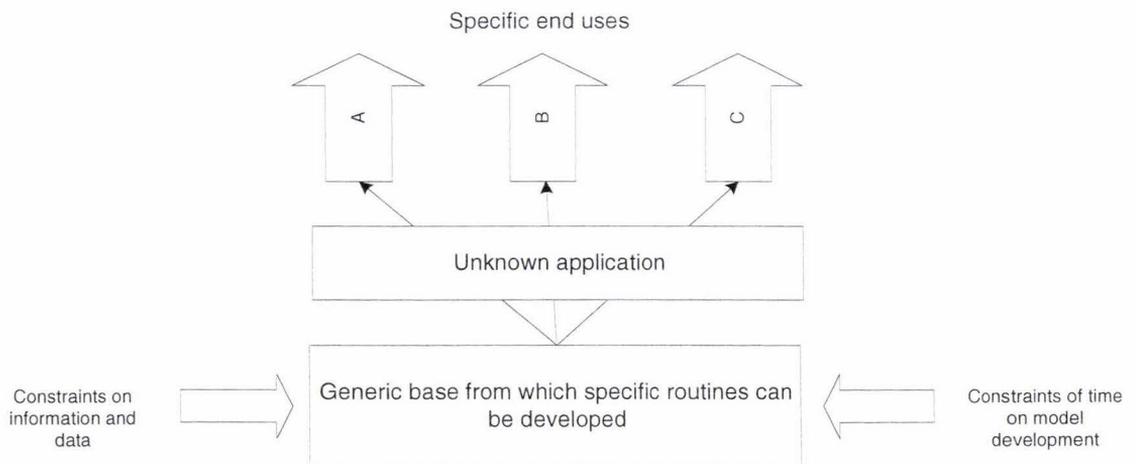


Figure 5-2: Capability versus End-Use of the Model

<sup>24</sup> Technologies numbered 7-9 do not generate electricity in their own right but produce useful thermal energy and can be termed virtual DG.

## Chapter Six

# Conceptual Model Development

*This Chapter outlines the 'philosophy' behind the model and how this can be used to design and build the mathematical functions that enable the value proposition for DG to be estimated.*

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### **6.1 Introduction**

The Chapter first outlines the value proposition as the overall driver for evaluating a DG opportunity. It describes how the value proposition can be assessed and categorised prior to development as modules. Secondly, it identifies the framework in which these modules were incorporated and how the whole model works. The functional calculations are given in Chapters 7 to 10.

### **6.2 Value Proposition**

The basis of the value proposition was to quantify the value of DG if it displaced traditional supply mechanisms [TSM] (i.e. displacement value). This problem was solved by looking at both supply and demand sides.

The demand side incorporates energy use and its changes over time (load profile). Demand was considered to comprise of thermal and residual electrical loads.

The supply side incorporates the means of meeting this demand and its changes over time. Supply side analysis is two fold; firstly from the TSM such as the grid and secondly from emerging DG technologies.

The model used an economic comparison based on net present value [NPV] as shown in Figure 6.1.

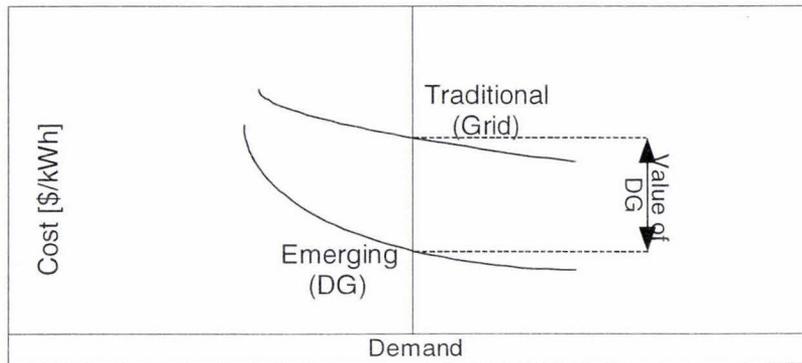


Figure 6-1: Cost of Meeting Demand

The difference in annualised production cost [APC] plus any initial marginal cost (capital + installation) over and above that for the TSM results in a net present value [NPV] between the alternative energy supply options being calculated.

$$NPV = \sum_0^n (APC_{TSM} - APC_{DG}) - \text{initial marginal cost for DG} \quad \text{Equation 6-1}$$

All the constituents of both the demand and supply side impact this value proposition. The model explored their effect on the APC and initial cost. Figure 6-2 shows where the value lies in providing for the energy needs of a residential load. Initially the demand and supply side can be seen as separate entities, both of which represent opportunities to provide the energy to a household in a value adding manner. However, it is the combination of these that allows an even greater value to be extracted as considerable synergy is obtained by influencing both aspects simultaneously. An additional aspect of this synergy is the effect of multiple units and their aggregate impact on the network.

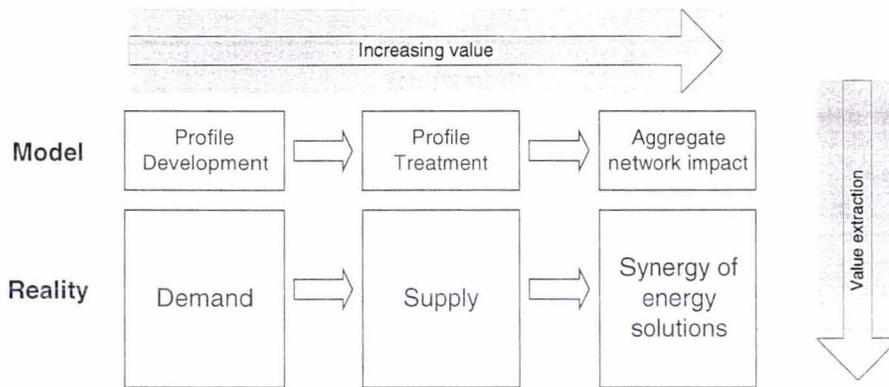


Figure 6-2: Value matrix

The potential synergy, also identified in Figure 5-1, means that a complete analysis of DG at the individual house level should incorporate the effect of multiple units at a neighbourhood level. Given that some of these effects were beyond the scope of this thesis, the model structure was designed to enable them to be more easily taken into account in the future.

### 6.3 Module Structure

The model framework consisted of discrete entities called modules that each represent a certain functionality of the model. The selection and structure of the modules was determined by 3 objectives:

- Accuracy: Each module and/or sub-modules must be capable of a reasonable level of accuracy for the components that are allocated to it and this level of accuracy should be known in order to determine areas which warrant future development.
- Flexibility: All modules were designed as generically as possible to allow the inclusion of additional variables and alternative calculation methodologies in the future.
- Expansion: It should allow for future complexities to be incorporated that were beyond the scope of this project

An additional reason for this modular approach was the practical implementation. A prototype development method was used which enabled each module to be developed independently whilst still being part of a working model.

Figure 6-3 outlines the main modules and their subdivision. Modules were chosen as the means to organise the many factors that effect the value of DG and to enable their affect as well as their interrelationship with each other to be quantified.

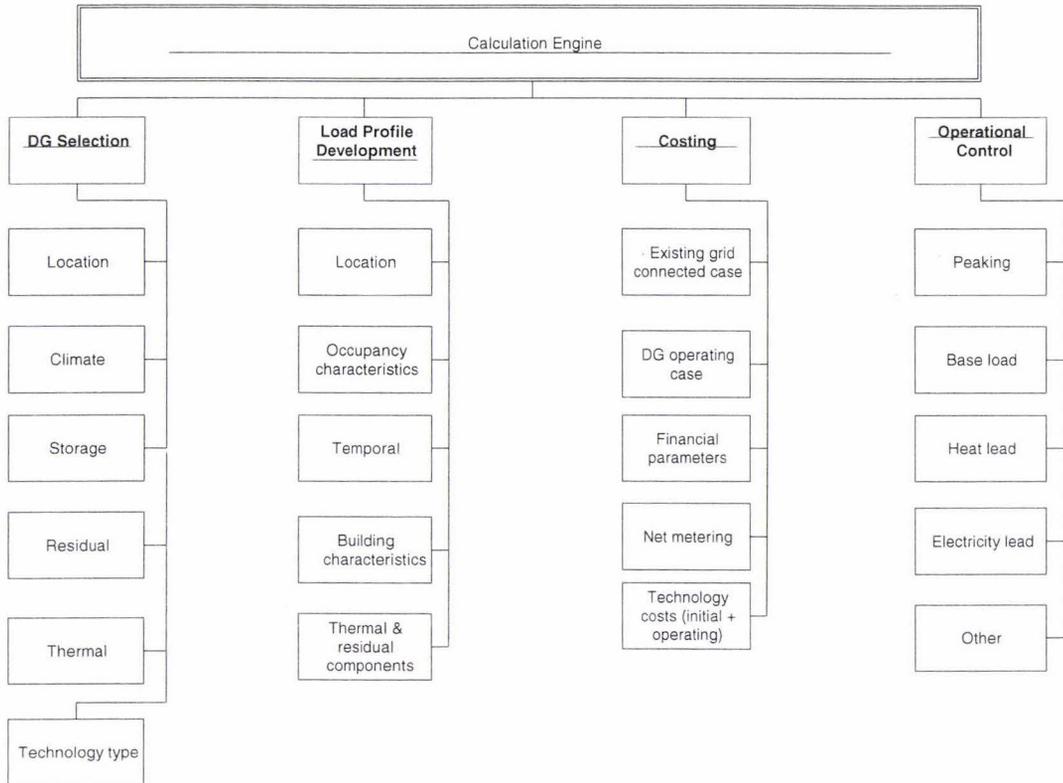


Figure 6-3: Modules and their Component Parts

A module consists of a database and associated set of calculations. The Calculation Engine acts as a pivot point in the calculation sequence and performs 2 tasks: control of the calculations performed in the modules and co-ordination and subsequent calculations of the results. For example, the Calculation Engine would specify what load profile is to be developed. The Load Profile Development module would construct this profile by using a database of standard profiles. The constructed profile is then used in the Calculation Engine for further processing.

Table 6-1 illustrates the concept of how a single variable can impact the NPV for a particular domestic scale DG installation. In this case the location of the house affects both its demand profile<sup>25</sup> as well as its supply costs. The Load Profile Development module, considers spatial climate variation to estimate the impact of location on the end use requirements. Conversely on the supply side, the climate has an explicit effect on the performance of the DG unit and hence the cost of the energy supplied. In addition, the price of energy (electricity and fuel) is also related to its location.

<sup>25</sup> Load profile and demand profile are used interchangeably

Location	Issue	Demand	Supply
	Module	Load Profile Development	<ul style="list-style-type: none"> <li>▪ Costing</li> <li>▪ DG Selection</li> </ul>
	Category	Profile development	<ul style="list-style-type: none"> <li>▪ Existing Grid case</li> <li>▪ DG case</li> </ul>
	Mechanism	Climate (Temperature & renewable energy resources)	<ul style="list-style-type: none"> <li>▪ Climate</li> <li>▪ Price of energy</li> </ul>
	Variables	<ul style="list-style-type: none"> <li>▪ SH</li> <li>▪ DHW</li> <li>▪ Residual</li> <li>▪ Total energy</li> </ul>	<ul style="list-style-type: none"> <li>▪ Performance of DG unit</li> <li>▪ Cost of energy supply</li> </ul>

Table 6-1: How the Impact of Location Affects the NPV of DG

The above serves as an illustration of the framework that was used to quantify, via NPV, the impact of any number of variables. The *nature* of the relationships between location and the variables are developed in the following chapters. For example, *how* does the location of a house impact the amount of space heating or the cost of electricity?

## 6.4 Model Overview

The overriding objective of this thesis is to define how and where value can be added to the business of Meridian Energy through the deployment of DG technologies in the residential market.

Figure 6-4 shows how the model functions in determining the market potential of residential DG and is seen as a first step in a larger process. The grey box denotes the limits of the models' functionality. The analysis is at a micro (individual house) level, and does not consider the complete market. Subsequent work would involve using the model to estimate the number of economically feasible sites.

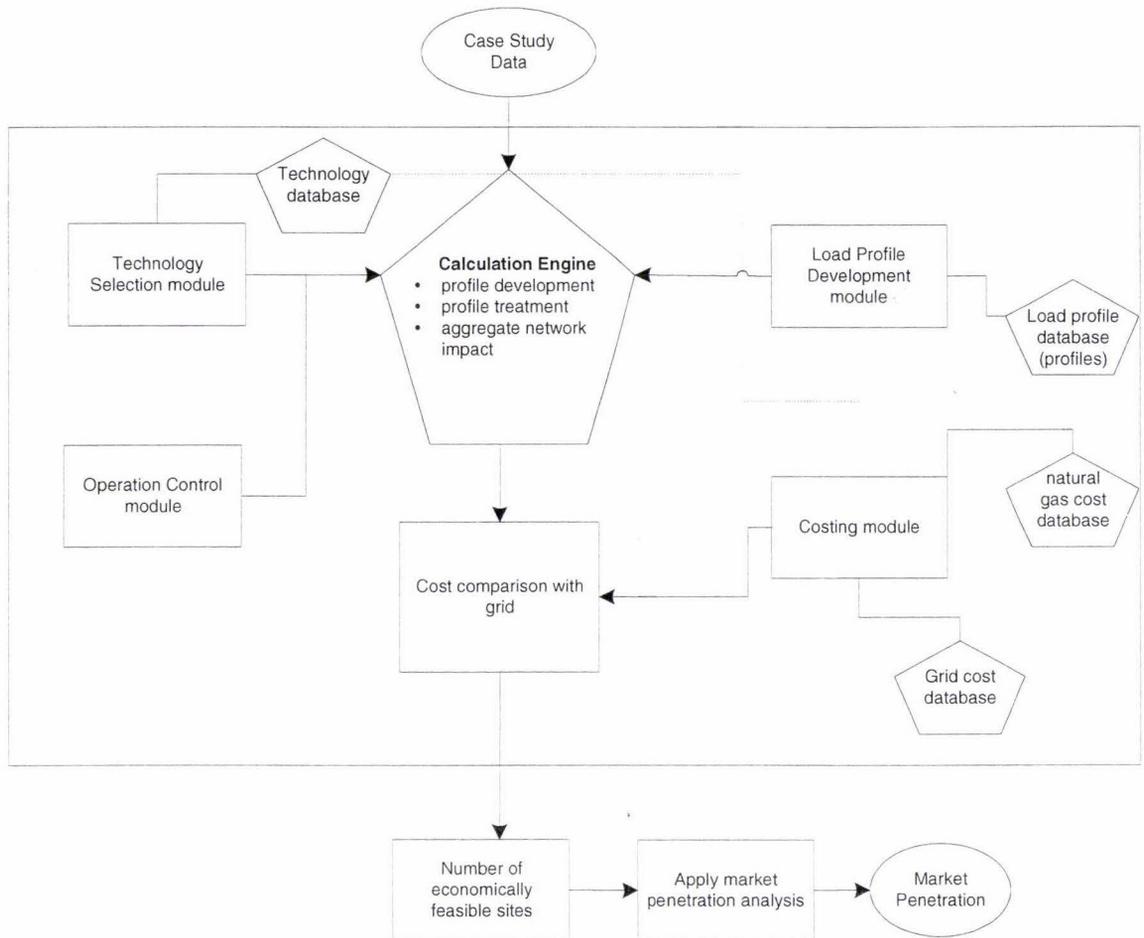


Figure 6-4: Overview of the Model's Structure and Function

This diagram shows the modules with the calculation engine as the core. A number of databases were developed to provide input into the engine:

1. Technology database

The available DG technology types, operating characteristics and costs are stored in a database which was developed to allow easy addition and modification to these parameters. Currently there are 8 different technology types.

2. Grid cost database

Grid costs are stored as composite retail values in the form of tariff rates (anytime and day/night) or spot market electricity prices plus a retail margin and line charge. The two approaches enable comparison between the price of electricity paid to a consumer and the cost incurred by the supplier. Spot prices for three reference GXP points (Benmore, Haywards and Otahuhu) were stored in ½ hourly increments, averaged for each month of the year. At present week-end and week-day prices are the same but are stored individually (i.e. to allow for enhancement of this database).

### 3. Load profile database

Due to the scarcity of available data, the load profile database does not contain raw profile data at the end-use level. Instead, there are stored profiles of total (electricity) consumption for 5 reference households for eight representative day types.

### 4. Natural gas and fuels database

The fuels included in this database are natural gas, LPG and wood. Costs for natural gas can be varied on a ½ hour basis (anticipating developments in the gas market) whereas the other fuels have fixed costs.

Overall the databases developed were relatively small due to the minimal use of raw data. However, their designs tried to anticipate future needs and expansion by using flexible coding.

## 6.5 Calculation Engine

The calculation engine is the mechanism through which the variable containing modules in Figure 6-3 are 'knitted' together. Conceptually this is done in four parts:

### **i. Load profile development**

New Zealand's housing stock of 1.3 million houses all have different load curves. A mechanism to produce load profiles that would reflect the variability due to house size, building type and location was developed. The resultant profile matrix for different days in a year becomes the basis of the DG performance and economic analysis.

### **ii. Profile treatment**

Once the profile is developed the process of matching it with the output of a DG unit was carried out. This treatment included simulating the output of a particular technology type to determine the residual import and export to the grid under the chosen control regimes.

### **iii. Aggregate network impact**

The detailed analysis on a micro level is repeated many times to produce a macro level result giving the cumulative impact on the distribution network from hundreds or thousands of DG units.

### **iv. Costing**

The output of the DG unit is costed out as well as the cost of supplying the load via the TSM and a comparison is done between the two.

On a more detailed level, Figure 6-5 shows how the calculation engine uses the load profile and DG output to create a cost comparison between the traditional supply mechanism or 'business as usual' and the DG case. It describes an individual house, with the potential of using more than one DG unit.

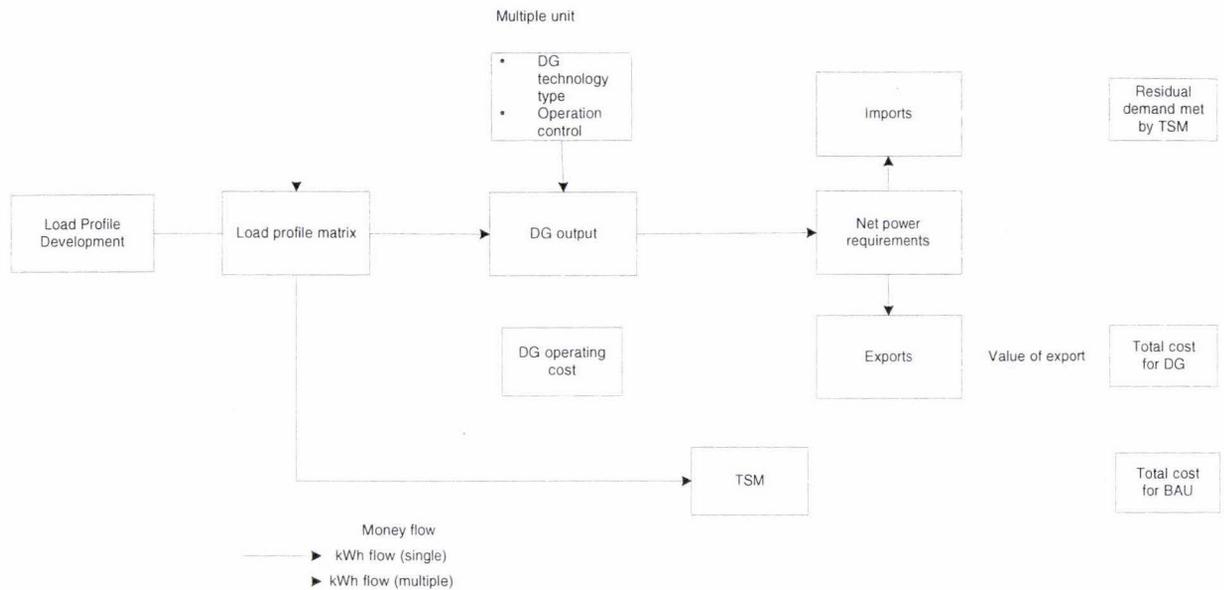


Figure 6-5: Calculation Philosophy

However, an important functionality of the calculation engine is the analysis of the impact of multiple DG units on the network. This was achieved by repeating the analysis for a single house many times and then aggregating it into an overall impact. Figure 6-6 shows the layers in this repetitive calculation structure. Likewise the analysis on a single house for a year is the weighted aggregate of separate analyses over 8 typical day types and 48 ½ periods within these days. Hence the base calculation engine analysis is for a single ½ hour period which repeated many times under the influence of a variety of variables to build up that overall result as follows:

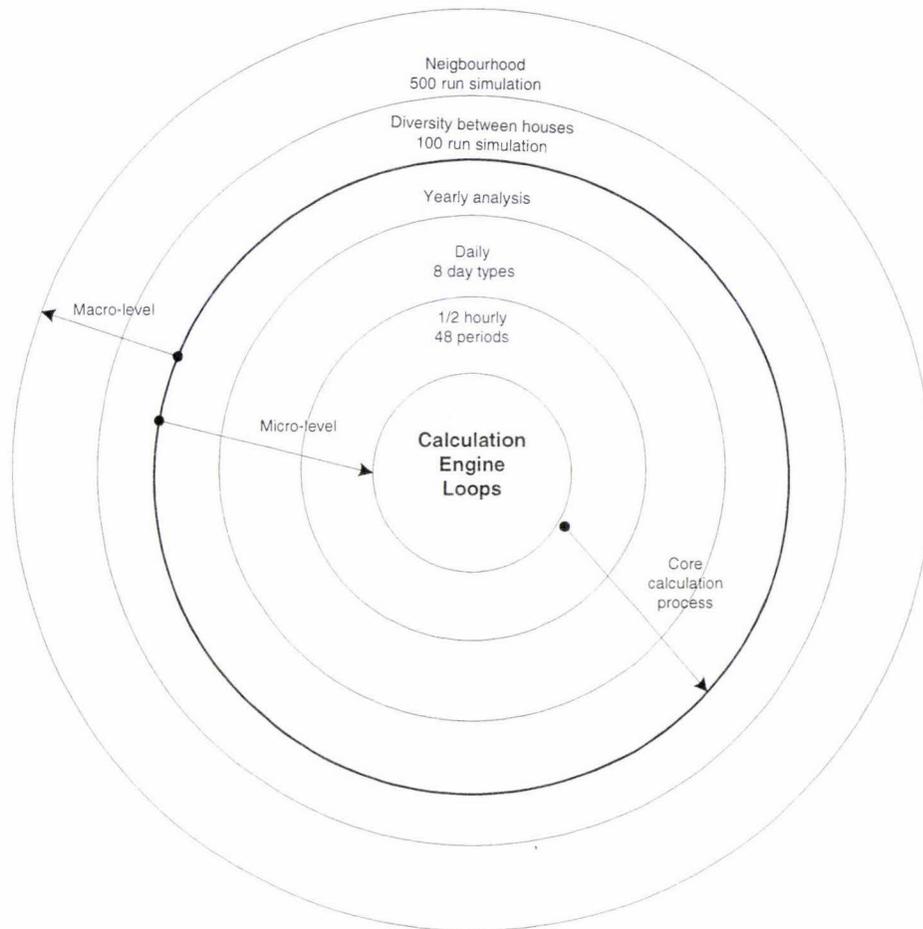


Figure 6-6: Layered Calculation Structure

Level 1:        ½ Hour Period

An individual ½ hour period for a single house is analysed.

Level 2:        Daily Period

The level 1 analysis is repeated for 48 periods to represent a typical day for the house.

Level 3:        Seasonal and Annual Period

The level 2 analysis is repeated for the following 8 days, representing a typical weekday and weekend day for the following seasons.

- i.        summer weekday
- ii.       summer weekend
- iii.      winter weekday
- iv.       winter weekend
- v.        spring weekday
- vi.       spring weekend
- vii.      autumn weekday
- viii.     autumn weekend

A weighted average of the 8 days is used to represent the annual demand and the annual supply profile for a DG unit.

Level 4: Diversity

The level 3 analysis is repeated many times to take account of house-to-house variability in load properties (for houses in the same profile class<sup>26</sup>), so that the effect of diversity can be assessed on the likely performance and economic feasibility for a single house. Diversity can also be used to simulate annual changes in demand for the same house.

Level 5: Neighbourhood

The level 4 analysis is repeated for each home with different characteristics (characteristics are represented here by profile class) to represent the aggregated impact on a network. Weighted averages of each class are used to construct neighbourhoods with different housing compositions.

The detailed mathematical formulation and implementation of the model is discussed in Chapters 7 to 11. The formulation is done on a ½ hourly basis as the majority of the calculations are at this level of detail. The repetitive nature of many of the calculations are shown using summation equations which define the process of going from a ½ hourly analysis to a daily, seasonal and yearly analysis. Some of the equations and procedures that are employed to transfer data from one module to another are not shown as they are not considered essential to the understanding of the model. Model implementation (Chapter 11) describes the overall data structure, calculation sequence, inputs and outputs and system architecture (programming environment).

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<sup>26</sup> A class is defined as a particular load shape with a particular consumption pattern over a 24hr period

## Chapter Seven

# Load Profile Development

*This Chapter describes the processes that are used to generate an individual load profile and the reasons why those processes were chosen.*

---

### 7.1 Objective

Assessment of DG opportunities requires the load profile for a particular house to be predicted, preferably from a small number of descriptive socio-economic variables. Given that many DG technologies produce heat and/or power, separation of the load into thermal and residual components is required. Ultimately, accurate profiles need to be generated that reflect the variation found throughout the residential market in NZ. Figure 7-1 shows the many variables affecting the residential load profile and how they relate to each other.

Even though the approach to determine the load profile is important, it was not the central objective in this thesis. Firstly, a basic requirement for the model is for it to be a generic, modular framework through which to perform analysis. This allows for the provision of a more sophisticated load profile development mechanism if deemed necessary in the future. Secondly, determining accurate load profiles as they relate to socio-economic data is an extremely complex task and one which is worthy of many studies on its own. Therefore, the profile development methodology must balance complexity and accuracy criteria. A number of alternative approaches were examined and that considered the best was chosen.

An important issue that the model should help address is market penetration e.g. how many houses in a region are economic opportunities for DG? The region might refer to New

Zealand as a whole or to a localised region if the impact on the local network is considered likely to be a significant factor. A large enough sample of houses must be analysed to ensure that the variability in the market is taken into account and that a 'critical mass' is available to be captured.

Another important aspect is whether the houses' load profile will naturally or can be actively changed to better suit the output of a particular DG unit. That is, DG may become more viable if energy use patterns change. The emphasis thus shifts from determining accurate load profiles for the current situation to being able to intelligently manipulate existing profiles or simulate future profiles i.e. to simulate change in energy use patterns. For example, future widespread adoption of telecommuting could result in profiles being significantly less "peaky" as homes are occupied for a greater fraction of the day.

## **7.2 Available Data**

### **7.2.1 Sources**

There have been a number of studies into load profiles in the NZ residential energy market (Section 4.2.5). TOU data is critical when analysing DG applications. Half hourly data is the coarsest time series data needed to estimate the 'match' for a particular DG technology because the DG unit operational decisions must occur at least every ½ hour in response to the load that is measured half hourly. This is true both at the micro-individual house level, to examine the feasibility for a particular house, but also at the macro-network level to estimate the impact on the distribution and generation network particularly during peak times. Half hour load data is time consuming and expensive to obtain, further a significant number of houses need to be logged for a substantial time in order for representative profiles to be generated. This quality of load profile data was not freely available to this study.

Some industry experts say that the use of both average profiles and/or 30 min period data is too averaged to get a good indication of DG performance (Cleland, 2001) because load within a ½ hour period can be so variable. Data logging at finer levels, 30 second interval for example, is substantially more expensive and not readily available. This issue is discussed further in Section 13.4.5.

The HEEP study (EECA, 1997<sub>b</sub>) provided some average profiles and the breakdown by end-use (Figure 7-2), but the number of houses logged was too few to be statistically representative of the variation found in NZ (e.g. 175 houses for space heating).

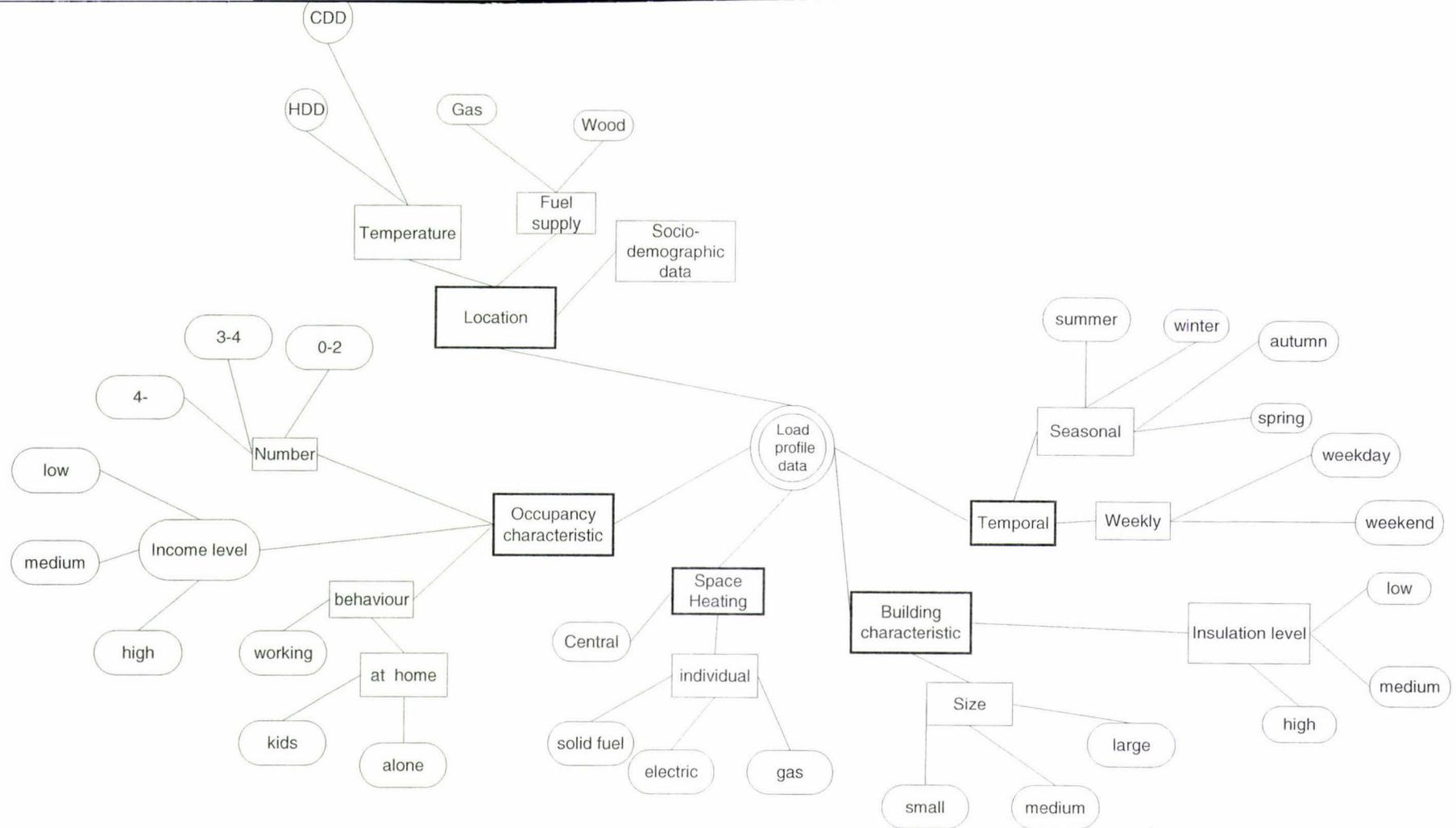


Figure 7-1: Factors Affecting the Domestic Load Profile

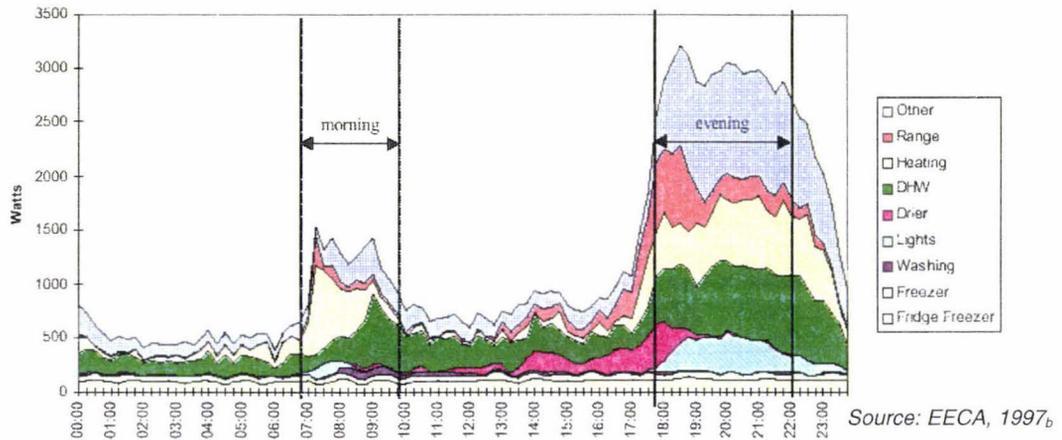


Figure 7-2: End-Use Energy Consumption Over a Day

EECA data (EECA, 2001) provided national level data for end-uses such as water heating, space heating and lighting as well as a break-down between energy sources such as electricity, natural gas and solid fuels (Section 4.2.4). Whilst being accurate on a national level, the data does not reflect the variability found on a regional or individual house level and was not time of year or time of day dependent .i.e. data were only on an annual basis.

IRL (Sanders, 2001) provided time series data of total electricity use for 74 houses logged in Christchurch (Figure 7-3).

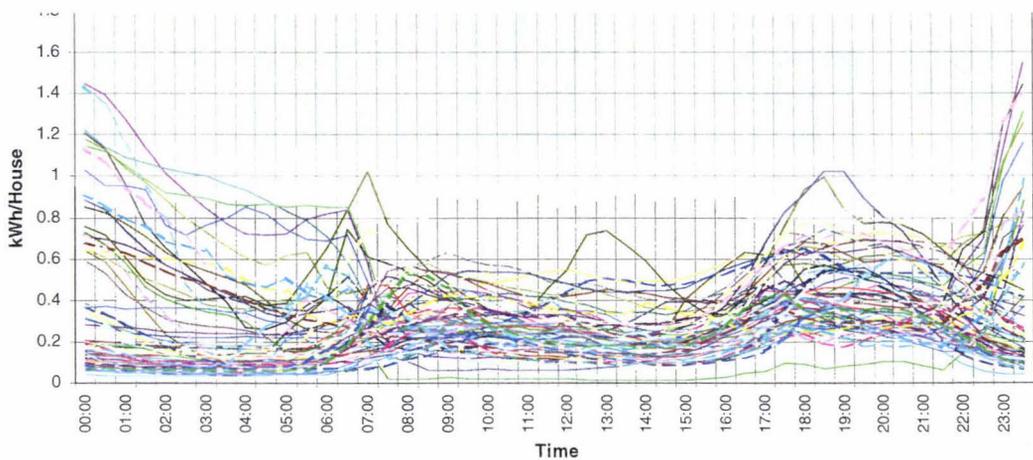


Figure 7-3: The Average 1/2 Hourly Load Profiles for a Group Of 74 Houses in Christchurch for the Year Oct '95 to Sep '96

Half hourly data was available for an average weekend and weekday for each month. Cluster analysis was used by IRL to create 5 different 'classes' of profiles (Figure 7-4). A clear distinction can be seen between houses with night-store heaters (Classes 4 & 5) and those

without. No socio-economic or demographic data was available to allocate individual households to the 5 classes.

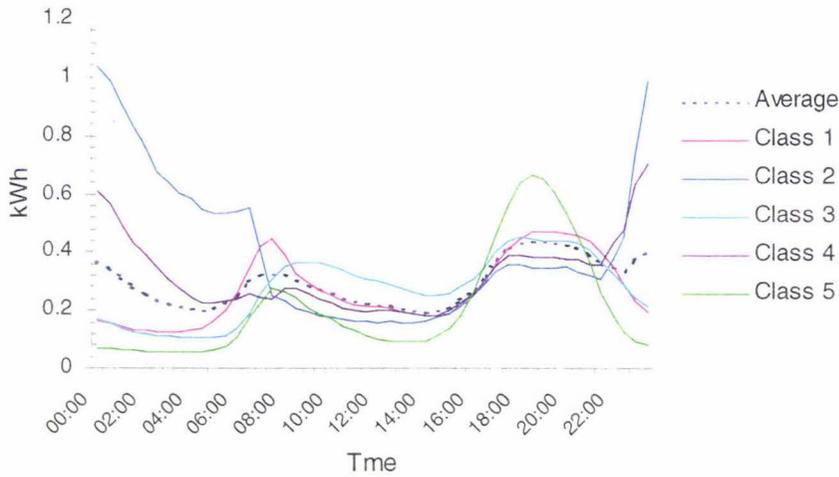


Figure 7-4: Profile Classes Derived using Cluster Analysis for a Week-Day Winter Day

### 7.2.2 Load Profile Detail

The breakdown of the overall load profile into components or end-uses is also important. Figure 7-2 showed how these end-uses may vary over the day. The end-uses show independent variability throughout the day, were the morning and evening peaks remain evident. However, it was not considered feasible to analyse each of these end uses in any significant detail because of the lack of data. Also there is no point in analysing the components of a profile if they do not represent a significant fraction of the total load or cost. Other factors such as anticipated growth or ability to shift load may make an end-use important enough to analyse in the future.

Overall there is a need to integrate high level data and data which is more detailed. On the one hand we have national average annual data for end-uses which was used to estimate the thermal (SH and DHW) and residual electrical constituents (Figure 4-4). On the other hand we have hourly profiles of total energy use for individual houses (Figure 7-4). This data supplied by IRL (Sanders, 2001) provided the total energy use for a Christchurch house as a function of the time of year and time of day. In addition, data showing seasonal variation of the SH, DHW and residual electrical constituents (Figure 7-9 and Figure 7-13) was also provided. Intuitively it makes sense with no space heating during the summer months and a relatively constant DHW energy consumption throughout the year. However, this data was for a single house, for a single year, and therefore could not be reliably used to disaggregate the overall demand profiles. However, the data could be used as the basis of a seasonal disaggregation. Therefore, it was decided that subdivision of total load into components of

SH/SC and DHW would be done on a seasonal basis only and not ½ hourly. That is the fraction of SH/SC out of the total was assumed to remain constant over each day but varied from season to season.

### 7.2.3 End Uses

Total energy demand was categorised into 4 types of end-use –SH, SC, DHW and residual electrical<sup>27</sup>. The first 3 combined comprise the thermal load. The four end-uses, were chosen because of their significant contribution to annual residential energy demand (Table 7-1) and their significantly different characteristics e.g. DHW require higher temperatures than SH.

End-use	Percentage of total
DHW	38
SH	36
SC <sup>28</sup>	-
Residual	26

Table 7-1: National Average End-Uses Breakdown

The distinction between thermal and non-thermal is required because many DG technologies produce both electricity and heat and it is through this comparison that the financial analysis is based.

### 7.2.4 Load Profile Diversity

There is uncertainty associated with load profiles that reflects on a day to day or house to house basis, the factors that affect energy consumption for an individual household or building. Much of the available data is for average house profiles so any variation is smoothed thereby decreasing peaks and increasing the base load. This is the result of diversity or non-coincidental load behaviour between houses. The loss of detail is dependant on the number of houses that are used in the averaging process as shown in Figure 7-5.

Load diversity is important because DG units are installed in an *individual* house and not an *average* house. If a DG unit was sized based on an average profile its control decisions and

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<sup>27</sup> Residual is defined as the non-thermal end uses, such as lighting and electrical appliances which are invariably supplied by electricity.

<sup>28</sup> Space cooling was included as it is postulated to be a growing end-use in the future. Some SC contributes to the residual load by way of electric air conditioners, however SC like SH will be more seasonal than other residual load components and should be separately analysed.

operating hours could be substantially different than if it were sized to an individual house. Operating constraints such as cycling limits (e.g. number of starts) are more likely to be encountered.

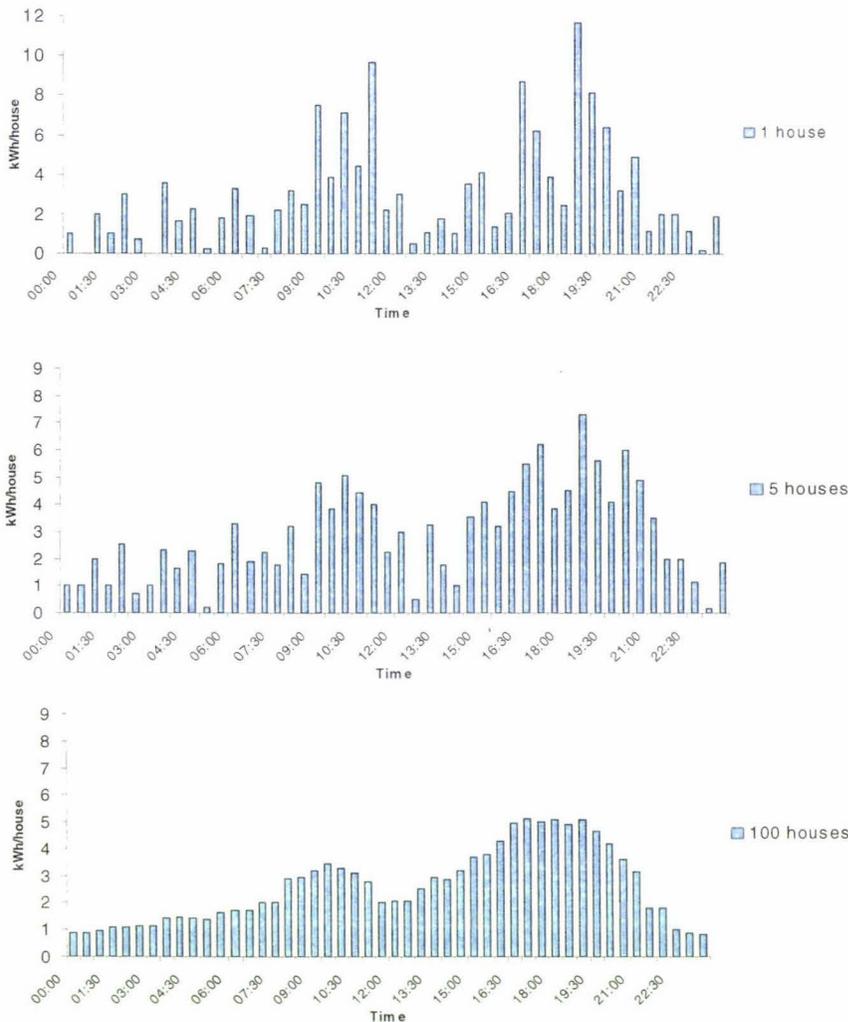


Figure 7-5: Illustration of the Diversity of Loads Between Houses

### 7.3 Modelling Approaches

Load profile development can take two broad approaches – bottom up or top down.

#### 7.3.1 Bottom-up Approaches

There are two alternative bottom-up approaches: Firstly, developing a households' energy-use profile analytically by describing the house as a thermal envelope and deriving from first principles, equations that describe energy use. This task is complicated and involves a high focus on the physical aspects of the building's structure, the heat transfer and storage characteristics. It would rely on an audit of the houses' appliances and occupancy behavior to

determine actual use. This time consuming process would be entirely theoretical with no actual data to back up estimates and therefore it was not used.

The second is to physically measure the houses' circuits thus obtaining time of use profiles. This is probably the most accurate method but has increased costs because data logging is expensive and time consuming. In addition, a large number of houses must be logged in order to get a statistically significant results. To be useful in a predictive manner such data must be analysed to determine the relationship between the end-use load profiles and household characteristics. This approach is still considered bottom up as it aggregates the various end-use profiles into an overall total energy use profile. Availability of data limited the use of this approach.

### **7.3.2 Top-down Approach**

This approach uses feeder level measured data for a number of houses, i.e. that obtained at the GXP or higher level. These aggregated load curves can be divided by the number of connections to obtain an average individual profile, but potentially critical information about the load profile is lost. However, such average information for a particular GXP or region can be used to relate energy use to a variety of factors such as socio-economic data and house size distributions. For example the information in Table 7-1 could be used to break-down a total energy use profile into its main constituents in a pro-rata fashion. This could be done for an individual house even though energy use for that specific house is unknown.

### **7.3.3 Hybrid approach**

A third approach is a combination of the bottom up and top down methods in order to take advantage of the respective merits of each. A number of combinations could be chosen. These options are generally limited by data availability. One method is to use actual measured data from houses, thereby generating a reasonably accurate profile shape capturing variation during the day and year. Such profiles could be manipulated using the top-down approach of scaling the profile based on national and regional energy-use data.

## 7.4 Chosen approach

It was decided to use this hybrid approach to develop the load profiles in this thesis. The main structure of the load profile development methodology for an individual residence is shown in Figure 7-6.

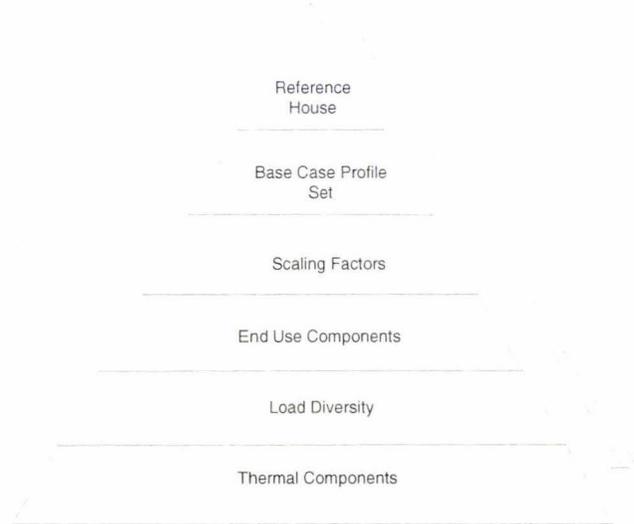


Figure 7-6: Steps in Creating a Load Profile

The main steps are:

### 1) Reference house

A reference case was created for a medium sized house in Christchurch with a medium level of insulation for a standard (climatic) year.

### 2) Establishment of the base case average profile set

A set of 40 base case (reference) profiles were formed from the original IRL data set (comprising of 5 classes of profiles for each of the 8 typical days, representing weekdays and weekend days for each of the four seasons). These 40 profiles were normalised using a scaling factor [ $SF_{ref}$ ] so that the annual energy consumption [ $AEC_c$ ] which is a weighed sum of the 8 day types, equated to that of the reference house  $AEC_{ref}$ . In essence, the reference house had a different shape profile for each of the day-types represented by the profile classes 1 to 5.

### 3) Scaling of the base profiles

The reference house,  $AEC$  was adjusted using another scaling factor [ $SF_c$ ] to account for different:

- location
- insulation level
- house size

4) Disaggregation of total energy load

The total energy load profile was allocated into the components:

- thermal load
- residual electrical load

using factors that were dependent on the season of year.

5) Load diversity

The average ½ hourly energy use was adjusted to take account of load diversity by adding variation based on the Gamma distribution of individual loads about the average load. The variation was introduced independently for the residual electrical load and the total thermal load.

6) Disaggregation of thermal energy load

Allocation of the total thermal load into the components:

- space heating and cooling
- domestic hot water

using factors that represented time of year dependent use (e.g. higher space heating in winter).

The most significant assumptions made about the load profile development methodology were driven by data availability. They were

1. The end-use profiles for SH / SC, DHW and residual electrical load were fractions of the total energy profile and were not individual profiles in their own right.
2. For each class of profile the difference in profiles between weekends and weekdays, and months of the year was consistent for all regions in New Zealand.
3. The segregation of the thermal load (i.e. the ratio of SH and SC to DHW) varies throughout the year but is assumed constant between regions.
4. Variation of the component thermal loads (DHW and SH/SC) from average demands were coincident (i.e. not independent).
5. The total energy use was derived from electricity only consumption data by scaling using national average energy to electricity ratios. Therefore regional and temporal variations of this ratio were not modelled.

## 7.5 Reference House

For the case studies the reference annual energy consumption [ $AEC_{ref}$ ], a value of 13,500 kWh/year was used which was based on an electrical load of 9,500 kWh/year for an average domestic household in Christchurch (Gardiner & Sanders, 1999) and that electricity is 69% of the total energy use.

## 7.6 Base Case Average Profile Set

The original IRL data gave 5 class profiles for both a weekday and weekend for each month (120 profiles). To reduce computational effort (which had an impact on calculation time), it was decided to reduce this to 8 profiles for each class (40 profiles) by averaging the profiles into the following seasonal groups:

summer -	December, January, February
autumn -	March, April
winter -	May, June, July, August
spring -	September, October, November

Modelling using seasonal average profiles instead of monthly averages was considered to give adequate sensitivity to time of year load changes especially given the impact of profile uncertainty (diversity).

These profiles (which were based on the average of 74 houses) were then scaled such that:

$$AEC_{ref} = AEC_c \cdot SF_{ref.c} \quad \text{Equation 7-1}$$

$c$  = Profile class (1 - 5)

Therefore the scaling factor, which was applied to every ½ hour block was calculated using:

$$SF_{ref.c} = \frac{\sum_d^8 \sum_n^{48} X'_{ndcm_d}}{AEC_{ref}} \quad \text{Equation 7-2}$$

where

$n$  = nth period of the day

$d$  = day type

$m$  = number of days in each season

$X'$  = demand of standard profile [kWh]

The final factor used to modify the base case average profile set was the type of climatic year. The number of days per season could be adjusted to mimic macroscopic, annual changes. For example, to convert from an average year to a cold year a greater number of winter days could be chosen with commensurate changes to the  $AEC_C$ :

	Number of days		AEC [kWh]	
	Average year	Cold year	Average year	Cold year
Summer	91	61	2545	1685
Autumn	61	91	2248	3635
Winter	122	152	5951	7344
Spring	91	61	2896	2105
Total	365	365	13500	14769

The limitation to this approach is that in a colder year generally certain end-uses are more likely to increase than others (e.g. space heating). The above methodology assumes that all end-uses increase equally.

In summary, a standard set of 40 profiles that contained inherent variation in load were used to model patterns of energy use over time throughout a year. This profile set served as a basis that could be adjusted to account for the effect of certain parameters such as location, size of house and building characteristics. The standard set of profiles used are given in Figure 7-7.



Figure 7-7: Base Case Reference Profile Set

## 7.7 Scaling factors

The objective was to be able to transform the *AEC* for the reference case to reflect some of the variation found in NZ. However, the relationship between load profile and socio-economic, demographic and house type characteristics, is complicated. Given the present scarcity of data it was decided to concentrate on the major contributing factors that could be modelled, albeit at an overall load level as shown in Figure 7-8.

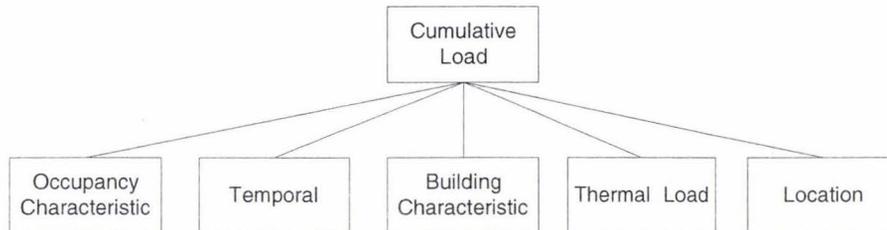


Figure 7-8: Factors Affecting the Annual Load Profile

The effect of these factors were modelled by using three scaling factors:

$$AEC = AEC_{ref} \cdot G \cdot I \cdot S$$

Equation 7-3

where

*G* = Geographic factor

*I* = Insulation factor

*S* = House size factor

Parameter	Parameter	Category
	Location	Auckland, Wellington, Christchurch, Dunedin
	Occupancy characteristics	Small, medium, large
	Building characteristics	No insulation, retrofit insulation, complete insulation

Table 7-2: Load Profile Analysis

### 7.7.1 Location (geographic factor)

The values of the geographic factor that were determined from electricity consumption data provided by Gardiner & Sanders (1999) are given in Table 7-3. It is noted that intuitively, the cooler regions have higher energy use. It was assumed that total energy use would have a similar regional effect on electricity consumption.

Region	Relative consumption (Geographic factor, <i>G</i> )	Annual energy consumption (average kWh/domestic customer) <sup>29</sup>
Auckland - Mercury Energy	0.75	7,175
Wellington - Capital Power	0.85	8,051
Christchurch- Southpower	1	9,153
Dunedin - Dunedin Electricity	1.06	10,104

(Source: Gardiner & Sanders 1999)

Table 7-3: Geographic Scaling Factor for Consumption of Electricity

Embedded in these regional electricity consumption data are factors such as different proportions of non-electricity energy sources and behaviour patterns. These scaling factors were compared to those obtained using the ALF 3 (ALF, 2001) model in Figure A-8. The results were similar except for the Dunedin (Lower South Island) region where ALF suggests a factor of 2 rather than 1.06. An explanation may be that ALF uses total energy (not just electricity) in its methodology suggesting that there is a higher use of non-electricity energy supply in Dunedin than Christchurch.

### 7.7.2 Occupancy Characteristics

Occupancy characteristics describes how the people living in the home consume energy both explicitly in proportion to the number of people, and implicitly by their behaviour e.g. lifestyle

Some possible factors to describe occupancy characteristics are:

- Lifestyle
- Income level
- Number of occupants

Since no data concerning these factors were available for the 74 houses used by IRL to define the profile classes, they were combined into a single factor called a generic size of user:

- Small
- Medium
- Large

The relative consumption factor based on a generic size of user was arbitrarily chosen and is given in Table 7-4. A small house was assumed 50% smaller (in terms of m<sup>2</sup>) than the medium and conversely the larger house 50% greater. These factors were compared to that obtained from the ALF model based on floor area alone (Table A-8 and Appendix I). There

<sup>29</sup> Reported as energy consumption, but should be electricity consumption.

was reasonable agreement except for the small house. ALF gave a factor of 0.2 suggesting a highly non-linear relationship between house size and energy consumption.

Category	Relative consumption (House size factor): <i>S</i>	Annual energy consumption (kWh) for Christchurch
Small	0.5	6,957
Medium	1.0	13,913
Large	1.5	20,870

Table 7-4: House Size Scaling Factor and Impact on Energy Consumption

It was assumed that behaviour, whilst probably having an effect on profile shape does not change the total demand significantly. House size was not considered separately from occupancy profile, that is a large empty house may have the equivalent AEC to a small house with a large number of people. In the future different values could be used and relationships between physical, socio-economic, demographic factors and the value of the size factor could be developed.

### 7.7.3 Building Characteristics

Building characteristics can provide an indication of energy use in two ways. Firstly by virtue of its size a large home would generally require more energy to heat than a smaller one. Secondly, by the *type* of building construction and in particular the nature of the insulation (often related to age as building codes have evolved). Three broad levels of insulation were modelled (Table 7-5). Insulation is seen as a significant differentiator in the energy efficiency and therefore energy consumption of a house. It also provides a convenient tool for market segmentation.

Insulation type	Relative Heating Energy (Insulation factor): <i>I</i>	Description
NZ National Building Code 1992	0.81	New home with roof, walls and floor insulated
Retrofit	1	Existing home with 75mm of fibreglass installed in ceiling
No insulation	1.21	Existing home with no insulation

(Source: Wright & Baines 1986)

Table 7-5: Insulation Level Scaling Factor

The insulation factor was assumed independent of climatic region and space heating type. Again, the value of insulation factor given in Table 7-5 were in close agreement with those estimated using the ALF model (Table A-7).

#### 7.7.4 Actual Demand

By combining the above factors, the energy demand in any ½ hour period for a particular standard class profile can be adjusted as follows to give the actual demand for a particular ½ hour period:

$$X_{nd} = X'_{ndc} \cdot SF_{refC} \cdot G \cdot I \cdot S \quad \text{Equation 7-4}$$

### 7.8 Disaggregation of Total Energy Load

Profile disaggregation in this section refers to the subdivision of the total load profile into its thermal and residual electrical components. The subsequent step of splitting the thermal load into its sub-components is done separately and is dealt with in section 7.10. This two step process allowed for diversity to be done separately for the thermal and residual electrical loads.

The demand profile for each single ½ hour block is split into the thermal and residual electrical components. The residual component is given by:

$$X_{ndr} = X_{nd} \cdot RC_d \quad \text{Equation 7-5}$$

where

$RC_d$  = Residual component factor for the season of the year.

$X_{ndr}$  = Residual electrical component of load [kWh]

$RC_d$  has a seasonal variation only. It was determined using data from IRL as shown in Figure 7-9.

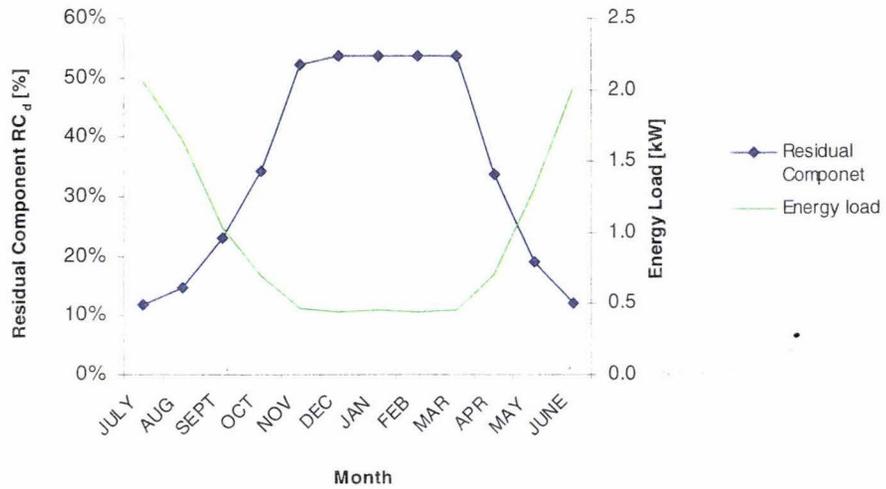


Figure 7-9: Seasonal Variation in Energy End-Use for a Christchurch House

The thermal demand profile is given by:

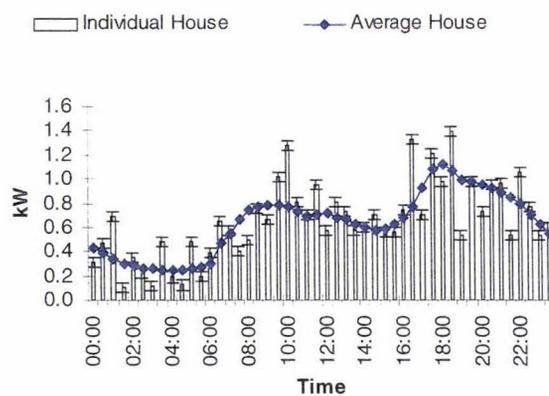
$$X_{nd\ t} = X_{nd} \cdot (1 - RC_d)$$

Equation 7-6

The  $RC_d$  values in Figure 7-9 are consistent with the national annual average thermal load being 74%.

## 7.9 Load Diversity

The outcome of the above procedure is an average profile for the house for each of the 8 seasonal day type cases. EECA (1998) summarised the ½ hour load data for 29 houses by expressing it as a mean and s.d. for each ½ hour period. Figure 7-10 shows the variation (error bars) of an individual house about the mean profile.



Source: Author, 2001

Figure 7-10: Average vs Individual Load Profile

To simulate the profile for an individual house, variation (uncertainty) was added to ½ hour mean. The variation was based on a cumulative Gamma probability distribution (ITL, 2000):

$$f(x) = \frac{\Gamma_x(\alpha)}{\Gamma(\alpha)} \text{ for } x \geq 0 \quad \text{Equation 7-7}$$

$\Gamma_x(\alpha)$  is the incomplete gamma function given in Equation 7-8.

$$\Gamma_x(\alpha) = \int_0^x t^{\alpha-1} e^{-t} dt \quad \text{Equation 7-8}$$

$\Gamma(\alpha)$  is the gamma function given in Equation 7-9:

$$\Gamma(\alpha) = \int_0^{\infty} t^{\alpha-1} e^{-t} dt \quad \text{Equation 7-9}$$

The general formula for the probability function of the Gamma distribution used was (Microsoft Excel 97):

$$f(x) = \frac{\left(\frac{x-\mu}{\beta}\right)^{\alpha-1} e^{-\frac{x-\mu}{\beta}}}{\beta\Gamma(\alpha)} \text{ for } x \geq \mu \quad \text{Equation 7-10}$$

where:

$$\beta = \frac{\mu^2}{\sigma} \quad \text{Equation 7-11}$$

$$\alpha = \frac{\sigma^2}{\mu^2} \quad \text{Equation 7-12}$$

$\mu$  = mean load (kW)

$\sigma$  = standard deviation of loads (kW)

$f(x)$  = cumulative probability of the load being less than  $x$

This function was used to give the load corresponding to a cumulative probability between 0 and 1 that was produced by a random number generator.

Values of  $\sigma$  were estimated using published figures in the HEEP Year 2 report. In general,  $\sigma$  was roughly about 30% of the base load usage. The Gamma distribution was used as it is bounded by zero and it had been used with success to simulate the variability in individual

profiles (Cleland, 2001). A normal distribution is not appropriate as it is infinitely double bounded meaning that negative consumption values could be generated at times of low average consumption (i.e. when the ratio of  $\sigma$  to  $\mu$  was large).

Figure 7-11 gives an example of the gamma distribution being used in a simulation of 100 individual load profiles. The variation in load of a single  $\frac{1}{2}$  hour period is shown in the form of a histogram. The histogram was used to verify that the model was producing profiles that had a Gamma distributions.

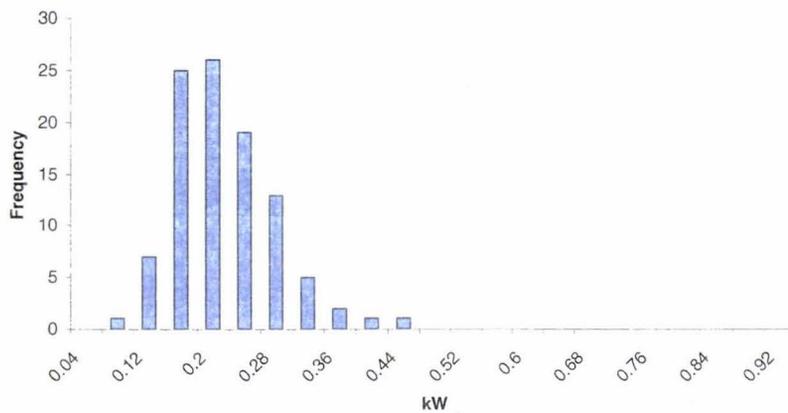


Figure 7-11: 100 Run simulation (Mean 0.2, SD 0.06)

The residual and thermal demand profiles were independently varied in the model. It was considered that residual usage would be more variable than thermal usage as the major thermal loads of SH and DHW would have slower switching cycles than appliances. Therefore a larger standard deviation was used for the residual electrical usage than the thermal usage. For the sake of simplicity, time constraints and the lack of data it was assumed that all components of the thermal load varied about the mean value in an identical manner. Therefore if the thermal load for a particular home and time period was 20% higher than the average, then both the DHW and SH/SC were 20% higher than the average.

## 7.10 Disaggregation of Thermal Energy Load

The thermal load profile comprises two main components:

- 1 Domestic hot water [DHW]
- 2 Space heating [SH] and space cooling [SC]

Figure 7-12 gives an example of these profiles along with the residual electrical profile that the model uses.

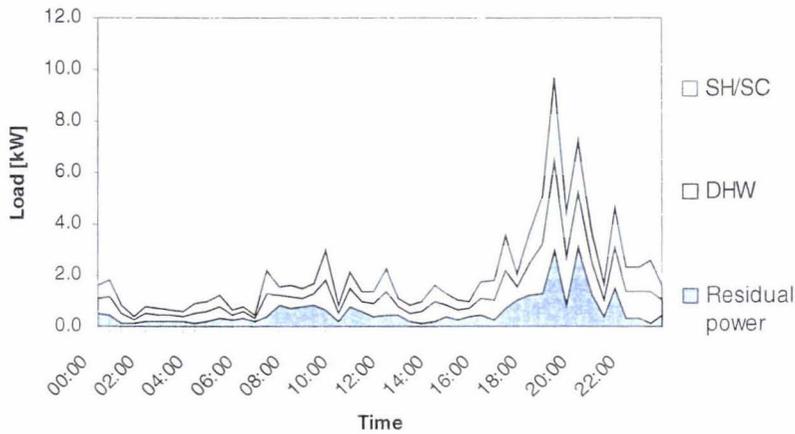


Figure 7-12: Load Profile Components as Used by the Model

The thermal sub-components were defined on a 1/2 hour basis:

$$X_{nd\ t} = X_{nd\ t(DHW)} + X_{nd\ t(SH)} + X_{nd\ t(SC)} \quad \text{Equation 7-13}$$

The space cooling component was given by:

$$X_{nd\ t(SC)} = TC_{d,SC} \cdot X_{nd\ t} \quad \text{Equation 7-14}$$

The space heating component was given by:

$$X_{nd\ t(SH)} = TC_{d,SH} \cdot X_{nd\ t} \quad \text{Equation 7-15}$$

The domestic hot water component was given by:

$$X_{nd\ t(DHW)} = TC_{d,DHW} \cdot X_{nd\ t} \quad \text{Equation 7-16}$$

Where  $TC$  = Thermal component factor. For any day-type or period:

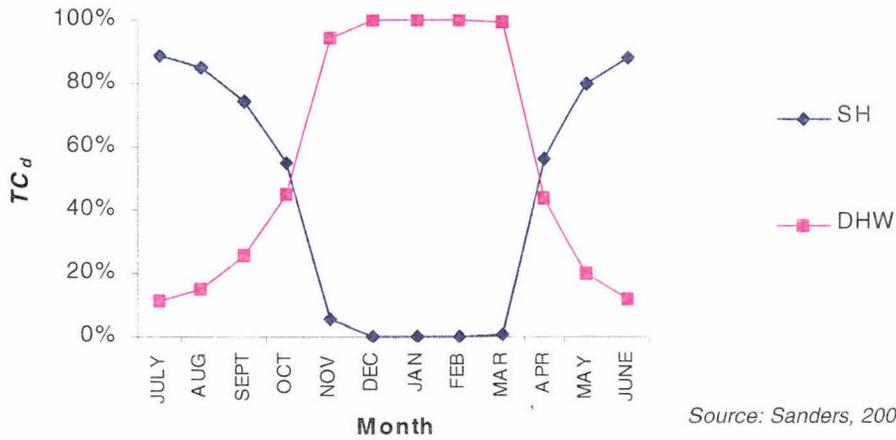
$$TC_{d,SC} + TC_{d,SH} + TC_{d,DHW} = 1 \quad \text{Equation 7-17}$$

The values of  $TC$  were varied for different day-types but were selected so that the annual breakdown of DHW and SH matched the national average of a 50:50 split as shown in Equation 7-18:

$$\frac{\sum_{n=1}^8 \sum_{d=1}^{48} X_{nd.DHW}}{\sum_{n=1}^8 \sum_{d=1}^{48} (X_{nd.SH} + X_{nd.SC})} = 1$$

Equation 7-18

Figure 7-13 gives IRL data for  $TC$  for a single house in Christchurch where there is no space cooling. The final values of  $TC$  used are given in Appendix C.1.6. Further research into the break-down of residential load components could be warranted.



Source: Sanders, 2001

Figure 7-13: Seasonal Variation in Thermal End-Use for a Christchurch House ( $TC_{d.SC=0}$ )

Some other key assumptions are outlined in Table 7-6.

Assumptions & Key considerations		Background	Impact on project
Current status	The percentage of total use that each end-use make up is constant throughout NZ.	While the weightings are able to be changed, they don't change automatically as a function of location.	Reduced sensitivity to location
	The energy supply to the thermal end uses does not change the absolute energy demand. The supply is adjusted depending of the device's energy efficiency only.	In reality this is saying that if you were to heat your home you would achieve the same comfort level (or useful energy) independent of the energy source used.	Minimal as control system works to maintain a similar comfort level independent of the energy source
Future provision	Have independent profiles for the main end uses	Would provide a more realistic pattern of energy use and possibly different results	Substantially more complicated load profile development module

Table 7-6: Profile Component Analysis and Major Assumptions

### 7.11 Thermal Conversion Efficiency [F]

The thermal conversion efficiency factor is a composite of two important efficiencies. Firstly, it takes account of the difference between supplied energy and delivered (useful) energy of the metered data. The load data was available as metered electricity. Therefore to estimate delivered energy a conversion efficiency [ $F_m$ ] was applied. Secondly, how efficient the heat transfer system is that recovers heat from the DG unit and supplies a thermal end-use was accounted for.

$$F = \frac{F_m}{H_T} \qquad \text{Equation 7-19}$$

$F_m$  = metered conversion efficiency

$H_T$  = efficiency of the DG heat transfer system as distinct to the efficiency of the DG unit as a power generator.

### 7.12 Neighbourhood Analysis

In order to study the cumulative impact of hundreds of DG units operating within a network, a hypothetical network was constructed. The hypothetical network had a population of 2,000 houses. Each house in the network was identical to each other in terms of insulation level and size (i.e. G, I and S can only be specified once). The housing class composition though could be chosen from any four house classes (i.e. 1, 2, 3, or 4). The fractional penetration of homes having a DG unit was selected for each of the class types previously chosen for the existing or BAU network. This became the hybrid network (See Table 12-6 for an example of a hybrid network used in Case Study 2). A simple comparison between the two networks was done by analysing the total demand profile of the hypothetical network for the BAU and DG cases as well as the total export profile for the hybrid (DG case) network.

## 7.13 Discussion and Recommendations

### 7.13.1 Profile Analysis

Developing load profiles is complicated with fundamentally different approaches available. The approach used in this Thesis has significant disadvantages that need to be addressed in the future. The thermal component of the energy load profile is made up of space air conditioning, mainly heating but also cooling and hot water heating. Different options exist to examine this substantial end use i.e. to realise what relationship exists between the total energy profile and its thermal components? One approach is to treat the thermal load as a separate, independent profile. A second is to infer the thermal use from the total energy profile by assuming it is a certain percentage of it. The choice between the two is driven by a number of factors:

1. Availability of raw data
2. Ability to carry out each approach
3. Consequence of either choice on final results

The raw data for the profile shapes are of total energy and since no data was available concerning what component was for thermal end-uses, the second approach was used. Practically this meant that whenever energy was being used, a certain percentage was for a thermal end use. Clearly though there are times when no thermal uses are being carried out. This approach impacts the model's ability to simulate a DG unit's ability to supply the energy needs of a household. For example, it arbitrarily forces a higher proportion of the thermal and residual loads to occur simultaneously so a DG unit running in CHP mode may appear to cater for more of the demand as its outputs (thermal and power) are also generated simultaneously.

Additionally, it is assumed that thermal output of a DG unit can be utilised equally for either DHW or space heating. This leads to difficulties both in analysing the financial impact of a particular end use and ignores the technical feasibility of recovering heat for air or water thermal loads.

Having the ability to model changes in occupant behaviour, and hence load shape and size, is an important aspect in examining residential DG. As the demand for living standards increase and central air conditioning becomes more common, then the space cooling is likely to become significant. This thesis incorporated space cooling into the structure as an additional end use to space heating. The combination of both can be regarded as air (space) conditioning. At present SC load is set to zero as no data regarding its use has been noted by the author.

### 7.13.2 Diversity Within the Half Hour.

Whilst the model uses a ½ hourly level of analysis, there is scope to go to an even finer level of detail. Figure 7-14 shows a comparison between ½ hourly data and 30 second load data. The most striking conclusion is the amount of detail lost from the coarser metering, particularly the reduction in peak demand. This can significantly affect estimates of import and export for a DG unit. The influence of diversity within the ½ hour period would mean that in general the actual export would be higher than if calculated using ½ hourly data.

A simple diversity constant is one possible way to convert the fraction of “internal” utilisation of DG based on a ½ hour analysis to an actual demand. Consider a heat-led Stirling engine with full load output of 1 kW electrical and 6 kW thermal. If the ½ hour period thermal demand is 2 kWh and the electrical demand is 0.25 kWh, the unit will operate 67% of the period to meet the thermal demand. Hence, the electrical output will be 0.33 kWh and since 0.25 kWh (75%) will be used internally,  $0.33 - 0.25 = 0.08$  kWh (25%) will be exported, and there would be no import necessary.

If the diversity constant is taken to be 0.7 then the actual output used internally could be estimated to be  $75\% \times 0.7 = 53\%$  (0.175 kWh). The export would become  $0.33 - 0.175 = 0.155$  kWh and the actual import would be  $0.25 - 0.175 = 0.075$  kWh. The ½ hour diversity (non-coincidence of thermal and electrical load) means that both export and import are occur in the same period. If there is net metering this has no effect on cost, but if export has lower value than import the economic viability of the DG is reduced. The above analysis assumes that all thermal output can be used (more likely than electrical output because of thermal storage) but in fact sometimes this is also not possible and hence there can be a diversity for thermal use as well.

The model goes some way to addressing this phenomena on a ½ hour basis by introducing diversity separately to the residual and thermal load profiles.

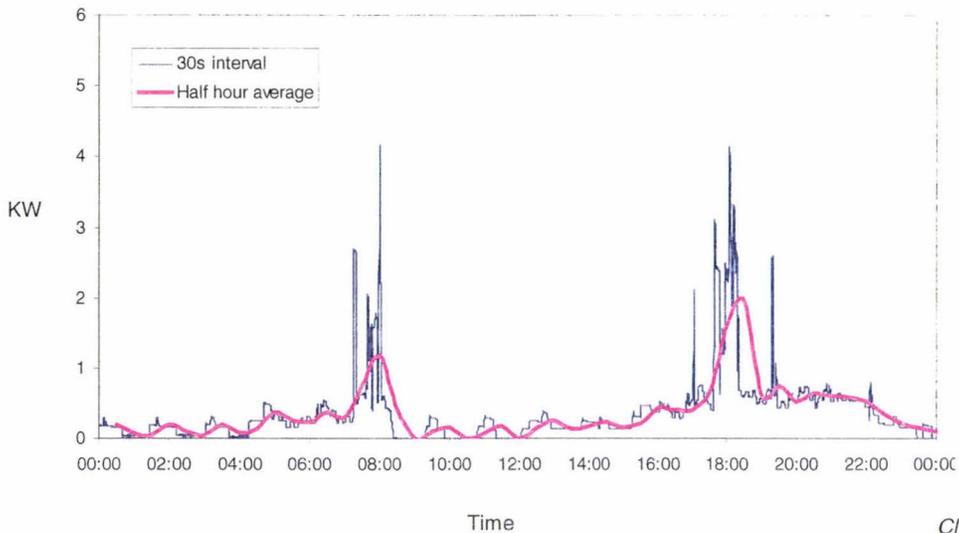


Figure 7-14: Different Levels of Interval Metering for a Residential Home

### 7.13.3 Multiunit Home Analysis

There are numerous examples of DG installations, particularly overseas, where co-generation or CHP plants provide district heating, and some cases district cooling, to the surrounding houses. In addition, apartments and commercial buildings that have shared HVAC systems are defined as multi-units as well. In these examples though, the shared service is thermal only. A DG unit, for example a 30kW micro-turbine, could be employed to serve the needs of a small apartment complex. The benefit of supplying multi-units are a smoothing out of the load profile. In practice this means a larger apparent base load to be served, allowing the DG unit to run for longer periods of time. The ability to model this situation should be developed.

### 7.13.4 Demand-side Management

Demand-side management could be employed to produce a demand profile that would better suit a DG output. The objective would be to maximise the run time of the DG unit (presuming it produces energy cheaper than the TSM) to displace more energy and thus improve profitability. This would involve analysing the components of the load curve and determining those that could be shifted, the magnitude and the methods to achieve this (e.g. thermal storage).

## Chapter Eight

# Technology Selection

*This Chapter provides a more in-depth description of the characteristics of the various DG technologies than in Section 4.6 and gives the mathematical relationship used to model their performance.*

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### 8.1 Overview

#### 8.1.1 Objective

The technology module allows for the selection of up to three different DG technologies for each household. The technology descriptions were chosen to allow flexibility in the specifications of each of the DG technologies so that specific features could be analysed for their impact on the feasibility of a particular technology. When selecting a particular type of technology the following parameters were taken into account (Figure 8-1):

- Location
- Operating regime
- Load profile
- Output profile

The relationship between these parameters is complex and affects the level of information required to assess alternative technologies. Thus, the descriptions of technologies were chosen on the basis of:

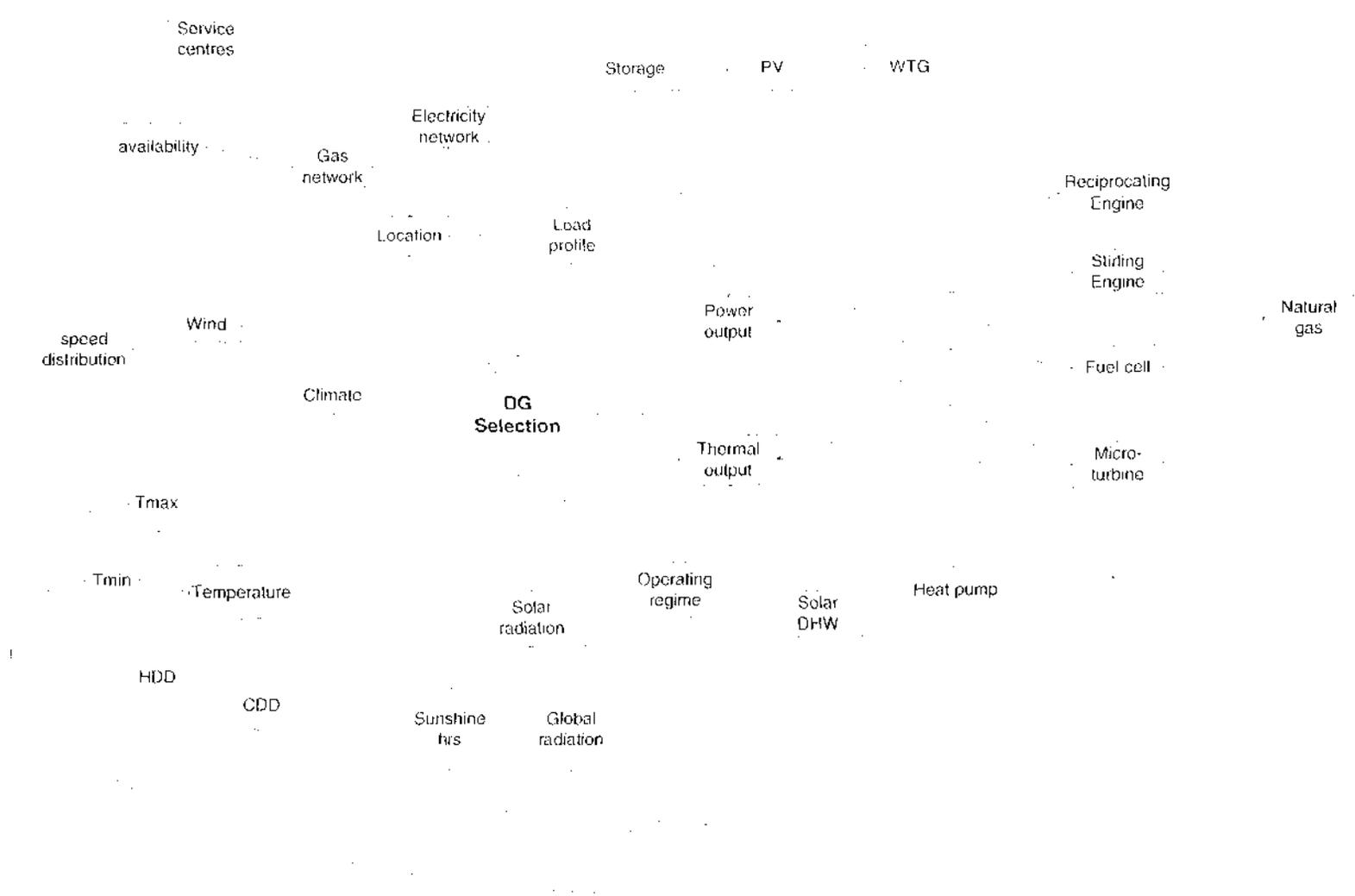


Figure 8-1 : Factors Affecting Technology Selection

- Ability to reflect changes in these parameters
- Synergy with other areas of the model, particularly data availability
- Impact on the model's output, i.e. the sensitivity of the model towards certain parameters.

## 8.2 Technology type

The technologies that were examined are categorised by two parameters, namely their level of sustainability and whether they are classified as a heat engine or not.

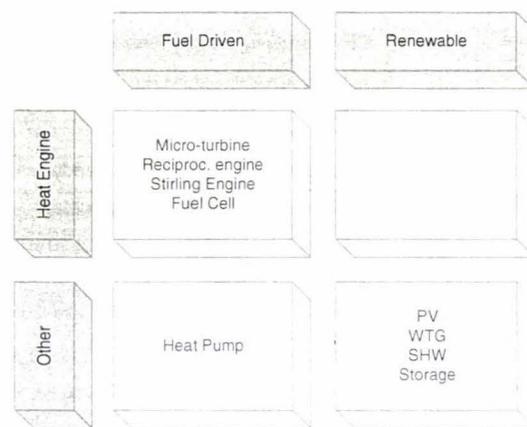


Figure 8-2: Modelled Technologies

The two categories affect the way the DG units are modelled. Micro-turbines, reciprocating engines and Stirling engines are similar in that they all produce heat and AC power, and use hydrocarbon fuels. Fuel cells, whilst using an electrochemical reaction rather than a combustion process are modelled as a heat engine as the basic outputs are also heat and power. Conversely, photovoltaics and WTG are similar in that they produce power only (no thermal output) and rely on intermittent renewable energy resources. Fuel-driven heat engines could be considered renewable if the fuel was generated by renewable means (e.g. bio-diesel or hydrogen).

In modelling residential sized renewable technologies, there is an added degree of complexity because the output depends on the availability of the natural resources (e.g. wind, solar radiation).

### 8.2.1 Heat Engines

Heat engines are the generic representation of a number of technology types (Figure 8-2). Table 8-1 gives a summary of the assumptions and considerations that were made regarding this technology type.

Assumptions & Key considerations		Background	Impact on project
Current status	The heat produced can be utilised for the all thermal demand (space heating , space cooling and DHW).	Specific temperatures, flow-rates and state (air, steam, water) of heat recovery stream are not considered in as much as they do not affect whether or not the recovered heat can be utilised. The utilisation of waste heat i.e. running the heat engine in CHP mode is of significance to the economics of a particular technology type, in particular the additional capital cost.	High – The capital cost would substantially affect the feasibility of a technology.
	All DG units will be run in parallel to the grid.	Since most houses will be already connected to the grid, and electrical storage is expensive, this situation will be the default option.	High – If DG units could not be grid connected, storage/redundancy measures would greatly increase cost .
Future provision	Waste heat stream characteristics specified	Stream characteristics are important (e.g. DHW requires temperatures >60°C)	High – only appropriately matched (to thermal demand) streams will be fully utilised.
	Dual fuel capability.	There are some advantages from dual fuel use that need to be explored.	Minimal – cost savings are likely to be small

The following parameters are specified:

Parameter Flexibility	Parameter	Scope
	Power output rating, $R_p$ [kW]	Function of operating capacity, which is significant when operating in a load following manner
	Heat output, $Y_t$ [kW]	
	Power output, $Y_p$ [kW]	
	Usable heat [%], $H_t$ [%]	Fixed
	Fuel conversion efficiency, $O_t$ [%]	
	Maintenance frequency, MI [service / hrs of operation]	

Table 8-1: Heat Engine Modelling

### 8.2.2 Heat Pumps

The modelling of HPs required a number of simplifying assumptions due to the complex relationship between its performance and the environment (ambient temperatures) in which it operates. Table 8-2 gives a summary of the assumptions and key considerations made when modelling HPs.

Assumptions & Key considerations		Background	Impact on project
Current status	The energy moved by the heat pumps can be utilised in both DHW and space heating and cooling requirements.	As with the heat engine, the heat produced is assumed equally applicable to SH, SC and DHW, even though the equipment requirements for space and water heating are quite different.	High. Significantly higher capital cost are required for both end uses
	Only air source heat pumps are analysed ground source heat pumps are not considered	Whilst offering a higher efficiency the increased capital cost of ground source do not make economic sense in New Zealand (Cleland et al, 1998).	Minimal
	$T_{cond}$ is modelled as a constant 18 °C above ambient or setpoint temperature	Used for ease of calculation	Medium
	$T_{evap}$ is modelled as a constant 14 °C below ambient or setpoint temperature	Used for ease of calculation	Medium
	Capacity is constant	Capacity changes with changes in ambient conditions	Medium
	Capacity is sufficiently large to cope with low winter temperatures (heating) and high summer temperatures (cooling)	The balance point (i.e. where supplementary energy is required when extreme ambient conditions exist) is not reached.	Medium – Hp are usually sized for the 99% climate condition
Future provision	Better estimation of COP	More accurate calculation to include compressor efficiency.	Medium
	Better estimation of $T_{evap}$ and $T_{cond}$ and capacity	Allows changes in ambient conditions to be reflected	Medium

The following parameters are specified:

Parameter Flexibility	Parameter	Scope
	$T_{evap}$	Constant set-point below ambient temperature
	$T_{cond}$	Constant set-point above comfort temperature

Table 8-2: Heat Pump Modelling

The performance of heat pumps were related to the Coefficiency of Performance or COP. The COP is defined as:

$$COP = \frac{(useful\ heating\ or\ cooling)}{(input\ power\ usage)} \quad \text{Equation 8-1}$$

The maximum possible COP for cooling defined by the Carnot cycle is:

$$COP_{max, cooling} = \frac{(273 + T_{evap})}{(T_{cond} - T_{evap})} \quad \text{Equation 8-2}$$

where:

$T_{cond}$  = refrigerant saturated condensation temperature [ $^{\circ}$ C]

$T_{evap}$  = refrigerant saturated evaporation temperature [ $^{\circ}$ C]

In heating mode:

$$T_{cond} = T_{setpoint} + 18 \quad \text{Equation 8-3}$$

$$T_{evap} = T_{ambient} - 14 \quad \text{Equation 8-4}$$

In cooling mode:

$$T_{cond} = T_{ambient} + 18 \quad \text{Equation 8-5}$$

$$T_{evap} = T_{setpoint} - 14 \quad \text{Equation 8-6}$$

$T_{setpoint}$  = Setpoint temperature [ $^{\circ}$ C]

$T_{amb}$  = Ambient temperature [ $^{\circ}$ C]

The ambient temperature is calculated on a ½ hour basis.

For a well defined designed and appropriately selected and operated HP then the actual COP should be half the maximum, so:

$$COP_{actual(cooling)} = COP_{max(cooling)} \cdot 0.5 \quad \text{Equation 8-7}$$

If heat losses are negligible then:

$$COP_{actual(heating)} = COP_{actual(cooling)} + 1 \quad \text{Equation 8-8}$$

### 8.2.3 Wind Turbine Generator

Wind is not ideally suited to residential sites, particularly those in high density settings, given the obtrusive nature of the towers. However they were included here for completeness sake given their applicability to rural housing. Table 8-3 lists the key assumptions and considerations for the wind module.

Assumptions & Key considerations		Background	Impact on project
Current status	Monthly wind speed data is used	These are determined from daily averages	High – ½ hour power production is therefor only a rough estimation.
	Wind has tremendous spatial variability, but is assumed constant within regions	To apply wind data across regions introduces large error in power production	High
	Weibull shape parameter of 2	2 is the value used for average wind sites	Minimal
Future provision	Site specific determination of shape factor	Impact of shape factor needs to assessed to determine if this parameter needs to be more accurate	Minimal
	Use of hourly wind data	Essential detail if realistic matching with load profiles is to be achieved.	High

The following parameters are specified:

Parameter Flexibility	Parameter	Scope
	Height of mast	Fixed (only 1 turbine type at present due to limited application of this technology)
	Turbine type	Soma 100 (chosen because of size suitability and available data)
	Location	Wind speed data based on 4 regions (Auckland, Wellington, Christchurch & Dunedin)

Table 8-3: Wind Turbine Generator Modelling

Power output is highly dependent on the wind speed, which means sites with high average wind speed ratings are particularly suitable. When estimating power available from the wind, speed variation must be taken into account because the average of the cube of many different wind speeds will always be greater than the cube of the average speed. Figure 8-3 shows a series of graphs that indicate the stages in estimating the power production from a wind turbine generator. A wind speed probability distribution for a particular site is combined with the power curve for a generator type to produce a power production curve, the area (integral)

of which gives an estimate of the electricity produced, in this case around 6.5 kWh over a 24 hour period.

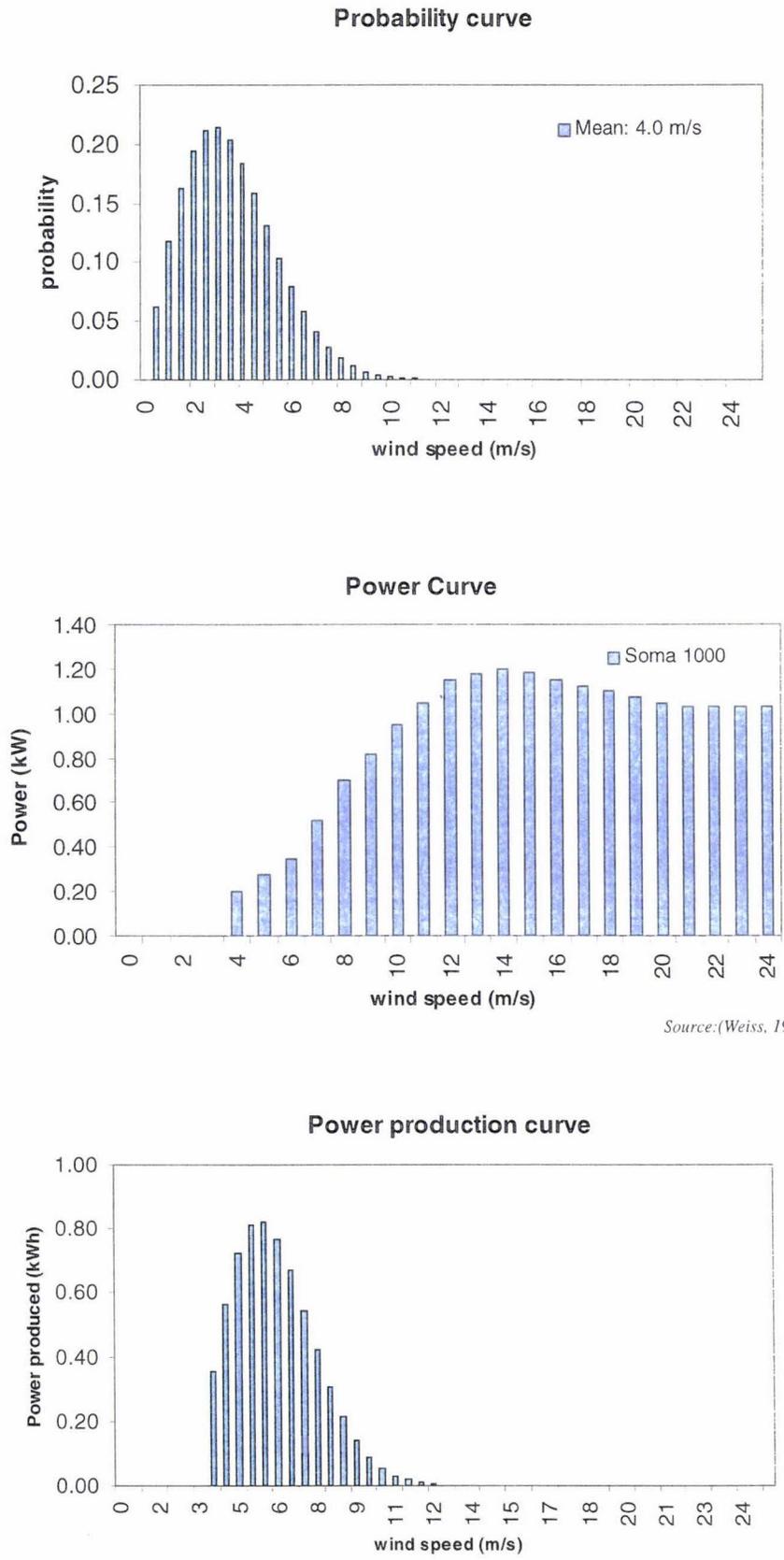


Figure 8-3 : Wind Power Production for a Soma 100 Over a 24hr Period

Wind data from a measuring tower must be translated into wind speed pertaining to a proposed turbine site. This involves making an adjustment for the height of measurement and the height of proposed use and the site topography.

$$v_1 = v_o \left( \frac{h_1}{h_o} \right)^\alpha \tag{Equation 8-9}$$

$h_o$  = original height

$h_1$  = new height

$v_o$  = wind speed at original height

$v_1$  = wind speed at new height

$\alpha$  = surface roughness coefficient (Table 8-4).

Surface Description	Roughness Coefficient, $\alpha$
Sea / sand	0.10
Low grass	0.13
Flat grassy surface	0.17
High grass / small bushes	0.19
Woodlands and urban	0.32

Source: (Weiss, 1992)

Table 8-4: Surface Roughness Coefficients for Typical Surfaces

The wind velocity distribution is generally based on the Weibull distribution (Equation 8.10) which gives the frequency of occurrence of a particular wind speed (Yeaman, 1998).

$$f(v_x) = \left( \frac{k}{C} \right) \left( \frac{v}{C} \right)^{k-1} \exp \left[ - \left( \frac{v}{C} \right)^k \right] \tag{Equation 8-10}$$

where

$C$  = Weibull scale parameter,

$$\approx v_{av} / (0.8864)$$

$v_{av}$  = the average wind speed for the site [m/s]

$k$  = Weibull shape parameter

The shape parameter gives the shape of the probability distribution of the wind speed. A value of  $k = 2$  which is a common value for a site of moderate speed was used. A distribution with a  $k$  value of 2 is known as a Raleigh distribution.

The determination of power produced by a wind resource is a difficult task given the sporadic nature of the wind and the scarcity of ½ hour data. The power generated by the WTG for each ½ hour period was determined by:

$$P_{wind} = \sum_v P_{WTG,v} \cdot f(v_i) \cdot 0.5 \quad \text{Equation 8-11}$$

$f(v_i)$  = probability of wind speed being  $v_i$

$P_{WTG}$  = output of WTG for speed  $v_i$

This gives an average (so same result for all ½ periods). The model currently assumes a constant  $v_i$  for all ½ hour periods.

#### 8.2.4 Photovoltaic

The methodology used to calculate the power output from a PV system was largely based on the model developed by Irving, (2001) as outlined in Table 8.5.

	Assumptions & Key considerations	Background	Impact on project
Current status	Measured solar irradiation is used	The alternative is to calculate irradiation based on analytical means. This however does not take into account cloud cover	Minimal
Future provision	Solar tracking devices	Greater capture of irradiation is possible. However the increased capital cost may not pay off.	Minimal
The following parameters are specified:			
Parameter Flexibility	<b>Parameter</b>	<b>Scope</b>	
	Size of collector		
	Orientation of collector	Single value	
	Tilt of collector		
	Efficiency of PV module	Constant value irrespective of conditions and type of panel	

Table 8-5: Photovoltaic Modelling

Solar resource data is generally in the form of monthly averages [kWh/m<sup>2</sup>/day]. This data must be translated into the available solar energy on a ½ hourly basis.

1. *Hourly radiation*

The relationship between hourly [I] and daily radiation<sup>30</sup> [H] (beam plus diffuse) is given (Suehrcke and McCormick, 1989):

$$I = H(a + b \cos \omega_s) \frac{I_o}{H_o} \quad [\text{kWh/m}^2] \quad \text{Equation 8-12}$$

where

$$\frac{I_o}{H_o} = \frac{\pi \cos \omega - \cos \omega_s}{24 \sin \omega_s - \omega_s \cos \omega_s} \quad \text{Equation 8-13}$$

and

$$a = 0.409 + 0.5016 \sin \left( \omega_s - \frac{\pi}{3} \right) \quad \text{Equation 8-14}$$

and

$$b = 0.6609 + 0.4767 \sin \left( \omega_s - \frac{\pi}{3} \right) \quad \text{Equation 8-15}$$

where

$\omega$  is the hour angle, [radians]

$$= \left( \frac{15 \cdot (\text{hour of the day} - 12)}{180} \right) \pi \quad \text{Equation 8-16}$$

$I$  = Global hourly radiation [kW/m<sup>2</sup>]

and

$\omega_s$  = the sunset / sunrise hour angle [radians]

$$= \cos^{-1}(-\tan \phi \tan \delta) \quad \text{Equation 8-17}$$

$\phi$  = site latitude [radians]

$\phi$  is positive for sites above the equator and negative for sites below

$\delta$  = declination angle [radians]

---

<sup>30</sup> H is measured data for a given site.

$$\delta = 23.45 \sin \left[ \frac{360(284 + n)}{365} \right] \quad \text{Equation 8-18}$$

$n$  = Julian day of the year

$H_o$  = daily mean extraterrestrial radiation on a horizontal surface, [kWh/m<sup>2</sup>/day]

$I$  = hourly extraterrestrial radiation on a horizontal surface, [kWh/m<sup>2</sup>/hr]

The Julian day for each month roughly corresponds to the middle day of that month (Table 8-6).

Month	$n$
Jan	17
Feb	47
Mar	75
Apr	105
May	135
Jun	162
Jul	198
Aug	228
Sep	258
Oct	288
Nov	318
Dec	344

Table 8-6: The Julian Day

The hourly radiation has 3 components:

$$I_o = I_d + I_B + I_G \quad \text{Equation 8-19}$$

$I_d$  = Diffuse radiation, [kWh/m<sup>2</sup>]

$I_B$  = Beam (direct) radiation, [kWh/m<sup>2</sup>]

$I_G$  = Ground reflected radiation, [kWh/m<sup>2</sup>]

## 2. Diffuse Radiation

The diffuse radiation is that which falls onto the earth's surface after it has been affected by cloud cover. The hourly diffuse radiation is related to the daily diffuse radiation by:

$$I_d = H_d \frac{I_o}{H_o} \quad \text{Equation 8-20}$$

$$I_d = K_d \cdot I_o \quad \text{Equation 8-21}$$

where

$K_d$  = The ratio of hourly average diffuse radiation,  $I_d$ , to hourly average global radiation  $I_o$ .

The diffuse clearness index or the ratio between the direct and diffuse radiation is defined by:

$$\left. \begin{aligned}
 K_d &= 1.0 - 0.09K && K < 0.22 \\
 K_d &= 10.9511 - 0.1604K + 4.388K^3 - 1 && 0.22 < K < 0.80 \\
 &6.638K^3 + 12.336K^4 && \\
 K_d &= 0.165 && K > 0.80
 \end{aligned} \right\} \text{Equation 8-22}$$

$K$  = average daily diffuse clearness index.

$K$  is defined as the ratio of the daily global radiation [ $H$ ] to the average extraterrestrial radiation [ $H_o$ ]. Essentially  $K$  takes into account the effect of cloud cover and of the atmosphere in reducing the extraterrestrial radiation:

$$H_o = \frac{86400 \cdot G_{sg}}{\pi} \left[ 1 + 0.033 \cos\left(\frac{360n}{365}\right) \right] \left[ \cos\phi \cos\delta \sin\omega_s + \frac{2\pi\omega_s}{360} \sin\phi \sin\delta \right] \text{Equation 8-23}$$

$G_{sg}$  = Solar constant = 1353 W/m<sup>2</sup>

### 3. Beam radiation

The beam radiation, or clear sky radiation is responsible for most of the collector's performance (Suehrcke and McCormick 1989).

$$I_B = I_o - I_d - I_G \text{Equation 8-24}$$

### 4. Ground reflected radiation

Negligible radiation reflected from the ground falls onto a *horizontal* surface, and hence  $I_G$  is assumed to be zero. Note this is different for a *tilted* surface.

### 5. Radiation on a tilted surface

Since the solar collector will typically be placed on roof-tops that are tilted, it is necessary to work out the radiation that would fall on such a surface. It has similar components to that of hourly global solar radiation.

$$I_t = I_{dt} + I_{bt} + I_{gt} \quad \text{Equation 8-25}$$

$I_{it}$  = Total hourly beam radiation on a titled surface [kWh/m<sup>2</sup>]

$I_{bt}$  = Hourly beam radiation on a titled surface [kWh/m<sup>2</sup>]

$I_{dt}$  = Hourly diffuse radiation on a titled surface [kWh/m<sup>2</sup>]

$I_{gt}$  = Hourly ground reflected radiation on a titled surface [kWh/m<sup>2</sup>]

(a) Beam radiation

$$I_{bt} = I_t R_r \quad \text{Equation 8-26}$$

where

$$R_r = \frac{\cos \sigma}{\cos \sigma_z} \quad \text{Equation 8-27}$$

$\sigma$  = angle of incidence of direct radiation to the normal of the titled plane

$\sigma_z$  = zenith angle

$$\begin{aligned} \cos \sigma = \sin \delta \sin \phi \cos \beta - \sin \delta \cos \phi \sin \beta \cos \gamma + \cos \delta \cos \phi \cos \beta \cos \omega + \\ \cos \delta \sin \phi \sin \beta \cos \gamma \cos \omega + \cos \delta \sin \beta \sin \gamma \sin \omega \end{aligned} \quad \text{Equation 8-28}$$

$$\cos \sigma_z = \cos \phi \cos \beta + \sin \phi \sin \delta \quad \text{Equation 8-29}$$

where

$\beta$  = angle of tilt of the collector to the horizontal plane, typically the slope of the roof [degrees]

(b) Diffuse radiation

$$I_{dt} = I_d \frac{(1 + \cos \beta)}{2} \quad \text{Equation 8-30}$$

(c) Ground reflected radiation

$$I_{g'} = I_d \rho_g \frac{(1 + \cos \beta)}{2} \tag{Equation 8-31}$$

where

$\rho_g$  is defined as the ground reflectivity (Table 8-7).

Surface characteristic	$\rho_g$
Snow	0.75
Light Building Surfaces (eg: light brick, light paints)	0.60
Dark Building Surfaces (eg: red brick, dark paints)	0.27
Green Grass	0.26
Weathered Concrete	0.22
Dry Grass	0.20
Crushed Rock	0.20
Soils	0.14
Water Surfaces	0.07
Earth Road	0.04

Table 8-7: Ground Reflectivity Values for Typical Surfaces

### 6. Power production

Once the available energy falling on a collector was calculated the useful energy was given by:

$$Power_{kW} = I_t \cdot Ac \cdot J \tag{Equation 8-32}$$

$Ac$  = Area of the collector [ $m^2$ ]

$J$  = Overall efficiency of the inverter, DC-AC conversion and the PV panel itself

$I_t$  = Radiation collected on a tilted surface [ $kWh/m^2$ ]

### 8.2.5 Solar Thermal

The assumptions were made in developing the solar thermal model are summed in Table 8-8:

	Assumptions & Key considerations	Background	Impact on project
Current status	A generic solar collector is used	Different configurations such as closed, open or active or passive are not explicitly considered. Considerable capital cost difference exists between these alternatives.	Medium
	$\Delta T$ is calculated from a constant $T_w$	$T_w$ was set at 15 °C (mains water temperature) This however would vary regionally and seasonally.	Minimal
Future provision	Variable $F_{r,c}$	Different collectors have different values for $F_{r,c}$	Minimal
	More accurate and dynamic calculation of $T_w$	Introduce regional and seasonal variability.	Minimal

The following parameters are specified:

	Parameter	Scope
Parameter Flexibility		For parameters relating to the solar resource consult the Photovoltaic model
	$F_{r,c}$	Range of optical efficiencies
	$F_{r,t}$	Single value (glazed collector)
	$\Delta T$	Temperature into collector is set at 15 °C

Table 8-8: Solar Thermal Modelling

The performance of the solar collector was modelled by RETScreen (2000):

$$Q = F_{r,c} \cdot G - F_{r,t} \cdot \Delta T \quad \text{Equation 8-33}$$

where

$Q$  = Energy collected per unit collector area per unit time [ $\text{W}/\text{m}^2$ ]

$F_{r,t}$  = Parameter used to characterise the collector's thermal loss [ $\text{W}/\text{m}^2\text{K}$ ]

$G$  = Global incident solar radiation on the collector [ $\text{W}/\text{m}^2$ ]

$F_{r,c}$  = Parameter used to characterise the collectors optical efficiency

$\Delta T$  = Temperature differential between the working fluid entering the collector and the ambient [ $^{\circ}\text{C}$ ]

Temperature of working fluid was not considered explicitly as a constant temperature differential was assumed for simplicity sake.

$G$  is estimated in the same way as in the Photovoltaic module, as a function of tilt and orientation of the collector.  $Fr_{UL}$  is set to a value  $5 \text{ W/m}^2\text{K}$  in the case studies which corresponds to a glazed collector (RETscreen, 2000).

### 8.2.6 Thermal Storage

There are two fundamentally different approaches that can be taken when dealing with thermal energy storage. One is to consider the mass flow-rates of the hot waste stream from the unit and to match it with demand via a storage device. The other is to consider only the energy content on a kilowatt-hour basis and ignore detailed consideration of performance of the storage device in terms of temperature, flow-rates and mixing. The first approach was discarded due to the complexity of modelling the physical characteristics of the storage device such as flow-rate, state, temperature and pressure.

Table 8-9 gives a summary of the assumptions and considerations when developing the storage module.

Assumptions & Key considerations		Background	Impact on project
Current status	SHW storage is integral to its operation	Since the majority of hot water is produced during the day, where there is generally less load, storage capacity is vital for fuller utilisation	High
	Storage is modelled on a energy basis (kWh) only	Done for simplicity sake	Medium
	Instantaneous availability	Stored energy is available at an instant and does not require time to extract	Medium
Future provision	Electrical storage to be considered	Given grid connectivity battery costs are prohibitive at present. Other electrical storage devices may be developed which change the economics	Medium
	Mass flows of thermal output to be modelled	Performing more detailed mass and energy balances would give a more realistic estimate of energy availability	Medium

The following parameters are specified:

Parameter Flexibility	Parameter	Scope
	Storage capacity	Single value
	Storage efficiency	Single value
	Discharge rate	Set percentage of current capacity
	Lower limit	Single value

Table 8-9: Modelling of Stored Thermal Energy

Thermal storage and their end use systems can either be open (direct) or closed (indirect). An open system requires no heat exchange from the exhaust heat flow (air or water) and the storage medium (e.g. excess heat from a SHW system is stored directly as hot water). Likewise the hot water or steam from a fuel cell can be used directly for space heating. A generic set-up may appear as follows:

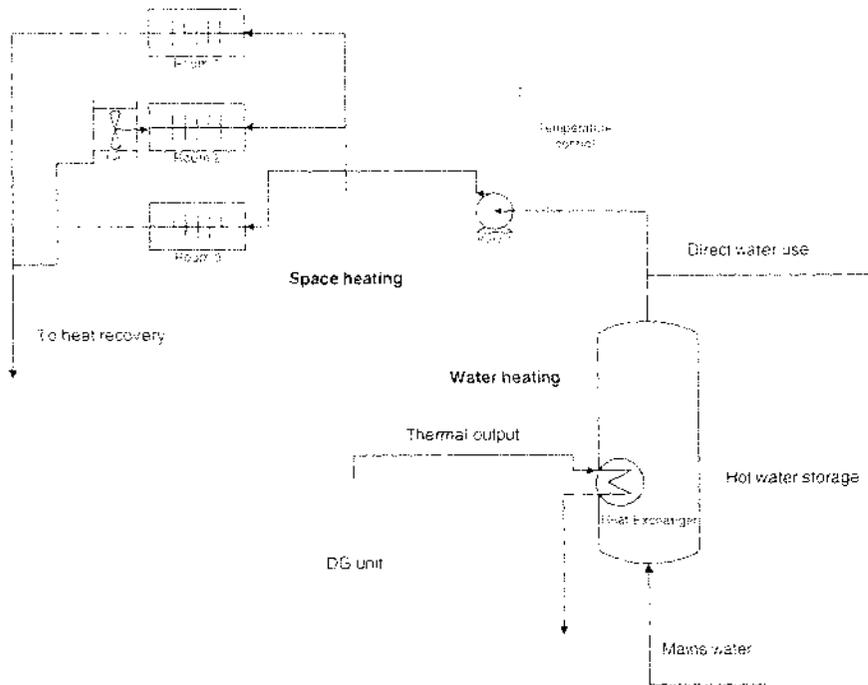


Figure 8-4: Layout of Thermal Storage and End Use

Since only the kilowatt-hour value of the thermal output is considered, it is less complicated than doing a full mass-energy balance approach. The generic equation describing the storage model is:

$$kWh_{stored} = \max[S_{max}, kWh_{stored\ n-1} + (kW_{in} - kW_{out})_n] \quad \text{Equation 8-34}$$

where

$n$  = Time interval ( 1/2 hr period of the day)

$S_{max}$  = Maximum storage capacity [kWh]

There are a number of constraints that govern  $kW_{in}$ ,  $kWh_{stored}$ , and  $kW_{out}$ . These are defined in Section 9.5.

### 8.3 Conclusions & Recommendations

#### 8.3.1 Heat Pumps

Heat pumps are a commercially proven technology and used residentially, in contrast to newer technologies which are perhaps 3 to 5 years away from domestic applications. The performance of the heat pump is directly related to its COP. Currently it is determined based on the Carnot cycle efficiency using a constant temperature difference with the ambient air to calculate the evaporation and condensation temperatures. It is recommended that the method used to estimate COP and changes in heating and cooling capacity as outlined by Cleland (2001) be incorporated. Improvements to the accuracy of the 1/2 hour ambient temperature profile would allow TOU variations to be better approximated.

#### 8.3.2 Solar Hot Water Heaters

Solar hot water heaters are a mature technology, have the 'green' tag and may be subject to government subsidies so it is therefore important that their analysis be as accurate as possible, as soon as possible. Improvements include calculating a more accurate temperature differential for the system and improving the storage analysis.

#### 8.3.3 Storage

Storage is an important value adding component to distributed generation and to the electricity industry as a whole. Storing electrical energy directly is not currently cost effective for the residential application since the already present grid offers a large and economic 'virtual' storage facility. However, this is not true for all DG applications, where at the larger scale, emerging technologies such as compressed air storage, flywheels and super-conducting magnetic storage, are providing more options. These should be borne in mind for future work.

Direct thermal storage, however is an essential element, particularly associated with solar hot water systems. It not only explicitly allows utilisation of more of the captured energy but it provides opportunities for load management. The storage module needs to be developed to enable inter-day transfer of stored energy, for example using energy captured during the afternoon of one day for the following morning peak.

#### **8.3.4 Wind**

Wind turbine generators, although included in the technology database, are not suitable candidates for high density urban settings. However, there may be future applications where the analysis provided by this thesis may be useful. For instance the production of hydrogen (via the electrolysis of water) for fuel cell applications. A critical area is in obtaining ½ hour or even smaller incremental wind speed data. It appeared from literature that many power curves use yearly or monthly wind speed data. When looking at individual applications, ½ hour data would provide a more accurate estimation of the load that could be met. Therefore a distribution to convert daily wind speed into ½ hour (or smaller) increments would be desirable. The Weibull distribution should be investigated for this purpose.

For all technology sub-modules it is suggested that testing of particular brands and models be carried out. This would enable the most promising models to be identified, and to establish a more accurate capital, installation and maintenance cost database.

# Chapter Nine

## Operational Control

*This Chapter gives a description of the control mechanisms that govern the operation of the DG units, the purpose of having different mechanisms and how they are applied. It also considers the issues involved in a network analysis.*

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### **9.1 Introduction**

#### **9.1.1 Objective**

The output capacity of a DG technology and the instantaneous demand of the household will seldom exactly match so control mechanisms are required. If the DG unit can provide cheaper energy than traditional supply mechanisms the aim is to capture as much of this energy as possible, to maximise its value proposition. Varying the useful DG output is one way to maximise energy capture. The other option is to manipulate the demand side by adjusting end uses.

#### **9.1.2 Structure**

Figure 9-1 shows the main operational control modes that were made available. In the model not all DG units are able to operate in every mode. For example, the capacity of renewable technologies is often determined by the climatic (natural resource) conditions.

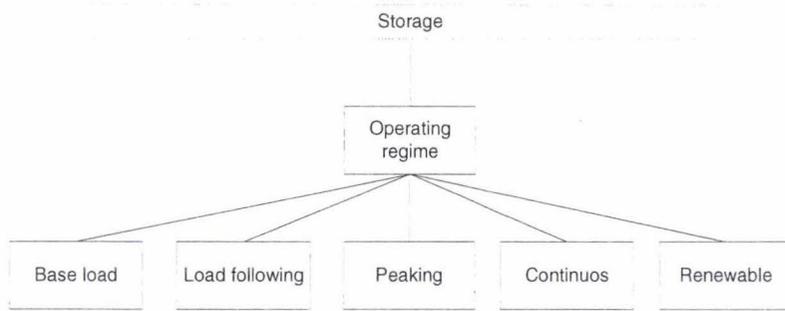


Figure 9-1: Operating Control Options

The following section describes each mode and how it was modelled.

## 9.2 Base Load

Base load is the continuous operation of the unit at its rated maximum output. It is the simplest form of control with the unit running 100% of the time and is applicable the heat engine technologies. Figure 9-2 shows an example Stirling engine operated in base-load mode. Generally the mode is only possible if excess thermal output can be dumped (extra capital cost) and excess power can be exported

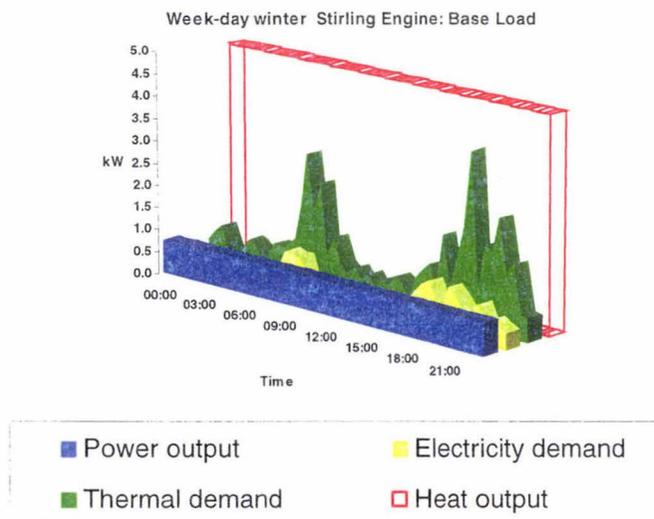


Figure 9-2: A Stirling Engine in Base Load Mode

The equations to describe the DG performance in base-load operational mode are:

Control Regime	Power Output	Thermal Output
Base load	$Y_{n,p} = R_{p,T}$	$Y_{n,t} = R_{t,T} \cdot H_T$ <p>where</p> $R_{t,T} = \frac{R_{p,T}}{O_f} - R_{p,T}$

Table 9-1: Base Load Control Algorithms

Where:

$Y$  = supply profile [kW]

$R$  = DG unit power rating [kW]

$O_f$  = operating efficiency (electrical)

$H$  = heat use efficiency

Subscripts:

$p$  = electrical (power) output

$t$  = thermal output

$T$  = technology type

$n$  = 1/2 hr period in the day

$H$  is the efficiency of the heat transfer system as distinct to the efficiency of the DG unit as a power generator.

## 9.2 Peaking

Peaking operation consists of the unit running when ever either the electrical or thermal demand exceeds its rated maximum output. Peaking operation is either heat led or electricity led. Figure 9-3 shows a Stirling engine operating in peaking mode. It highlights one potential disadvantage of having units that are oversized. If heat-led, the Stirling engine does not operate. However, if the thermal demand was greater, such as in a colder climate, heat led might be the preferred option.

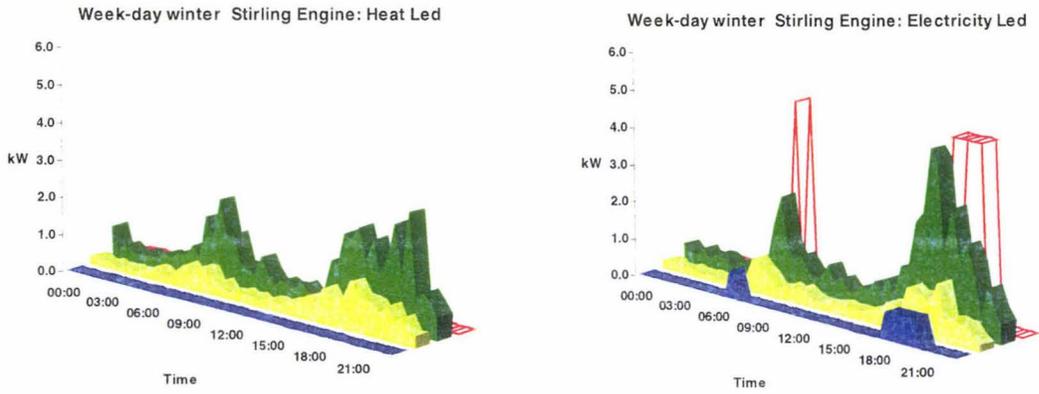


Figure 9-3: A Stirling Engine in Peaking Mode

The equations to describe the DG performance in peak mode are:

Control Regime	Power Output	Thermal Output
Peaking	electrical led $\text{if } R_{p,T} < X_r \text{ then } Y_{n_p} = R_{p,T}$ $\text{if } R_{p,T} > X_r \text{ then } Y_{n_p} = 0$	$\text{if } Y_{n_p} = 0 \text{ then } Y_{n_t} = 0$ $\text{if } Y_{n_p} > 0 \text{ then } Y_{n_t} = H_T \cdot R_{t,T}$
	heat led $\text{if } R_{t,T} < X_t \cdot F \text{ then } Y_{n_p} = R_{p,T}$ $\text{if } R_{t,T} > X_t \cdot F \text{ then } Y_{n_p} = 0$	$\text{if } Y_{n_p} = 0 \text{ then } Y_{n_t} = 0$ $\text{if } Y_{n_p} > 0 \text{ then } Y_{n_t} = H_T \cdot R_{t,T}$ <p>and</p> $R_{t,T} = \frac{R_{p,T}}{O_f} - R_{p,T}$

Table 9-2: Peaking Control Algorithms

where

$X_r$  = residual demand [kW]

$F$  = thermal end use efficiency

### 9.3 Load Following

Load following is different from peaking in that the technology can operate through a continuous spectrum of operating capacities, whereas peaking is only at 100% of rated output. Load following generally increases both the operating hours and displaced energy as shown in Figure 9-4 compared with Figure 9-3. However this comes at a cost of decreasing operating efficiency at part-load. As for peak mode, load following can be either electricity-led or heat-led.

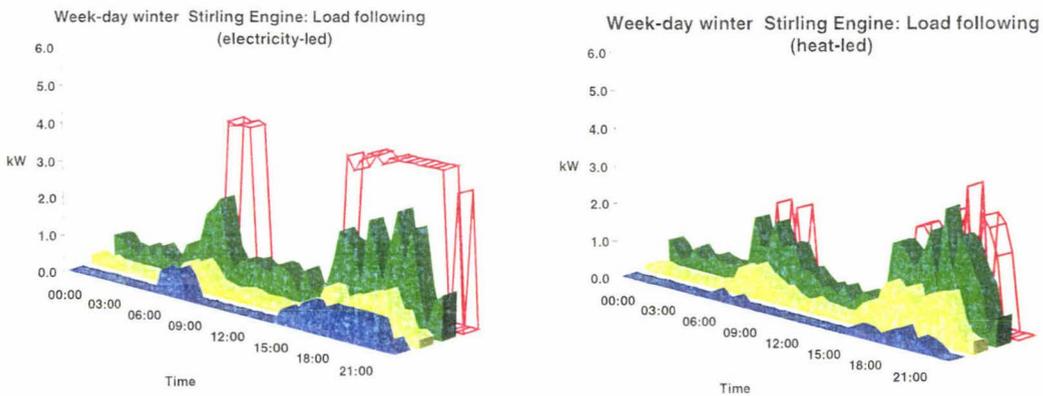


Figure 9-4: Stirling Engine Operating in Load Following Mode

Load-following calculations involves 4 steps:

1. Calculation of the partial loading,  $O$ : power loading if electricity led or heat loading if heat led. There is a fractional limit, below which the DG technology will not operate.
2. Conversion of partial loading to an operating capacity<sup>31</sup> using the part-load curves, specific to each technology. For example Figure 9-5 gives a part-load curve for a Stirling engine.

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<sup>31</sup>  $OC$  is a hybrid (thermal and power) operating capacity that was used in the calculations given the nature of the data available.

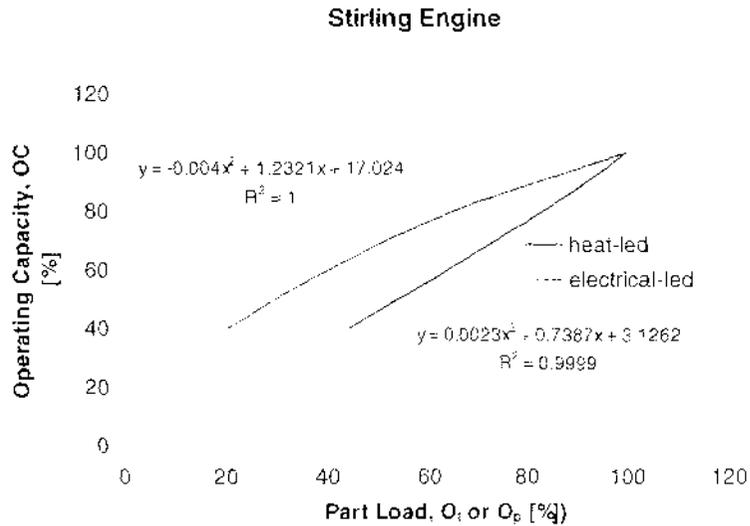


Figure 9-5: Stirling Engine Part Load Curve

3. Calculation of normalised heat and electricity output (R values) at the operating capacity using output curves, specific to each technology. For example Figure 9-6 gives an operating curve for a Stirling engine. Output curves for other technologies are located in Appendix H.

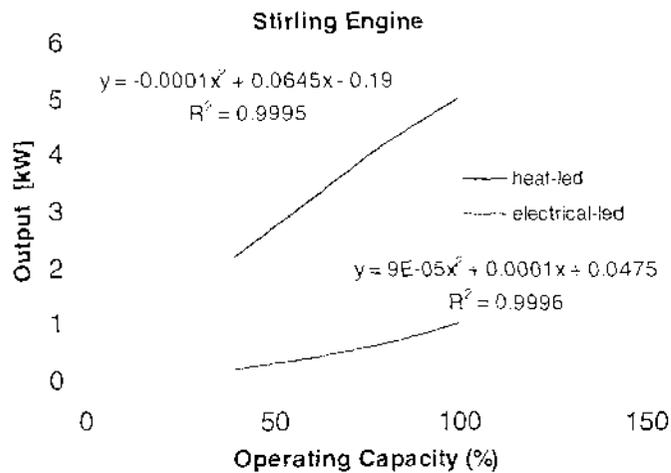


Figure 9-6: Stirling Engine Output Curve as a Function of Operating Capacity (1 kW<sub>e</sub> unit)

4. Calculation of actual heat and electrical output by scaling the results to engine sizes of greater than 1 kW electrical.

Table 9-3 shows the algorithms used for each of the four steps for heat-led operation, whilst Table 9-4 shows the case for electrical-led operation. The tables use a Stirling engine as an example. The model though, uses the same algorithms, but different data sets and

relationships (i.e. part-load curves and output curves) for a micro-turbine, fuel cell and reciprocating engine.

Control Regime	Power Output	Thermal Output	
Load following	Heat-led	1. Part-load	
		$\text{if } X_{n,t} \cdot F > R_{t,T} \cdot H \text{ then } O_{n,t} = 1$ $\text{if } X_{n,t} \cdot F > PL_t \cdot R_{t,T} \cdot H \text{ then } O_{n,t} = \frac{X_{n,t} \cdot F}{R_{t,T} \cdot H}$ $\text{if } X_{n,t} \cdot F < PL_t \cdot R_{t,T} \cdot H \text{ then } O_{n,t} = 0$ <p>where</p> <p><math>PL_t</math> = Thermal fraction limit is the minimum operating capacity</p>	
		2. Operating capacity	
		$OC_{t,T}$	$OC_{t,T} = f(PG_{t,T}, O_{n,t})$ <p><math>PG</math> = Part-load curve</p> $= -0.004x^2 + 1.2321x + 17.0224 \text{ (Figure 9-5)}$ <p><math>OC</math> = Operating capacity</p>
		3. Normalised heat and electrical output	
		$N_{n,p} = f_p(OU_{p,T}, OC_{t,T})$ <p><math>OU</math> = Output curve</p> $= 9E-05x^2 + 0.0001x + 0.0475$ <p>(Figure 9-6)</p> <p><math>N</math> = Normalised output</p>	$N_{n,t} = O_{n,t} \cdot R_t$
		4. Actual heat and electrical output	
$Y_{n,p,T} = \frac{N_{n,p}}{N_{n,t}} \cdot Y_{n,t,T}$	$Y_{n,t,T} = R_{t,T} \cdot H \cdot O_{n,t}$		

Table 9-3: Heat Led Following Algorithms

Control Regime	Power Output	Thermal Output
Load following	1. Part-load	
	if $X_{n,T} \cdot F_m > R_{p,T}$ then $O_{n,p} = 1$	
	if $X_{n,T} \cdot F_m > PL \cdot R_{p,T}$ then $O_{n,p} = \frac{X_{n,T} \cdot F_m}{R_{p,T}}$	
	if $X_{n,T} \cdot F_m < PL \cdot R_{p,T}$ then $O_{n,p} = 0$	
	where	
	$PL_p$ = Power fraction limit is the minimum operating capacity	
Electrical-led	2. Operating capacity	
	$OC_{p,T} = f(PG_{p,T}, O_{n,p})$	$OC_{p,T}$
	$PG = -0.004x^2 + 1.2321x + 17.024$	
	(Figure 9-5)	
	3. Normalised heat and electrical output	
$N_{n,p} = O_{n,p} \cdot R_{p,T}$	$N_{n,T} = f_t(OU_{n,T}, OC_{n,T})$	
	$OU = -0.0001x^2 + 0.0645x - 0.19$	
	(Figure 9-6)	
	4. Actual heat and electrical output	
$Y_{n,p,T} = R_{p,T} \cdot O_{n,p}$	$Y_{n,T} = \frac{N_{n,T}}{N_{n,p}} \cdot Y_{n,p,T}$	

Table 9-4: Electrical Load Following Algorithms

A heat pump can be modelled as load following heat-led, without any electrical output.

## 9.4 Renewable

Renewable technologies are assumed to operate at their maximum output level depending on availability of their natural resource. Electrical storage was not considered and thermal

storage was an inherent part of the solar hot water model. The majority of the analysis for renewable technologies relates to estimating available energy from the relevant natural resource (Chapter 8). For example, Figure 9-7 shows the energy delivered by a 1 kW photovoltaic array (12-15 panels) in winter. Any excess electricity is assumed to be exported back into the distribution network

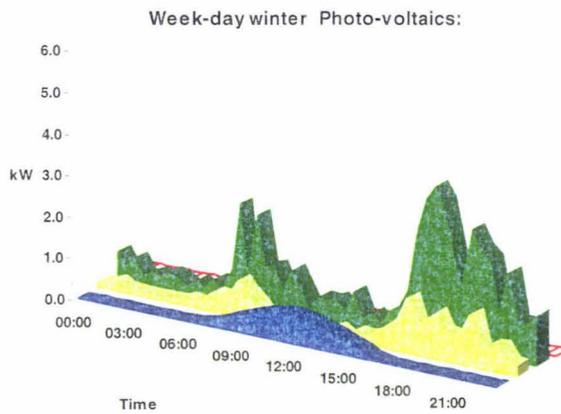


Figure 9-7: Photovoltaic Output

Control Regime	Power Output	Thermal Output
Photovoltaic	Details of I are shown in Section 8.2.4	
	$Y_p = J \times Ac \times I_t$ <p>where</p> <p><math>I_t</math> = Radiation collected on tilted surface</p> <p><math>J</math> = PV efficiency</p> <p><math>Ac</math> = Area of collector</p>	$Y_t = 0$
Solar Hot Water	$Y_p = 0$	$Y = Y_{n,t,b} + kW_{out}$ <p>where</p> <p><math>kW_{out}</math> = Output from storage vessel (Section 9.5)</p> <p><math>Y_{n,t,b}</math> = Direct output from SHWH</p>

Table 9-5: Algorithms for Renewable Based Technologies

## 9.5 Storage

The development of a storage functionality in the model, whilst conceptually simple, involved a substantial coding overhead and spreadsheet analysis because it requires an iterative calculation. Storage is only possible if the output of the DG technology is greater than demand, so the contribution of (availability) storage can only be estimated once an analysis of the match of the DG technology to the demand is made. However the contribution of storage affects the amount of export from the DG so an iteration is required. A simplifying assumption was made that the cumulative storage at the end of the day is zero and hence only one iteration is required. Direct use of the DG thermal output is given priority over use of storage.

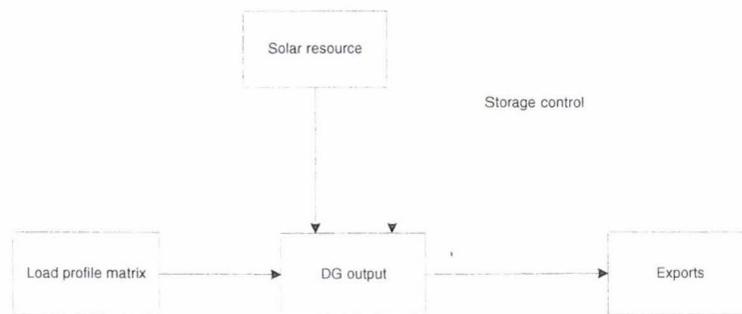


Figure 9-8: Storage Methodology

Figure 9-9 shows the match of a SHW operating in winter. The excess thermal energy produced which is available for storage is minimal, but never the less represents over 30% of the energy produced.

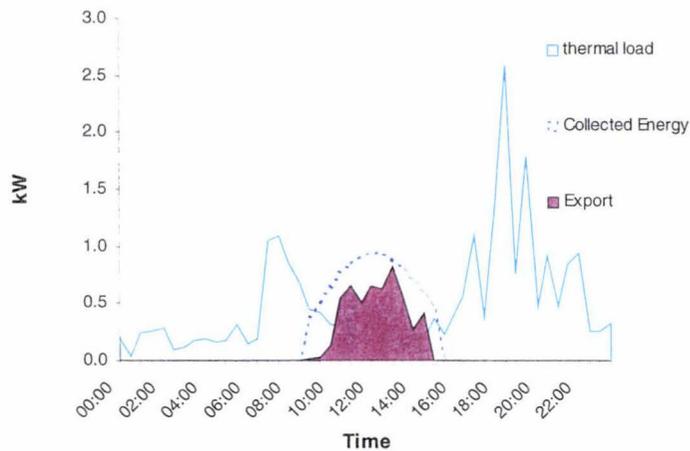


Figure 9-9: Winter SHWH Performance

### Step 1: Base Profile

The first step in working out the new profile is to calculate a base profile, that is given by Equation 9.1. The base profile is the smaller value between the energy that is delivered **and** energy used during the day:

$$Y_{n,t,T,b} = \min(Y_{n,T,t}, X_{n,t})$$

Equation 9-1

where

$b$  = base profile

Note there is no storage efficiency associated with this base profile as it represents the energy used at the time it is produced.

### Step 2: Input Energy

The input energy to be stored is worked out by a simple decision structure:

$$kW_{in} = \max\left[\left(Y_{n,t} - X_{n,t}\right) \cdot S_{eff}, 0\right]$$

Equation 9-2

$Y_{nt}$  = Supply profile

$X_{nt}$  = Demand profile

$S_{eff}$  = storage efficiency [%]

### Step 3: Output Energy

$$kW_{out} = \min\left[kWh_{stored} \cdot S_{DR}, \max\left[X_{n,t} - Y_{n,t}, 0\right]\right]$$

Equation 9-3

where

$S_{DR}$  = Discharge rate [%]

It was found that in many situations the cumulative storage at the end of the day is zero, thus justifying the original assumption.

The base profile is subsequently combined with the output of the storage module ( $kW_{out}$ ) to give an overall energy supply profile.

## 9.6 Network Analysis

### 9.6.1 Introduction

An important benefit and hence one of the main drivers for DG is the positive impact on the network in terms of reducing load and particularly peak loading. As owners and operators of the electricity network, the lines companies are in a pivotal role in determining the benefit and value of DG and ultimately its widespread use. The question is: how is this benefit quantified and then valued? This section sought to identify some of the issues associated with estimating the value derived from network benefits. Olsson and Neville (1999) have estimated that the value of load control in a typical South Island city is \$130 per kW/year. This relates to the distribution network only. There are also transmission and spot market savings but they are not considered in this analysis.

Future demand and the prediction of it provides focus to a line companies' asset management plan. Currently the electricity network's primary role is the provision of a cost effective, reliable, sustainable and safe supply of energy to its customers. The development of the network is very capital intensive and is subject to an increasing amount of scrutiny in today's regulatory environment. The capital expenditure is related to two primary factors:

1. The addition of new customers
2. Increasing demand from existing customers

There are however a number of secondary drivers that influence capital expenditure.

1. Meeting safety compliance requirements on ageing equipment.
2. Shareholders and consumers demand on environmentally sound response to system upgrade.
3. Meeting the requirements for suitable metering, control and data acquisition technologies for the competitive retail environment.

However, the overall maximum network system demand is the definitive driver in network capital investment. Maximum demand is influenced by both short term cyclic events, medium term regional growth factors and long term national influences. The lines companies can utilise resources like ripple control of hot water cylinders during peak demand. DG could provide an alternative way to reduce maximum demand.

However, to be effective these resources must be controlled by the network company, either directly or indirectly. There are many significant issues that need to be addressed before the widespread application of dispatch-type micro-generation can occur. Communication and control of hundreds of units will need to be established. Numerous internet based solution providers such as 6<sup>th</sup> Dimension and Silicon Energy (Esource, 2001<sub>a</sub>) have tools available for this. There are complications with DG units running in co-generation mode. For example, how is their rating or load reduction potential determined? The load reduction must take into account the thermal energy produced by the unit and how much of this is displacing thermal load that would otherwise have been met via the grid. For example, for a Stirling engine embedded on the customer side of the meter, the load profile of the house and its interaction with the DG units must be analysed. Moreover if they are operating anyway, there would be a background reduction in demand and therefore whether this would be attributed to dispatch of the DG units, needs to be determined. Also having a suitable place to dump excess heat (increasing capital cost) is essential since the dispatch would be electricity led. Finally, the effect of temporarily interrupting a DG technology providing space heating means it is more likely to be operating during the next control period, this flow-on effect would mean diminishing load reduction potential to the network operator.

As stated in the model's scope, analysing how this network impact would be controlled was not considered, but in the future would likely involve the development of a network analysis module utilising statistical analysis to estimate load profiles under the influence of load management.

Figure 9-10 shows the progression of analysis from an individual house level up to a regional level. It is envisaged that the model could in the future use an iterative process to estimate the network benefit of a number of DG units and then apply this benefit to the individual case which in turn may alter its value proposition, change the market penetration and hence network impact.

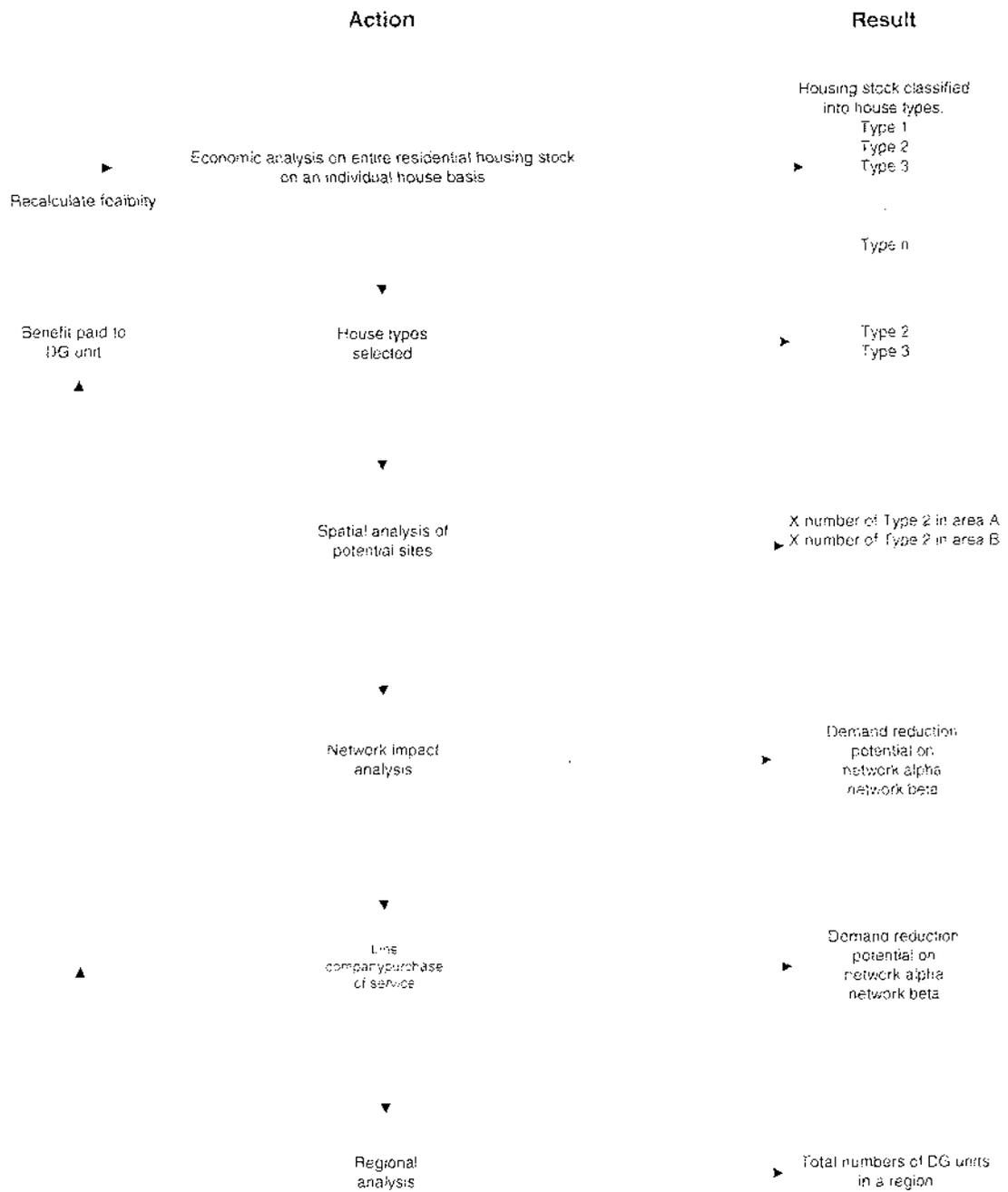


Figure 9-10: Regional Network Analysis Methodology

Table 9-6 gives more detail of the activities required at each step.



Level	1	2	3	4	5
	<b>Individual</b>	<b>Neighbourhood</b>	<b>Network (Individual)</b>	<b>Network (Collective)</b>	<b>Regional</b>
<b>Goal</b>	Which houses are suitable for a particular DG technology	DG unit serving more than one load	Determine the impact on a part of the network	Determining overall impact of an application on a GXP load profile	Regional assesment of DG
<b>Analysis</b>	First iterative run looking at basic value proposition	Looking at multiple loads aggregated together, sharing power and thermal output from DG unit(s)	Examine - DG penetration rate for area being served by network in question	Examine - DG penetration rate for area being served by equipment in question	Accumulation of network outcomes
<b>Informational requirements</b>	Details on existing expenditure on energy, house size, insulation level	As above but with additional data on communal heating schemes	Network asset management plan  Housing size distribution - number of sites in target area	Network asset management plan  Network design structure	Intra-regional network structure
<b>Outcome</b>	Type A house - suitable  Type B house - suitable  Type C house –unsuitable  (suitability depends on economic criteria)	Type A aggregation - suitable  Type B aggregation - suitable  Type C aggregation - unsuitable	Equipment A load profile, existing, future, with DG factored in.	GXP profile and price changes	Overall numbers of sites within a region

Table 9-6: Steps from an Individual to Regional Analysis

## 9.7 Other Considerations

### 9.7.1 Hybrid Systems

An interesting application when assessing different technologies is to consider hybrid systems or multiple technologies. This scenario is commonly found in rural settings where for example a photovoltaic - battery -diesel generator system may provide an alternative to grid connection. However in more urban settings where grid connection is predominately available multiple systems are unlikely to be economically viable as the large increase in capital cost is not readily recouped resulting in payback periods that are significantly longer than for single systems. This is due to the proportionately smaller increase in captured energy. The DG units effectively compete with each other to service the load. This competition is more pronounced due to the lack of electrical storage. The model though, could be expanded in anticipation of capital cost reduction and electrical storage advancements for DG technologies meaning a variety of hybrids would become economically feasible.

Currently the model can part-evaluate a photovoltaic, solar hot water and Stirling engine combination. A full analysis was not achieved due to time constraints and considers only an average house profile (i.e. without the effect of diversity). Essentially, the calculations involve a 3-step process where the resultant profile, after the first DG technology has been controlled against, becomes the “new” profile to which the secondary DG technology is controlled. This is repeated again for the third DG technology.

### 9.7.2 Economic Dispatch

DG could be dispatched based on certain economic criteria. For example, if used in conjunction with real time pricing, [RTP] the cheapest overall running cost could be achieved. This would provide a basis to analyse TOU rate structures and their impact on the profitability of DG. In addition, the economic criteria could be representative of other external factors such as distribution network peak loading, in which case the DG would run at set times of the day, coinciding with peak periods. It is proposed that this functionality be included into the model in future developments. However, this type of system peaking operation is unlikely to be economically feasible (from a retailers/generators perspective) due to the reduced operating hours and uncertain energy savings. Base-load operation though is not favoured by lines companies as it potentially reduces system throughput and hence revenue.

### 9.7.3 Load Following Calculations

The load-following control module could be further refined. The author suggests that a more direct relationship between  $O$  and  $N$  be established, potentially reducing the number of steps for the load-following algorithms (i.e. Tables 9-3 and 9-4).



# Chapter Ten

## Costing

*This Chapter provides the methodology used to estimate the operating cost of a DG unit as well as the traditional supply mechanisms and how they are compared to each other.*

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### 10.1 Introduction

In order to assess various solutions to a building's energy requirements, a common indicator is needed to allow comparison of alternative investment options. This indicator should reflect as much as possible the costing and operational performance on a micro-scale but should also reflect factors that are used to assess investment decisions in general. NPV based on a discounted cash flow<sup>32</sup> analysis was chosen to be the indicator. Its purpose was to quantify the many variables, as illustrated in Figure 10-1, that impact the cost of providing a household's energy requirements.

#### 10.1.1 Cash flow Analysis

An example cash flow is shown in Figure 10-2. The analysis is shown for a Stirling engine but is generically similar for all the technologies. It is split into two sections, the first showing the total annualised cost of the DG case and the second section showing the annualised cost for the BAY case. It is the difference between the two that generates the components (cash flow) for the NPV analysis.

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<sup>32</sup> A discount rate of 9% is used



## Cash Flow

	Year											
	0	1	2	3	4	5	6	7	8	9	10	11
<b>Stirling Engine</b>												
Capital cost	4,500											
Installation	500											
Maintenance	-	-	-	-	-	-	-	-	-	-	-	-
Fuel (fixed)	150	150	150	150	150	150	150	150	150	150	150	150
Fuel (variable)	434	434	434	434	434	434	434	434	434	434	434	434
Net metering	-	-	-	-	-	-	-	-	-	-	-	-
<b>Total</b>	<b>5,584</b>	<b>584</b>	<b>584</b>	<b>584</b>	<b>584</b>	<b>584</b>	<b>584</b>	<b>584</b>	<b>584</b>	<b>584</b>	<b>584</b>	<b>584</b>
<b>Make-up</b>												
Electricity (fixed)	200	200	200	200	200	200	200	200	200	200	200	200
Electricity (variable)	2	2	2	2	2	2	2	2	2	2	2	2
Gas (fixed)	-	-	-	-	-	-	-	-	-	-	-	-
Gas (variable)	-	-	-	-	-	-	-	-	-	-	-	-
LPG	-	-	-	-	-	-	-	-	-	-	-	-
Solid fuel	-	-	-	-	-	-	-	-	-	-	-	-
<b>Total</b>	<b>202</b>	<b>202</b>	<b>202</b>	<b>202</b>	<b>202</b>	<b>202</b>	<b>202</b>	<b>202</b>	<b>202</b>	<b>202</b>	<b>202</b>	<b>202</b>
<b>Total DG Operating Case</b>												
Electricity (fixed)	200	200	200	200	200	200	200	200	200	200	200	200
Electricity (variable)	2	2	2	2	2	2	2	2	2	2	2	2
Fuel (fixed)	150	150	150	150	150	150	150	150	150	150	150	150
Fuel (variable)	434	434	434	434	434	434	434	434	434	434	434	434
LPG	-	-	-	-	-	-	-	-	-	-	-	-
Solid fuel	-	-	-	-	-	-	-	-	-	-	-	-
Capital cost	4,500	-	-	-	-	-	-	-	-	-	-	-
Installation	500	-	-	-	-	-	-	-	-	-	-	-
Maintenance	-	-	-	-	-	-	-	-	-	-	-	-
Storage(capital)	-	-	-	-	-	-	-	-	-	-	-	-
Storage (O&M)	-	-	-	-	-	-	-	-	-	-	-	-
Net metering	-	-	-	-	-	-	-	-	-	-	-	-
Carbon tax	-	-	-	-	-	-	-	-	-	-	-	-
<b>Total</b>	<b>5,786</b>	<b>786</b>	<b>786</b>	<b>786</b>	<b>786</b>	<b>786</b>	<b>786</b>	<b>786</b>	<b>786</b>	<b>786</b>	<b>786</b>	<b>786</b>
<b>Traditional Supply Mechanism</b>												
Electricity fixed	200	200	200	200	200	200	200	200	200	200	200	200
Electricity variable	641	641	641	641	641	641	641	641	641	641	641	641
Gas fixed	150	150	150	150	150	150	150	150	150	150	150	150
Gas variable	54	54	54	54	54	54	54	54	54	54	54	54
Solid Fuel	-	-	-	-	-	-	-	-	-	-	-	-
LPG	-	-	-	-	-	-	-	-	-	-	-	-
<b>Total</b>	<b>1,045</b>	<b>1,045</b>	<b>1,045</b>	<b>1,045</b>	<b>1,045</b>	<b>1,045</b>	<b>1,045</b>	<b>1,045</b>	<b>1,045</b>	<b>1,045</b>	<b>1,045</b>	<b>1,045</b>
<b>Total</b>	<b>- 4,741</b>	<b>259</b>	<b>259</b>	<b>259</b>	<b>259</b>	<b>259</b>	<b>259</b>	<b>259</b>	<b>259</b>	<b>259</b>	<b>259</b>	<b>259</b>
<b>NPV</b>	<b>- 4,741</b>	<b>238</b>	<b>218</b>	<b>200</b>	<b>184</b>	<b>168</b>	<b>154</b>	<b>142</b>	<b>130</b>	<b>119</b>	<b>109</b>	<b>100</b>
<b>NPV</b>	<b>- 3,078</b>	(capital paid at beginning of period)										

Figure 10-2: Discounted Cash Flow Analysis for a Stirling Engine (Discount Rate = 9%)

### 10.1.2 Economic Comparison

The overall costing equation used is that in the form of a standard net present value [NPV] calculation:

$$NPV = -C_T + \frac{I_1}{1+r} + \frac{I_2}{(1+r)^2} + \dots + \frac{I_n}{(1+r)^n} \quad \text{Equation 10-1}$$

where

$C_T$  = Initial cost [\\$]

$I_k$  = Yearly cash flow [\\$]

$r$  = Discount rate [%]

$T$  = Technology type

$I_n$  = Cash flow in year 0 [\\$]

Other economic indicators considered:

Term	Definition	Relationship
Payback	Payback is defined as the number of years it takes for a proposition to break even.	$Payback = n \text{ when } NPV > \frac{I_1}{1+r} + \frac{I_2}{(1+r)^2} + \dots + \frac{I_n}{(1+r)^n}$
Return on investment	ROI expresses the ratio of the initial investment with the annualised cash flow. It assumes a constant cash flow over the analysis period.	$ROI = \frac{I_n}{I_1}$
Internal rate of return	The IRR expresses the discount rate when the net present value would be equal to zero.	$IRR = r \text{ when } NPV = \frac{I_1}{1+r} + \frac{I_2}{(1+r)^2} + \dots + \frac{I_n}{(1+r)^n}$

### 10.1.3 BAU Case versus DG Case

Not all of a home's energy needs will be provided for by the newly installed DG unit. The remaining component is supplied by the existing set-up, which invariably means electricity from the grid and other energy sources from solid fuels, liquid fuels or reticulated gas.

Table 10-1 shows the key considerations when costing the TSM under the DG case.

Assumptions & Key considerations		Background	Impact on project
Current status	All scenarios assume that the load (house) remains grid connected	Costs of storage and nature of demand profile dictate this	Large
	When assessing unmet load, the residual component is supplied by the grid	The grid is the only source of residual power	Large
	The thermal component of the unmet load is proportioned to each individual energy source or fuel type. In the same ratio as without DG	For ease of cost calculation this is done, however, practically only one energy source would probably be used.	Large
	The DG unit will always take priority in meeting the load.	Feasibility of DG is determined by the proportion of demand that it can capture. Unmet demand is supplied by the TSM	Large
	SH and DHW are treated as equals in terms of their ability to be supplied by the thermal output from a DG unit	For ease of cost calculation this is done, however, practically only one end use would be provided for.	Large
Future provision	Unmet load can be met by a <i>specified</i> energy source	This would allow for a more realistic view of what actually happens in a house	Large

Table 10-1: Overriding Concepts in Costing the TSM with a DG Unit

The following sections outline how the terms in Equation 10-1 were calculated using generalised equations that include a combination of TSM and DG factors.

## 10.2 Initial Cost

Initial costs are the marginal costs associated with installing a DG unit and any avoided TSM investment for the BAU case. They both typically occur once in the lifetime of the DG unit.

$$C_T = Cc_T + Ic_T - Ca \quad \text{Equation 10-2}$$

$Cc$  = Capital cost [\$]

$Ca$  = Avoided TSM costs [\$]

$Ic$  = Installation cost [\$]

$Cc$ ,  $Ca$  and  $Ic$  are evaluated in the first year only.

The significant assumptions made about the initial cost component are given in Table 10-2.

	Assumptions & Key considerations	Background	Impact on project
Current status	There is an envisaged capital cost decrease of many of the emerging DG technologies	To determine the capital cost entry point is an important application of the model	Large
	The exchange rate will have a large influence on the capital cost	The vast majority of emerging technology DG units will be manufactured overseas.	Large
	The installation cost will have components that reflect grid connection fees like installation and inspection of safety control equipment.	Interconnection standards may prove to be inhibitory to the introduction of DG if they significantly increase initial costs	Large

Table 10-2: Initial Costs for a DG Unit

### 10.3 Yearly Cash Flow

The yearly cash flow represents the difference between the operating or annualised costs of the BAU case and the DG case.

$$I_n = C_E + C_{NG} + C_{SF} + C_{LPG} + Mc - C_{CO_2} \quad \text{Equation 10-3}$$

where:

- $C_E$  = Cost of electricity [\$/yr]
- $C_{NG}$  = Cost of Natural Gas [\$/yr]
- $C_{SF}$  = Cost of solid fuel [\$/yr]
- $C_{LPG}$  = Cost of liquified natural gas [\$/yr]
- $C_{CO_2}$  = Cost of CO<sub>2</sub> emissions [\$/yr]
- $Mc$  = Maintenance cost [\$/yr]

These fuel types were chosen as they provide the dominant sources of energy used in NZ homes (Figure 4-5).

### 10.3.1 Maintenance Costs

Maintenance costs [ $Mc$ ] are a collection of:

- Regular maintenance
- Service / overhaul
- Permitting

Certain operating costs are obviously linked to the DG units output which in turn determined by its operation control and the load its serving.

$$Mc = H_{op} \cdot MI \cdot CM \quad \text{Equation 10-4}$$

where

$MI$  = Maintenance frequency [service/hours of operation]

$CM$  = Cost of maintenance unit [\$/service]

$H_{op}$  = Annual hours of operation [hours of operation /yr]

and

$$H_{op} = \sum_d^8 h_{op} \cdot m_d \quad \text{Equation 10-5}$$

$h_{op}$  = The number of 1/2 hour periods per day that the DG unit operates.

Table 2-1 shows the assumptions and key considerations when examining the maintenance costs.

Assumptions & Key considerations		Background	Impact on project
Current status	The operating costs are independent of the age of the unit and independent of its operating regime.	For simplicity sake the costs have a linear relationship with operating hours only.	Minimal
	Maintenance costs are calculated on hours of operation	Alternatively they could be based on kWh (power and/or thermal) produced and less dependent of the number of hours of operation	Minimal
	Servicing, permitting and depreciation are not considered separately	For simplicity they are assumed to be included in the maintenance costs	Minimal

	Assumptions & Key considerations	Background	Impact on project
Future provision	The cycling of a DG unit incurs increased costs that need to be realised	Increase numbers of start up and shut downs introduces increased wear and hence increased maintenance costs	Medium
	The inclusion of service costs.	For example if major engine over-haul is required	Medium
	Inclusion of auxiliaries such as permitting and depreciation	These could be prove significant, if not accounted for	Medium
	Maintenance costs	Geographic regions may have different wear on equipment (climatic) and differing labour rates for maintenance procedures.	Minimal

Table 10-3: DG Maintenance Cost Analysis

### 10.3.2 Energy Costs

Fuel costs are a significant factor in determining the profitability of DG. Therefore fuel costing was done on an end-use basis, energy-type and seasonal basis to provide detailed information as to where and what increased DG profitability. Table 10-4 shows the components for each of the energy-types used. These equations were used to cost out the DG and BAU case.

Fuel Type	Costing Equation
Electricity	$C_{E} = C_{E,DHW} + C_{E,SH} + C_{E,SC} + C_{E,F}$
Natural Gas	$C_{NG} = C_{NG,DHW} + C_{NG,SH}$
Solid Fuel	$C_{W} = C_{W,DHW} + C_{W,SH}$
LPG	$C_{LPG} = C_{LPG,SH}$

Table 10-4: Fuel Costs and their Individual Components

To calculate cost, the end-use energy demand must be converted to a "fuel" use by applying conversion efficiency data appropriate for the chosen technology. For example, the common efficiency for an electrical DHW cylinder might be 100% (treating standing losses as true end-use demand) where as it might only be 80% for a gas cylinder. Hence, if DHW demand is 10 kWh/day than this translated to 10 kWh of electricity or,  $10/0.8 = 12.5$  kWh of gas.

Table 10-5 gives the typical efficiencies used in the model for appliances using different fuel sources.

End-use appliance		Efficiency %, <i>H</i>
DHW	Gas	80
	Electricity	100
SH	Electricity	90
	LPG	70
	Reticulated gas	70
	Solid fuel	20

Table 10-5: End-Use Appliance Efficiency

### 10.3.3 Electricity

The costing of electricity is an important component to the model, as it is the dominant source of energy in the market (Figure 4-5). There are a number of ways to approach the value of electricity. What the consumer pays is defined here as the price of electricity, yet what an integrated generator-retailer like Meridian is concerned with is the cost to supply that particular consumer. If the customer is to be profitable, the cost of supply must be less than the price the customer is paying. The generic costs components are:

- 1) Wholesale price
- 2) Lines company charges (including transmission)
- 3) Retail margin

As Meridian is a vertically integrated generator/retailer and the market is a 'blind-market' the cost of providing electricity is determined by Retail<sup>33</sup> hedge price<sup>34</sup> (i.e. the electricity price that Retail pays Meridian Generation is set by the hedge). Figure 10-3 shows an example of the differences in hedge and spot price. As described in Section 4.8 retailers buy a proportion of their electricity from the GXP, via the market on a normalised basis. Therefore the product of the hedge price, normalised demand profile and the absolute metered amount determines the energy supply cost of electricity to the retailer. To this is added line charges from the distribution company that are passed onto the consumer as fixed and variables charges. The way in which a retailer can pass on the costs of electricity provision vary a great deal, often due to line company charge structure and have led to some retailers having as many as 6,000 different tariffs.

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<sup>33</sup> The retail unit of Meridian

<sup>34</sup> A hedge is a form of financial insurance that protects the purchaser and supplier from spot market instability

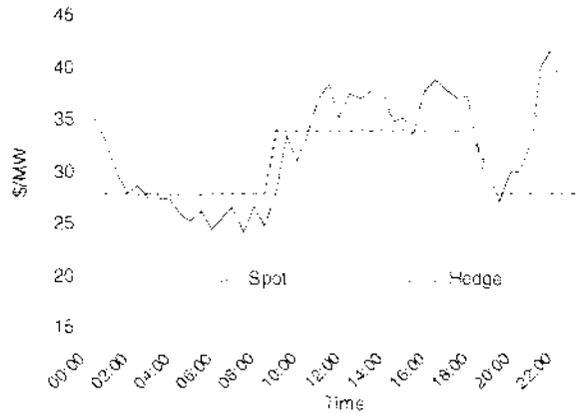


Figure 10-3: Typical Hedge vs Spot Price During a Day

Table 10-6 gives the assumptions and key considerations made in order to model electricity prices/costing.

	Assumptions & Key considerations	Background	Impact on project
Current status	Electricity has the capability to energise all end uses	In many homes electricity is the only source of energy	Minimal
	2 tariffs were modelled: <ul style="list-style-type: none"> <li>• Anytime</li> <li>• Day/night</li> <li>• TOU</li> </ul>	Since there are over 6,000 different tariffs, only the most common 'types' were modelled. Given the general nature of TOU costing most pricing mechanisms could be represented by changing the TOU data.	Medium
	Tariff price is used to cost DG, from a customers point of view	Residential DG units in the future must have the ability to operate with dynamic 48 1/2 hourly pricing	Medium

Table 10-6: Cost Analysis: Electricity

### 10.3.4 Natural Gas

Reticulated gas, although only currently providing 9% of domestic energy, it is expected to increase its share and importantly it represents the fuel of choice for fossil fuelled DG units such as Stirling engine, micro-turbine, new reciprocating engines and some fuel cells. This is especially so in areas where reticulated gas is already present.

The price of reticulated gas is simpler than that of electricity as there does not exist a spot market through which gas has to be traded. However as Table 10-7 shows the costing of gas

used has the capability to utilise ½ hour variation in anticipation of changes to the gas supply market.

Table 10-7 gives the assumptions and key considerations made in order to model natural gas prices/costing.

	Assumptions & Key considerations	Background	Impact on project
Current status	All regions in NZ have the potential to be supplied with any fossil fuel.	If this requires the introduction of new delivery systems than the price will reflect this.	Large
	Fuel is the major running cost component of a fossil fuel DG unit.	Variability in price is essential in predicting the value of DG in the future. This is particularly important for NG (See Section 8.3.1).	Large
	The possible increase in demand for fossil fuel could drive network constraints.	Gaining an understanding of the magnitude of the change and response by the network as price affecting drivers is considered an important objective.	Large
	Natural gas is the only fossil fuel option for DG	Current technologies and environmental considerations make diesel fuel reciprocating engines unlikely in residential markets	Minimal
	All gas supplied will have the same energy content	All source gas data is expressed in kWh.	Minimal
	Gas price is broken down into fixed and variable charges	Gas pricing is done from the perspective of a consumer only. Access to wholesale gas is not considered.	Large
	Costing is based on fuel use for the total output of the DG unit.	Total output (electrical + thermal) is determined by an efficiency of the fossil fuel engines that is independent of loading.	Large
Future provision	Dual fuel of operation is allowed.	Some units, especially reciprocating engines will have the ability to run on both NG and diesel (see Section 4.6.1 for more detail on dual fuel operation)	Minimal
	Gas is currently not traded, but could be in the future so a provision in the model allows for this i.e. regional and seasonal gas price variation.	The price of gas is constant, however the increase in gas use may lead to points of constraint giving rise to price variation.	Large
	Operating efficiency used in the costing to become dependant on loading	The efficiency at part-loading is already known and will be used in future developments.	Large

Table 10-7: DG Costing: Fossil Fuel



Assumptions & Key considerations		Background	Impact on project
Current status	All LPG use will be assumed to be for space heating only.	Gas cooking e.g. BBQ's will be ignored as it does not represent any significant replacement value for DG.	Minimal
	LPG costs are assumed to be static.	There is some dynamic nature to the pricing of LPG, from broad seasonal and geographic factors.	Minimal
	LPG use is only a small component of energy use and is difficult to measure accurately.	Gas flow meters are cumbersome and are not readily able to measure gas consumption, hence data is not plentiful	Minimal
	Fixed costs of LPG are not considered.	The costs of most LPG cylinder are small (~ \$50, although dependent on cylinder size	Minimal
Future provision	Location	Location factor affecting the cost of LPG is a possibility, especially places where gas has to be shipped in, eg. The South Island	Minimal
	Seasonal	Increased demand for LPG, particularly for space heating might drive higher prices during the heating season.	Minimal

Table 10-9: Cost Analysis: LPG

### 10.3.7 Renewable Energy

The costing of renewable resources relates to the following technologies:

- Photovoltaics
- Solar hot water
- Wind turbines

The resource is essentially free, in the form of solar energy either directly or indirectly in the form of wind. Therefore the running costs are only those associated with the maintenance of the system itself and any ancillary equipment such as storage units.

Table 10-10 highlights the issues encountered when examining renewable energy based DG units.

	Assumptions & Key considerations	Background	Impact on project
Current status	PV produced electricity is converted from DC to AC for use in the house or exported	There is no storage costs for renewable electricity, i.e. it is either consumed immediately on site or exported	Large
Future provision	Electricity storage to be included	Advances in technology make this option both technically and economically viable e.g. flywheels and super-conducting magnetic storage	Large

Table 10-10: DG Costing Renewable Energy

## 10.4 Costing Equations

The costing equations below account for both the DG and BAU cases:

### 10.4.1 Thermal End-uses

The cost of meeting a particular end-use with a particular energy type is given by:

$$C_{end-use, fuel} = Z_{end-use, fuel} \cdot y_{end-use, fuel} \cdot \max \left( X_{end-use, fuel} - F_{end-use, fuel}, 0 \right) + C_{fuel}$$

Equation 10-6

The value of any thermal export (i.e.  $Y > X$ ) is 0.

$y$  = Fraction of an end-use provided for by an energy type.

The  $y$  matrix is chosen to simulate the fuel composition for various houses. Table 10-11 gives an example of the energy-use matrix chosen for a house with reticulated gas. This is used for both the BAU case and the DG case. For example here, setting all  $y_w$  to 0 means wood is not a supply option available.

End-use	Fuel Type			
	Electricity	Reticulated gas	LPG	Wood
$y_{ec}$	1	0	0	0
$y_{sc}$	0	0	0	0
$y_{sm}$	0.25	0.5	0.25	0
$y_{mw}$	0	1	0	0

Table 10-11:  $y$  Matrix for a House on Reticulated Gas with Additional LPG and Resistance Space Heaters

$Y_n$  is given in Sections 9.2 to 9.4.

$C_{n \text{ fuel},T}$  is the cost of the fuel supply to the DG unit. The cost of this supply profile is given by

Equations 10-7 and to 10-10:

a) fossil fuels (Stirling engine micro-turbine, fuel cell and reciprocating engine):

$$C_{n \text{ fuel},T} = Z_{n \text{ fuel}} \cdot \frac{Y_{n t}}{H \cdot (1 - O_f)} \quad \text{Equation 10-7}$$

$H$  is efficiency of the heat transfer system

Note: for renewable energy technology  $Z_{n \text{ fuel}} = 0$

$Z$  = Unit cost of energy source[\$/kWh]

$Z_{n E} = f(\text{location, time of year, time of day})$

$Z_{n NG} = f(\text{time of day})$

b) heat pump:

$$C_{n \text{ fuel},T} = \frac{Y_{n t}}{COP_{actual} \cdot H} \cdot Z_{n E} \quad \text{Equation 10-8}$$

$COP_{actual}$  = Coefficiency of performance, either in heating or cooling mode (See 8.2.2).

#### 10.4.2 Residual Electrical Demand

For residual demand there are two scenarios:

a)  $X > Y$  then,

$$C_{n \text{ fuel},r} = Z_{n E} \cdot \left( \frac{X_{n r} - Y_{n p}}{H} \right) + C_{n \text{ fuel},T} \quad \text{Equation 10-9}$$

$$C_{n,net,T} = Z_{n,net,T} \cdot \frac{Y_{n,p}}{O_n} \quad \text{Equation 10-10}$$

b)  $X < Y$  then,

$$C_{n,net,T} = C_{n,net,T} - \left( \frac{Y_{n,p}}{O_n} - \frac{X_{n,p}}{O_n} \right) \cdot Z_{export} \quad \text{Equation 10-11}$$

where

$Z_{export}$  = Price of export into the distribution network [\$/kWh]

## 10.5 Carbon Tax

### 10.5.1 Introduction

A carbon tax is one of the mechanisms that will be introduced in 2007 in response to the government's commitment to ratify the Kyoto Protocol. As discussed in Section 2.8.5 this ratification would form part of government's energy policy objective.

*"to ensure the delivery of energy services to all classes of consumer in an efficient, fair reliable and sustainable manner".*

Renewable energy and energy efficiency matters are opportunities for DG to gain additional value and the regulatory framework may provide a mechanism for this as discussed earlier. How this value can be quantified is the subject of this particular discussion. One mechanism is carbon tax. Future carbon taxes could have significant impact on the feasibility of a DG application.

### 10.5.2 Methodology

The basic premise used to assess carbon tax is the same value proposition used to assess the overall value of DG. That is, the revenue generated from a carbon tax is:

$$C_{CO_2} = K_{CO_2} \times Z_{CO_2} \quad \text{Equation 10-12}$$

where

$Z$  = carbon tax value [\$/tCO<sub>2</sub>]

$K$  = Amount of CO<sub>2</sub> produced [tCO<sub>2</sub>/year]

The value of Z is not known. At the Sustainable Energy Forum (SEF) in 1999 a figure of NZ\$30 /tonne CO<sub>2</sub> was raised while the Ministry of Economic Development quoted a figure of NZ\$13 to NZ\$26 /tonne CO<sub>2</sub>. Recently the government has put a cap on a possible CO<sub>2</sub> tax of NZ\$25 /tonne CO<sub>2</sub>.

The relative carbon emissions from the various energy sources are shown in Figure 10-4. Wood has the highest value but this could be negated in the future if one assumes that the CO<sub>2</sub> emitted during the burning of wood is part of a closed-loop carbon cycle.

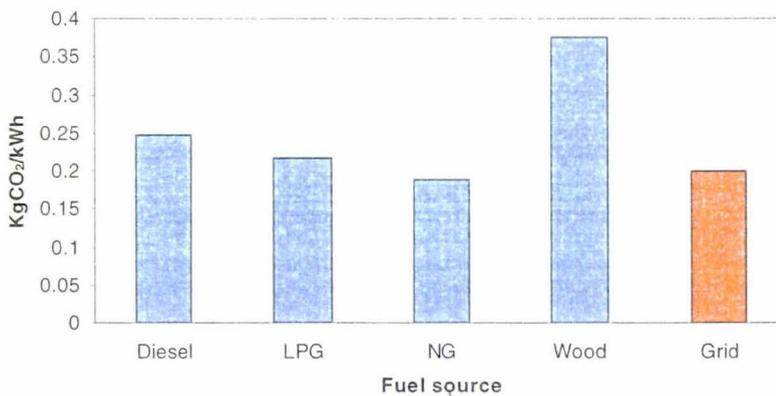


Figure 10-4: CO<sub>2</sub> Emissions for Various Fuel Energy Sources [CPK]

CPK = Amount of carbon emitted when a particular fuel/energy is used [kgCO<sub>2</sub>/kWh]

Grid electricity currently has a value of 0.2 kgCO<sub>2</sub>/kWh or 56 tCO<sub>2</sub>/TJ which is slightly higher than that for natural gas. This value was chosen to reflect the marginal plant that is being called to generate. The marginal plant is the most expensive in terms of the price it bid its supply into the market and is often a thermal power station, running on natural gas.

The additional electricity that needs to be supplied by the grid to account for losses in the transportation of electricity to the end user was not considered. This would have the effect of underestimating the CO<sub>2</sub> emissions by around 8%. The carbon emitted to supply a particular load is thus calculated based on its proportional fuel supply. For example a household that exclusively used electricity would use the grid emission figure times the total kWh consumed.

Overall the net CO<sub>2</sub> produced is given by:

$$K_{CO_2} = K_{BAU} - K_{DG} \quad \text{Equation 10-13}$$

where

$$K_{BAU} = K_{import} \quad \text{Equation 10-14}$$

and

$$K_{DG} = K_{fuel\ use} + K_{import} \quad \text{Equation 10-15}$$

The amount of CO<sub>2</sub> produced using the TSM is given by:

$$K_{import} = K_E + K_{NG} + K_W + K_{LPG} \quad \text{Equation 10-16}$$

The amount of CO<sub>2</sub> can be determined for each fuel/energy type:

a) *thermal end-use*

$$K_{thermal\ use} = \left( \frac{Y_{fuel}}{1 - O_f} \right) CPK \quad \text{Equation 10-17}$$

*CPK* = Amount of carbon emitted when a particular fuel/energy is used [kgCO<sub>2</sub>/kWh]

b) *residual electricity use*

$$K_E = Y_{net} \cdot CPK \quad \text{Equation 10-18}$$

For the DG case, *K<sub>fuel use</sub>* is given by:

$$K_{fuel\ use} = \left( \frac{Y_f}{O_f} \right) CPK \quad \text{Equation 10-19}$$

Some key assumptions made were:

- The CO<sub>2</sub> output of the DG unit is based on the fuel it used.
- Losses associated with the gas supply network and the other delivery systems for LPG and wood are not considered.
- For DG units based on renewable energy resources there are assumed to be no emissions.
- A heat pump's emissions are based on grid supply electricity figures.
- 100% of the carbon content of the fuel used is converted to CO<sub>2</sub>
- Results are worked out on an annual basis.

In the future, an addition factor to Equation 10-15 may be added,  $-K_{export}$ . Essentially this will quantify the gross (system) reduction in electricity usage if there is any export during the DG case.

## 10.6 Discussion

### 10.6.1 Net Metering and Price of Export

To determine the value of energy exported back into the grid is a complex task. Net metering is a term often used. Net metering effectively allows the price of export as the same price the customer would pay the retailer i.e. only the net import is paid for. This allows the DG owner to fully utilise the distribution network for free and to get paid for the losses from the transmission system as well, since these costs are built into retailer's charge. If net metering is not used and another rate is charged, a separate meter or channel would be needed to measure export. In addition net metering disguises the value of energy at peak times, since the tariff rate will not reflect the variability of the spot price. This may be off-set though by the high cost to use the distribution network at peak periods. The model allows the export price to be set independently of the import so both net metering and dual metering options can be examined.

### 10.6.2 Free-ridership

The obvious benefit of distributed generation is that it can reduce the energy cost for the person whose load its serving. In the particular case of a residential customer they would save through the reduction in energy used from the grid. However the reduction of load on the network, albeit small, would have the effect of reducing the nodal price factor. This 'value' cannot be exclusively captured and will be shared by all the retailers who purchase electricity from the price affected GXP so other non-DG customers may benefit by becoming free-riders. Figure 12-8 graphically shows this free-rider phenomenon.

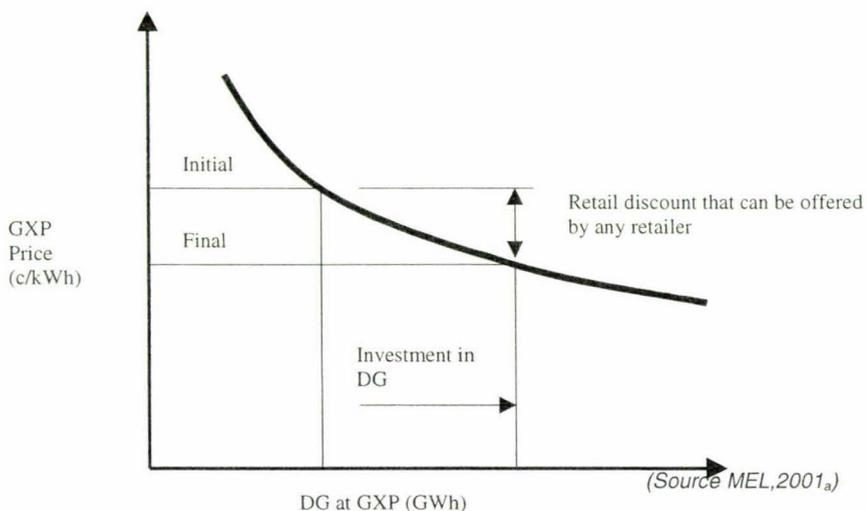


Figure 10-5: The Concept of Free-ridership

In addition there is the impact on the distribution network. The reduced loading, particularly at peak times, may alter line company's tariff structure, again something which all retailers and ultimately consumers will benefit or lose from. Also the change in energy and line charges may alter the value proposition of a DG installation, making further installation uneconomic.

Another important issue is whether the price-time differential can be captured. In order for a retailer to (exclusively) realise the benefit of reduced demand at periods of high price it must have either a registered profile or a TOU meter. If not, this reduced demand would be proportioned, to all retailers.

To be ultimately competitive DG needs to capture all the benefits it provides. However many of these mechanisms to achieve this don't yet exist, as there has been no need for them in the past.

# Chapter Eleven

## Model Implementation

*This Chapter shows how the mathematical expressions developed in the proceeding four Chapters were combined and outlines the computational environment through which this occurred.*

---

### **11.1 Introduction**

The implementation phase was the last step in producing a working model. It involved not only the quantitative process of programming the expressions into a computer program but also consideration of the qualitative issues of ease of use of the model (user interface) and areas for future development.

### **11.2 Calculation Sequence**

Figure 11-1 shows the calculation sequence that was used. The dashed line represents the iterative method of determining the market penetration of a particular DG type, based on its economic performance and then using this information to ‘construct’ the hypothetical network for a network analysis.

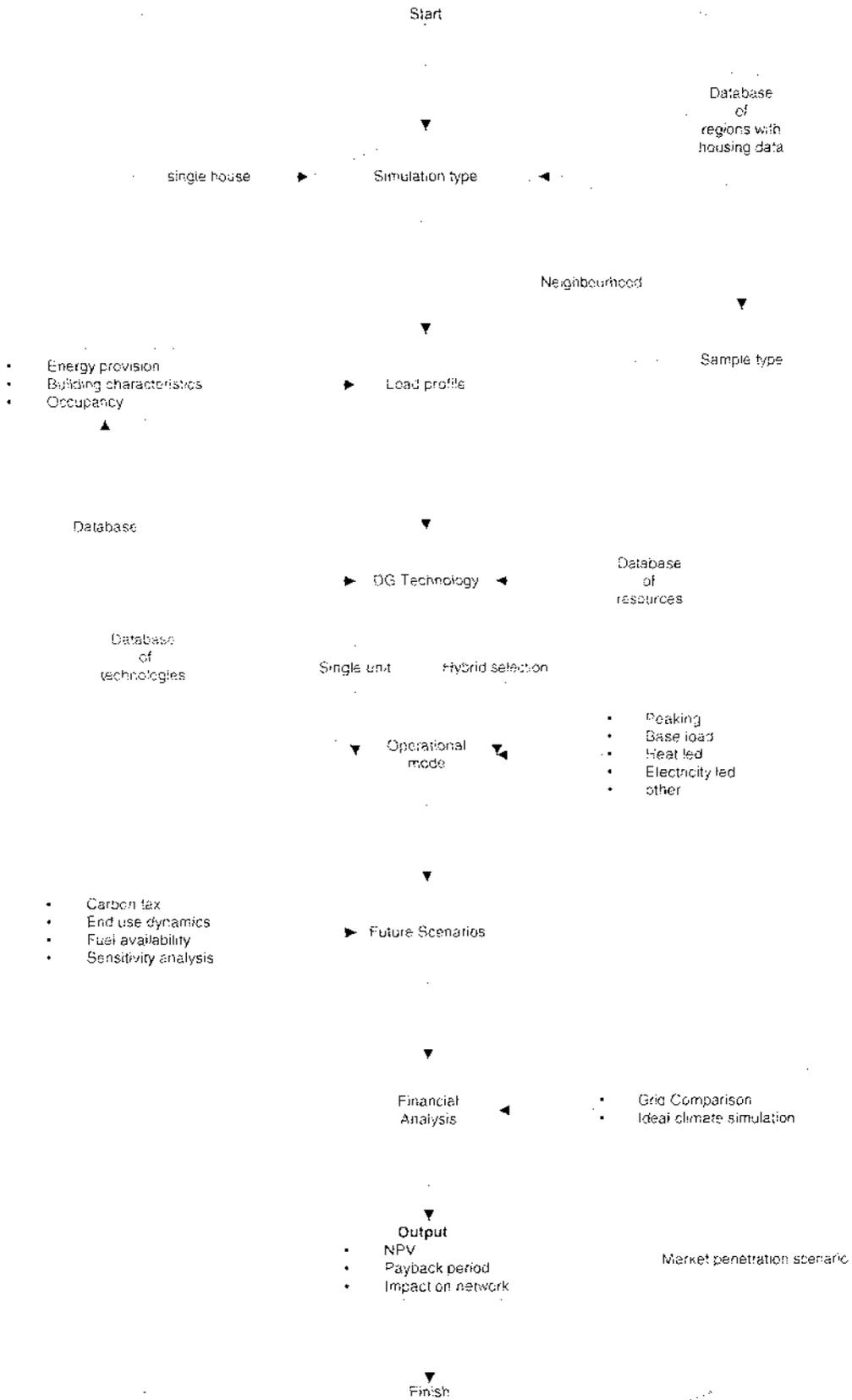


Figure 11-1: Generalised Calculation Sequence of the Model

## 11.3 System architecture

### 11.3.1 Application

System architecture is a description of how the calculations are controlled with respect to the applications that they occur in. The model was implemented in Microsoft Excel. The reasons for this were familiarity of the software which aided in the speed of implementation and the product itself. Excel provides a ready platform to conduct the analysis which involved a relatively small amount of data but a large number of calculations, many of which utilised Excel's built in mathematical functions. If far larger data sets were involved a database application would have been considered. Moreover Excel's built in analytical, statistical and graphical functions allowed for the analysis to be contained within one application. Perhaps though the most significant factor in choosing Excel was the Visual Basic for Applications [VBA] programming environment. It can readily be accessed and used to create customised applications.

Figure 11-2 shows the relationship between VBA and Excel. The VBA interface is set over the central Excel file, *Engine* and contains the code that controls the periphery files and databases. These relationships are either hard (direct link) or soft (controlled by VBA code). The *Engine* contains the majority of the soft relationships but also a substantial amount of direct links from the peripheral files and databases. See Appendix F to find the VBA code.

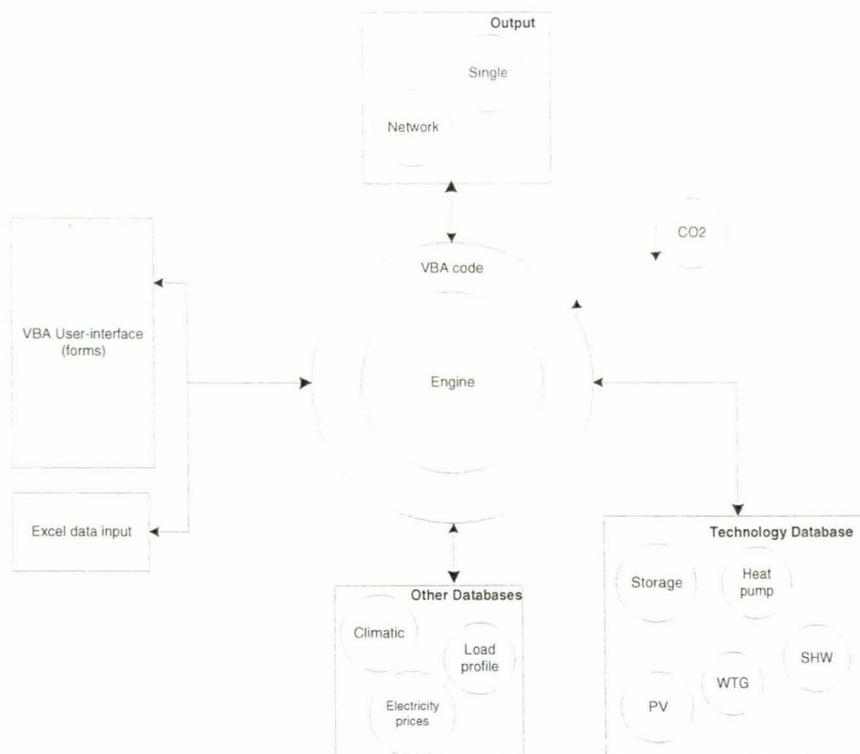


Figure 11-2: System Architecture

### 11.3.2 User Interface

Figure 11-3 shows an example data input screen. These user-forms serve a number of purposes, one of which is operability. The controls which are located in the user-forms needed to be constructed 'tightly' enough to ensure that proper data input sequence is followed, but also at the same time 'loosely' enough for changes to be made to a particular variable without having to go through redundant steps. Another purpose is preliminary checks of the inputted data or selection choices. That is, the form provides a check that the model is using the values specified by the operator. In addition, the user-forms are used to provide feedback during a calculation sequence, particularly during a network analysis. Appendix B gives the complete set of user-forms.



Figure 11-3: User Interface Showing Selection Options for a Single DG Unit

### 11.3.3 Coding

The computer code that was written to instruct the computer how, what and when to action the formulation described in Chapters 7 to 10. How these instructions are written (syntax) and how they are organised (code structure) must satisfy two important objectives of the model. (1) to provide a flexible structure to enable different scenarios to be examined and (2) to incorporate an open methodology to enable future development to take place (this would specifically mean the expansion or addition of modules).

The model uses event-driven-form-centric programming. This can be compared to procedural programming where applications execute logically through the program code one line at a time. In contrast event-driven applications execute only when a specific event calls a section of code. This event could be triggered by an user input such as a mouse click for example.

## 11.4 Model Performance

### 11.4.1 Flexibility

Development of the programme involved a careful compromise between how much time was put into designing routines to allow greater functionality and flexibility and what allowance was made to accommodate future capability. The greater the functionality of the model the more complex the code and thus the more difficult it is to manipulate the code in the future. Given the obvious time constraints it was decided to concentrate the development of functionality in certain areas and limit it in others. For example introducing diversity (between houses) into the calculation sequence was seen as a critical function, however by doing this other areas of profile analysis such as load management were not developed. In addition, automated functions such as capital cost change over a period of years (to simulate market trends) were dismissed in favour of simplifying calculation routines.

### 11.4.2 Calculation time

When writing the procedures, performance feedback was considered in order to minimise calculation time. This was important because the model could perform a 'run' consisting of 100 repetitions for each house, and up to 500 houses. With the current model a 100 run simulation for a single house can take up to 3.5 minutes<sup>36</sup> on a Compaq DeskPro Pentium II, not including the time taken to set up the correct parameters and variables. The entire process can be up to 6 minutes, so 10 scenarios would equal 1 hour of computation time. More complex analysis e.g. one requiring thermal storage could double the calculation time. This issue was addressed by storing only values of calculations and not the data links themselves, if the calculations were carried out in files external to the *Calculation Engine*. In addition minimising code length (by using looping functions to remove redundant coding) and incorporating VBA techniques such as minimising 'screen updating' significantly reduced calculation time.

### 11.4.3 Stability

With over 13 Excel files<sup>37</sup> and around 50 worksheets with a cumulative total of up to 35 MB, issues about stability were a design issue. The aim was that the model would run easily on a standard desktop. Stability issues were exacerbated as generally around 7 files need to be

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<sup>36</sup> Calculation time is strongly dependent on the speed of the machine that the model is running on.

<sup>37</sup> These files consisted of databases, technology modules and intermediate data storage.

open during any calculation run and there is a large amount of data transferred between files. Stability was improved by using the same techniques that reduced calculation time such limiting data transfer and storing raw values only. In addition, any redundant files (e.g. those that were no longer in use after a certain point in the calculation sequence) were closed in order to further free up operating memory.

## **11.5 Verification**

The computer code was verified in two parts:

- 1) Periphery files and databases
- 2) Central calculation engine

### **11.5.1 Periphery Files and Databases**

Manual checks were made on all the natural resource technology modules (e.g. PV and SHW) to ensure they produced similar results to the models they were based on. Appendix A gives some of these comparisons. Other modules (e.g. HP), were not based on external models so values of critical indicators were informally observed to ensure that reasonable results were obtained (e.g. COP was the indicator used for HPs). The load profile database and the associated code was validated by ensuring the end use components of the *AEC* [kW/yr] such as hot water and space heating were comparable to national average figures (ECCA, 2000).

### **11.5.2 Calculation Engine**

Results from the periphery files and databases were transferred to the calculation engine. This transfer of data was readily checked, ensuring what was outputted from one module became the input into the calculation engine. The vast majority of calculations and data manipulation occurred in the calculation engine so a more rigorous approach to model validity was required here. In addition, most of the calculations employed were developed specifically for this model and had no existing basis for comparison, highlighting the need to be carefully checked.

As shown in Figure 11-4 the engine uses two separate pathways to calculate the cost to supply the load profile. Comparison between the pathways were used to validate the code.

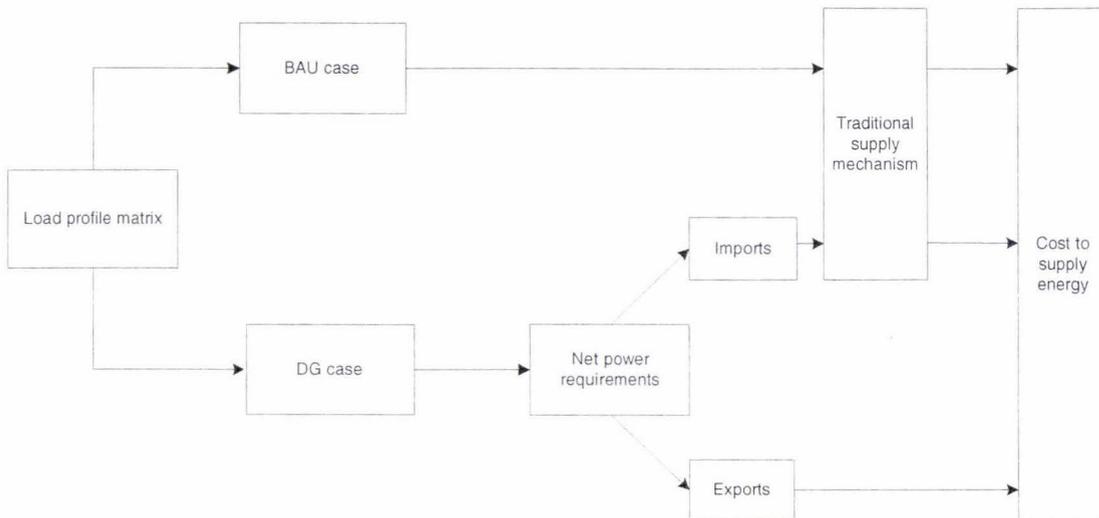


Figure 11-4: Simultaneous Calculation Pathway

For example if the DG unit was controlled in a way as not to run, then the import amount in kilowatt-hours and dollars should equal that as calculated via the traditional supply mechanism. The comparison was made at each of the daily, monthly and yearly levels for end-uses, as well as different fuel/energy types.

An alternative verification methodology was a comparison with hand calculations. This option though was not chosen due to the extensive number of calculations involved particularly considering the large number of combinations of possible (technology type and operating regime) variables. In addition it would be difficult to assess where an error had actually occurred, whether in the hand calculations, which is a real possibility, or in the coding, therefore bringing the author no closer in validating the model.

Extensive checks were conducted using extreme values (this is a different concept from the separate calculation pathways noted above) on a wide range of variables. For example, if the variable  $Z_{NG}$  [\$/kWh] tripled there was an associated tripling of DG fuel costs. With research showing that over ninety percent of all spreadsheets with more than 150 rows contained at least one significant formula mistake (Talbot, 2002), additional checks were made on all calculation tables to ensure correct computation.

User input data was controlled through the user-forms by allowing only pre-defined options to be chosen.

## 11.6 Discussion

### 11.6.1 Coding

A methodology that would have been beneficial to include was a more systematic treatment of variables. The consistent use of variables can have a dramatic effect on the use of the code, its structure, ability to further changes and the overall performance of the model. Given the instructions for the model are written in VBA inside an Excel workbook, it lends itself to using a centralised sheet that contains all the variables used throughout the model. This would allow for easier variable control, which becomes an issue when there is over 4,500 lines of code. Having a foundation for good variable management has an important and cascading effect on the syntax and then structure of code and ultimately its functionality. Writing an instruction as generically as possible requires the substantial use of variables, hence the syntax is affected. If a sequence is generic it can be used numerous times, thus saving time writing redundant code. In addition less code generally means quicker and easier debugging and faster computation time.

In future developments it is recommended to replace the large tracks of code with a sequence of code modules. These modules would be generic and able to be executed through a call statement. The desired code structure would therefore be a map of which instructions to run, rather than all the instructions put together.

# Chapter Twelve

## Case Studies

*This Chapter provides examples of the functionality of the model and its applicability to real life market scenarios.*

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Four case studies were chosen to show a different aspect of functionality and/or to produce results that are meaningful in a commercial setting. It is pertinent to note that although it was desirable to fully utilise the model in a case study, the availability of data made a complete analysis beyond the scope of this thesis.

### **12.1 Case Study 1 - Broad overview**

#### **12.1.1 Introduction**

The purpose of this case study was to demonstrate the model's ability to examine the use of various DG technologies. Five technology types and three operating regime were considered for three house types. For all technologies, data was chosen to reflect current prices and performance.

#### **12.1.2 House Type**

A summary of the characteristics of the three house types used is given below. Appendix C.1 gives more detail on each house's end use energy requirements and fuel mix.

Type	Description			
	Size	Location	Insulation	Main heating fuel
House 1	Small	Dunedin	Full insulation	Wood
House 2	Medium	Auckland	No insulation	Electric
House 3	Large	Wellington	Retrofit	Gas

### 12.1.3 Operating Regime

A wide range of regimes were chosen throughout the case studies to demonstrate the model's functionality. Three operating regimes (base load, load following: electricity led and peaking: electricity led) were used for the fossil fuel technologies. Renewable DG technologies ran as their resources dictated and hence were independent of the demand profile. SHW operates as a renewable but with the addition of having a thermal storage component.

### 12.1.4 Input Data

The complete set of input data are given in Appendix C.1. Crucial data is given in the Tables 12-1 to 12-3.

Parameter			Stirling Engine	Fuel Cell	PV	SHW	Heat pump
Power output	$R_{p,i}$	[kW]	0.75	4	0.20 (3m <sup>2</sup> )	0	0
Heat output	$R_{h,i}$	[kW]	6	3	0	1.3 (4m <sup>2</sup> )	3.2
Usable heat	$H$	[%]	80	75	0	100	80
Energy conversion efficiency	$O_i$	[%]	15	35	7	31	COP 380
Capital cost	$C_i$	\$	4500	7,000	4500	3,500	3,000
Installation cost	$I_i$	\$	500	500	500	500	1,000
Maintenance frequency (cost)	$M_i$	[hrs of operation]	2,000 (\$150)	8,000 (\$150)	10,000 (\$100)	5,000 (\$300)	5000 (\$300)

Table 12-1: DG Technology Characteristics for Case Study 1

<b>Energy type</b>		Anytime tariffs apply		
		Controlled tariff (DHW) \$0.10/kWh		
		Export price \$0.09/kWh		
<b>Electricity</b>	<b>Auckland</b>	Energy price	\$/kWh	0.13
		Fixed price	\$/yr	280
	<b>Wellington</b>	Energy price	\$/kWh	0.103
		Fixed price	\$/yr	275
	<b>Dunedin</b>	Energy price	\$/kWh	0.13
		Fixed price	\$/yr	200
<b>Gas</b>		Energy price	\$/kWh	0.04
		Fixed price	\$/year	150
<b>LPG</b>		Energy price	\$/kWh	0.06
<b>Wood</b>		Energy price	\$/kWh	0.05

Table 12-2: Energy Costs used in Case Study 1

Profile description [kWh/yr]	House 1	House 2	House 3
Annual energy load	6,036	12,322	20,624
Annual heat load	4,397	8,783	14,805
Annual DHW load	2,622	5,240	8,758
Annual SH load	1,776	3,542	6,047
Annual SC load <sup>38</sup>	-	-	-
Annual residual load	1,639	3,539	5,820

Table 12-3: Energy Loads for the Major End Uses for Houses in Case Study 1

The data in Table 12-3 relates to an average individual house's requirements. There will be some variability to the values shown as dictated by the Gamma distribution.

<sup>38</sup> Due to the low penetration of air-conditioning in the residential market it was assumed in the case studies that there was no space cooling load (i.e.  $TC_{sc}=0$ ).

### 12.1.5 Results

#### *Stirling Engine*

Figure 12-1 shows the impact of house size on NPV. House 1 was too small for a 0.75 kW<sub>e</sub> Stirling engine. Indeed, even the larger houses have difficulty in achieving a positive NPV in peaking electricity led mode because the demand for electricity did not rise above the output threshold for enough time during the year. Base loaded operation, for the larger homes, had a positive NPV, due to a high percentage of the required energy being captured.

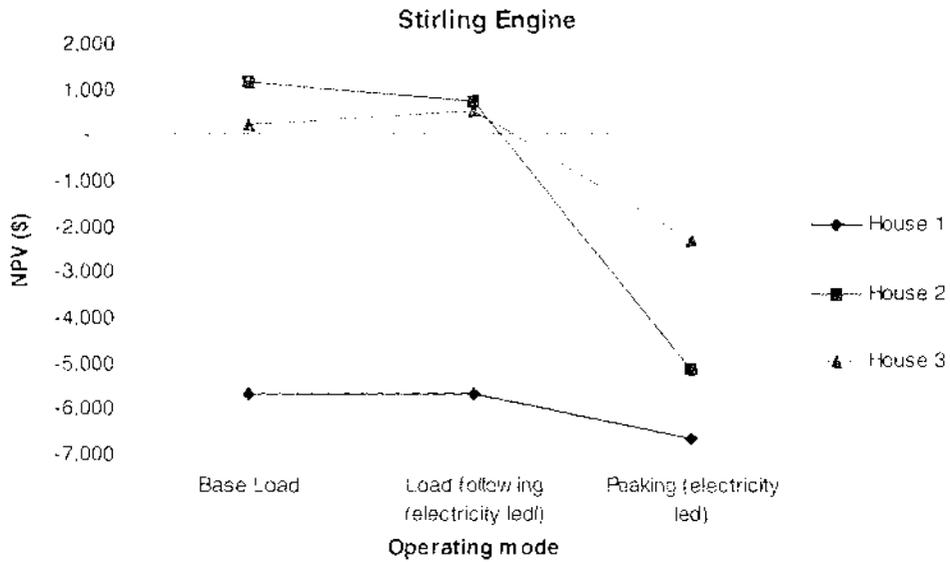


Figure 12-1: Results for a Stirling Engine for Various House Types and Operating Regimes

#### *Fuel Cell*

Figure 12-2 shows that fuel cells performed poorly due to the incompatibility of their size to the demand profile and the high capital cost of NZ\$ 7,000.

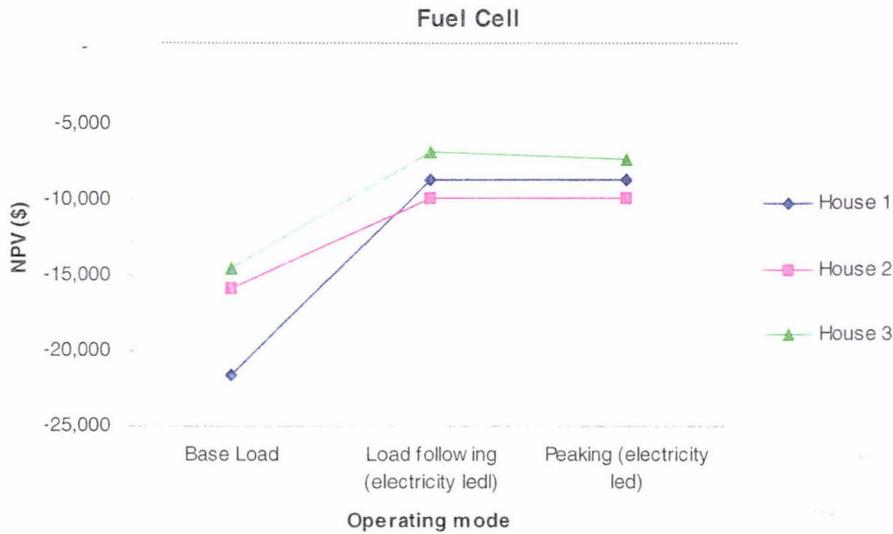


Figure 12-2: Results for a Fuel Cell for Various House Types and Operating Regimes

The base load operation shows to be consistently the poorest operating regime, due to the cost of gas used being very large. This was in contrast to the Stirling engine, as at  $4 \text{ kW}_e$  the fuel cell consumed far too much gas for the load it was displacing, i.e. little of the thermal output could be usefully deployed.

### Renewables

Figure 12-3 shows that the solar hot water system outperformed photovoltaics in all three houses, although neither gave a positive NPV. This was largely due to the lower capital cost of the SHW heaters.

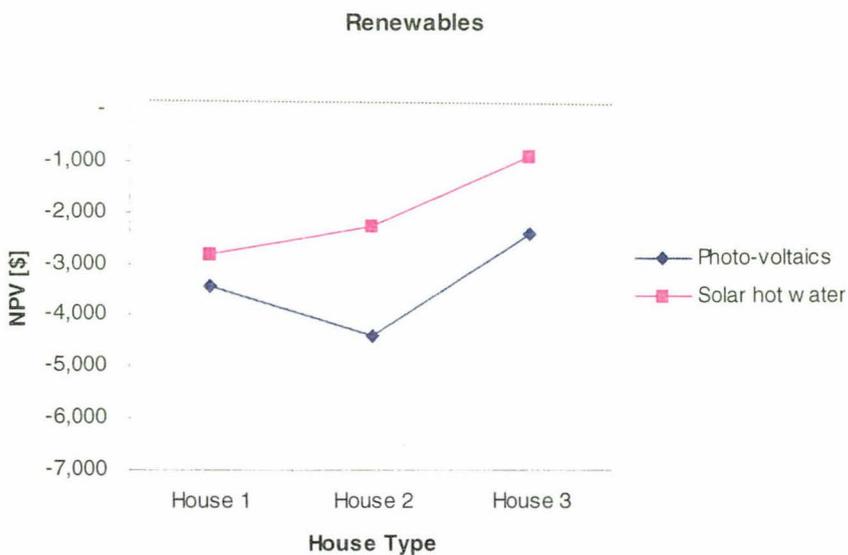


Figure 12-3: Renewable Energy Technologies for Various House Types

House 3 was the most economic which was surprising as it was in Wellington and had a gas fired hot water cylinder. The reason was that although Auckland (House 2) had slightly better radiation levels, it had a far smaller hot water load. Therefore, House 3 could use more of the captured heat immediately (without having to store it, and hence incur losses. Even though the cost of the displaced energy on kWh basis was less than House 2 (gas vs electricity) the overall annual running cost was also less for the same reason.

### Heat pump

Heat pumps can only operate in load following (heat-led) mode. Figure 12-4 show that heat pumps are most attractive (highest NPV) for House 2.

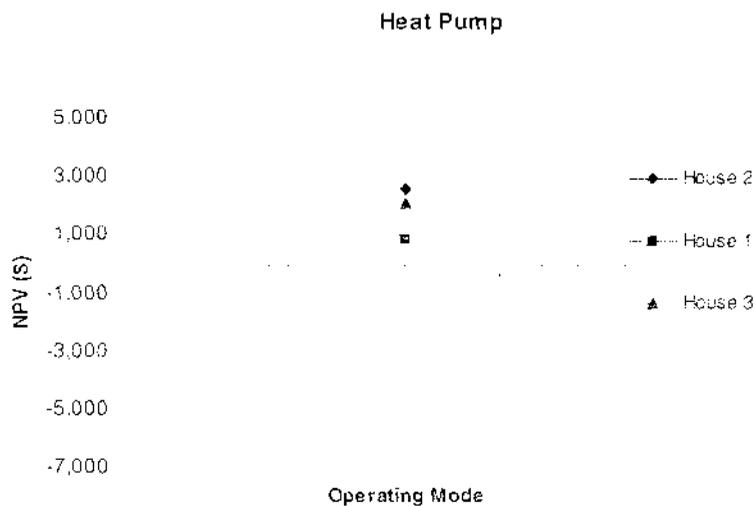


Figure 12-4: Heat Pump Results for Various House Types

Heat pumps have a very large turn-down ratio. Therefore the small space heating load in House 1 could be easily delivered whereas the other DG technologies often struggled. The better economics for the larger loads reflected better sizing of the technology.

### 12.1.6 Conclusions

Currently it appears that the DG technologies evaluated look marginal economically. The Stirling engine (operating heat-led) and the heat pump look most promising. However this case study involved a number of different variables that were not analysed individually, therefore large changes in NPV could occur without the relative influence of individual variables being known.

## 12.2 Case Study 2 - Christchurch Area Study

### 12.2.1 Background

Christchurch was chosen as a location in New Zealand to do a more in depth analysis as it has characteristics that suit Meridian Energy, and the local regulatory environment is more favourable to distributed generation. The major drawback is the unavailability of reticulated gas. However this is not seen as completely prohibitory to the introduction of gas fired DG units (Smith. G, 2000). The key features are:

- It has a relatively large population base. This allows for economies of scale in terms of DG distribution and servicing networks to be realised. The large number of houses would also allow for large enough niche groups to exist to make it worthwhile to target them.
- The location of Christchurch relative to Meridian's generation resources
- The large number of customers that Meridian has acquired from On-Energy, means that Meridian has a significant number of customers already in Christchurch and brand enhancing/advertising would be effective retention tool.
- Environment Canterbury's drive to reduce air pollution. Currently 90% of the suspended particulates comes from home heating so there are subsidies for replacing an open fire or coal burning appliance.
- The relatively long heating season in Christchurch means that there is a greater demand for space heating, meaning that the thermal demand would better suit some DG technologies.
- Sunshine hours in Christchurch are conducive to solar hot water heaters. There are already 1,400 such installations.

### 12.2.2 Introduction

The purpose of this case study was to undertake an analysis of DG in a particular urban area, including the cumulative impact on the network. Thus, the unique combinations of climate, energy prices, regulatory regime and housing composition could be examined. A Stirling engine, SHW and heat pump were examined.

### 12.2.3 The Market

Figure 12-5 shows some pertinent statistics for the city of Christchurch. They are needed for a holistic analysis of DG opportunities which involve a wide range of load profiles and other drivers. Since the analysis was conducted on a small sample, the process of estimating the market potential required some knowledge of housing characteristics as well as an

understanding of other variables that may influence the uptake of DG. For example, whether a home is owned or rented may affect a home dweller's decision to install a DG unit.

Characteristic		Number	Notes
Population		309,033	
Total private dwellings		116,619	
Separate houses		87,549	
Two or more flats joined		27,942	
Percentage of dwellings owned		69.8%	Includes with / without mortgage
Average annual spend of power and fuel		\$1,230	
Fuel spend percentage	Electricity	90%	
	Wood	5%	
	Other	5%	
Insulation level	No	28%	Percentage of houses using this insulation level
	Retro-fit	45%	
	Building code	27%	
Space heating	Electricity	90%	Percentage of houses using this energy type
	Wood	45%	
	Gas (LPG)	20%	
Water heating	Electricity	100%	Percentage of houses using this energy type
	Electricity + wetback	20%	
Wood-burners		31,000	Number of units
Open fires		14,000	Number of units
Hot water cylinder sales <sup>39</sup>		4,600	Numbers/annum
Average temperature		12.5	°C
New houses to be built		2,000	Number/annum

Source: CCC, 2001

Figure 12-5: Christchurch Statistics

<sup>39</sup> Based on data from the survey of 14,000 households and equipment in the period of the survey. MW sales

### 12.2.4 Key Variables

Figure 12-6 outlines the variables studied in this case study:

Variable	Drivers	Effect
Export electricity price	Regulatory environment, real time pricing, net metering	Increased revenue from operation, decrease in DG unit running costs
Operating regime	Displacing higher proportion of traditionally supplied energy	Increased energy capture, change in value of displaced energy
Load size	House size	Increase in energy available to be captured, change in value of displaced energy
	Insulation level	
Electricity price	Market forces	Value of displaced energy
Gas price	Market forces	DG unit running costs
Capital cost	Market forces, regulatory environment	Investment cost

Figure 12-6: Key Variables Examined for the Christchurch Case Study

They were chosen as they represented one or a combination of three factors:

- 1 Their value is likely to change over time
- 2 They strongly influence the profitability of residential DG
- 3 They enable the market to be segregated into easily defined categories, e.g. house size.

### 12.2.5 Scenarios<sup>40</sup>

The two scenarios examined are described below. Both assumed gas to be widely reticulated within the Christchurch urban region. Scenario 1 broadly represents the status quo, whereas Scenario 2 represents possible future conditions likely to be more favourable to DG.

Technology		Scenario	
		1	2
Electricity price[\$/kWh]		0.13	0.15
Capital cost [\$]	Stirling engine	4,500	2,500
	Heat Pump	3,000	2,000
	SHW	3,400	2,400
Gas price [\$/kWh]		0.04	0.06
Export electricity price [\$/kWh]		0.00	0.09

Table 12-4: Price Comparison for the 2 Scenarios Examined in Case Study 2

<sup>40</sup> Other data for Case Study 2 is given in Appendix C.2

### 12.2.6 Input Data

Energy load data, house characteristics and end-use demands for Case Study 2 are given in Table 12-5.

House type	A	B	C	D	E	F
Insulation level	Building standard	Retrofit	No insulation	Building standard	Retrofit	No insulation
Size	Medium			Large		
Profile class	Profile class 3					
End Use	Annual energy load [kWh/yr]					
Total	11,459	14,156	17,230	17,302	21,398	25,790
Total heat	8,203	10,164	12,391	12,412	15,220	18,534
DHW	4,780	5,916	7,196	7,216	8,917	10,785
SH	3,424	4,248	5,195	5,196	6,302	7,749
SC						
Residual	3,255	3,992	4,839	4,890	6,178	7,256

Table 12-5: House Type Energy Characteristics used in Case Study 2

### 12.2.7 Hypothetical Network

For the sake of simplicity a hypothetical network was created. The composition of the network is outlined in Table 12-6

Hypothetical Network			
Existing network	House Class	Number of houses	
	Class 1	500	
	Class 2	500	
	Class 3	500	
	Class 4	500	
Hybrid network (with 25% DG penetration)	House Class	Number of DG homes	Number of non-DG homes
	Total	500	1500
	Class 1	175	325
	Class 2	150	350
	Class 3	175	325
Class 4	0	500	

Table 12-6: Hypothetical Network Characteristics

One aspect that is considered important to developing a more realistic network analysis, is the ability to diversify house size, and insulation level *within* the network. Currently the network design can specify only one combination of size and insulation level, that combination being the same as the house type the DG units are serving. This is an important limitation of the current model.

### 12.2.8 Stirling Engine Results

Figure 12-7 shows the NPVs for a variety of load sizes serviced by a Stirling engine, operating in load following heat-led mode. These load sizes correlate to the size of the house and its insulation level. Houses with no insulation have a greater load as their space heating requirements are larger.

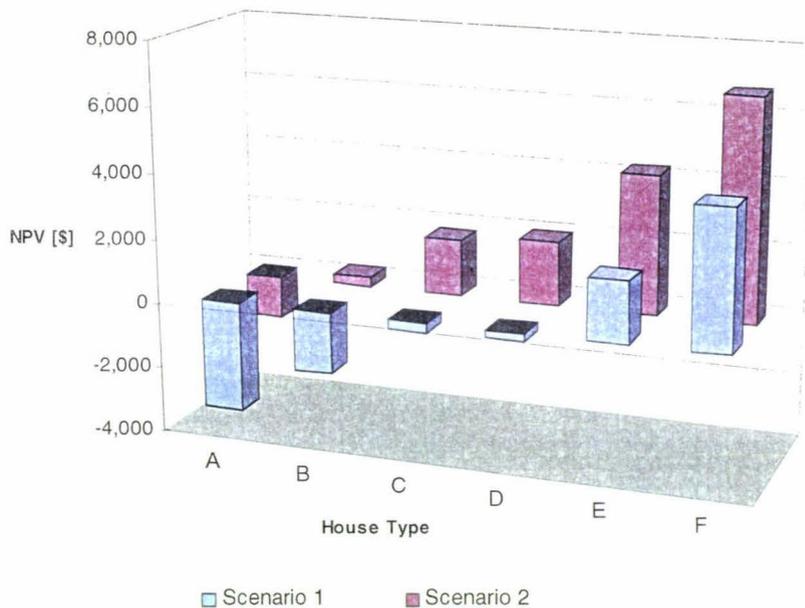


Figure 12-7: Stirling Engine Results: NPV versus House Type

Figure 12-8 shows the following 3 indices for Scenario 1:

- 1) ROI
- 2) Percentage of time operating
- 3) Percentage of energy captured

As the load size increases a greater proportion of the demand falls within the engine's operating range, so it runs more often and captures a greater proportion of the energy requirement. As a consequence, more traditionally supplied energy, is displaced. Since TSM is at a higher cost than that provided by the Stirling engine, a greater annual savings is realised giving a higher ROI.

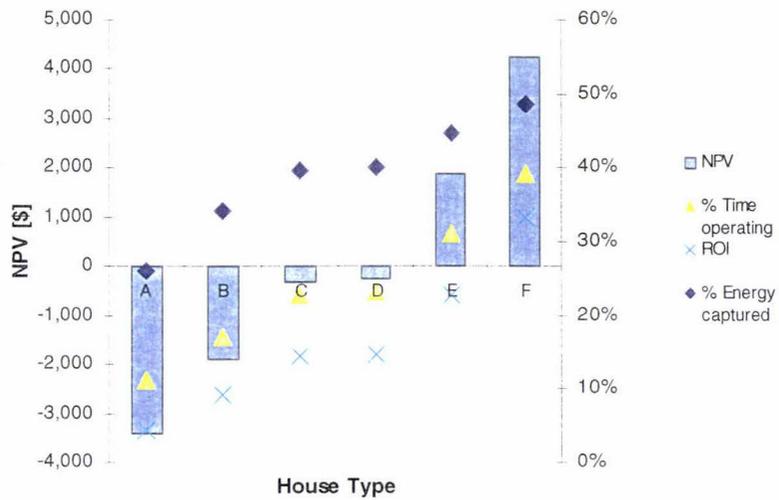


Figure 12-8: Scenario 1: Stirling Engine Economic Indices

House Type	Payback [yrs]
A	14
B	14
C	12
D	10
E	6
F	4

Table 12-7 Scenario 1 : Payback Results

*Network impact*

The large house with no insulation (House F) had the lowest payback period of 4 years and therefore was the most likely candidate to be fitted with a Stirling engine. The effect of installing 500 Stirling engines into this housing type in the hypothetical network was examined. Figure 12-9 shows the network profile for a week-day winter. The reduction in electrical demand for the hybrid network is clear.

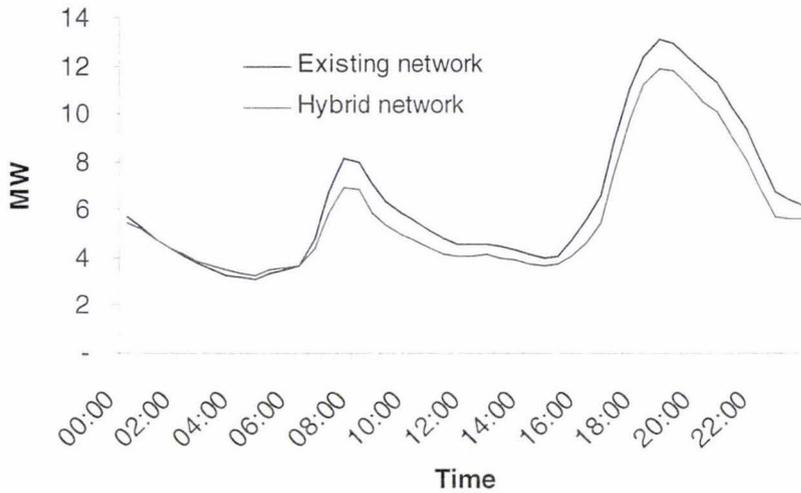


Figure 12-9: Network Impact of 500 Stirling Engines During a Winter Weekday

Table 12-8 summarises the winter effect of 500 Stirling engines on the residual network load. There is no weekday summer benefit because the lower space heating requirement in the summer reduces the simultaneous production of electricity.

	Winter Weekday			Summer Weekday		
	Existing	Hybrid <sup>41</sup>	Net	Existing	Hybrid	Net
Total [kWh]	311,530	279,702	31,828	191,576	191,852	-276
Average [kW]	6,490	5,828	664	3,992	3,996	-6
Min [kW]	3,172	3,324	-152	1,780	1,784	-6
Max [kW]	13,298	12,048	1,250	6,602	6,604	-2

Table 12-8: Residual Load on the Network for Scenario 1 with 500 Stirling Engines Installed

The apparent small increase in the hybrid network load in the summer is due to the stochastic methods used to simulate demand.

Figure 12-10 shows how the load reduction for a winter day was proportioned over 48 half hour periods. It shows a clear reduction of load in the 12 MW and above category. This would be of significant benefit to a network company if a particular part of the network was reaching its capacity limit and was in need of an upgrade.

<sup>41</sup> Hybrid network includes homes with the DG units.

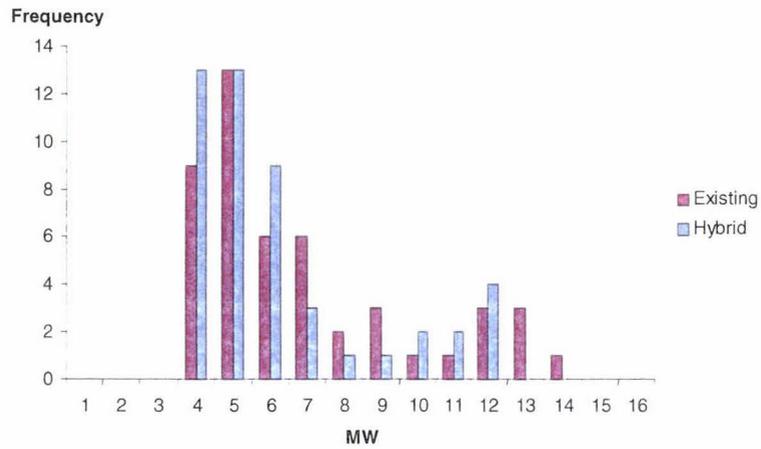


Figure 12-10: Histogram of Demand for the Existing and Hybrid Networks

Figure 12-11 provides a break-down of the contribution that each of the 3 profile classes<sup>42</sup> make to the total import quantity. There are equal numbers of each of the shape profiles. The dotted line gives the amount of imported electricity that the 500 houses require as a percentage of what they would have done in the existing network. The number of DG units in the network represent is 500.

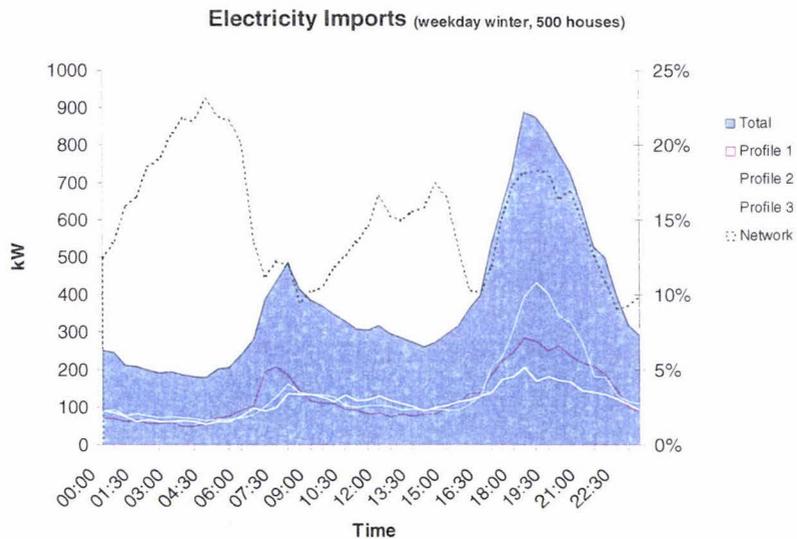


Figure 12-11: Network Import Profile for 500 Houses Equipped with Stirling Engines

<sup>42</sup> There were no DG units installed in class profile 4 houses, hence only 3 profiles are of relevance

### 12.2.9 Heat Pump Results

Heat pumps were chosen to be examined as they offer the opportunity to enter into the domestic market with a proven technology and established distribution and service networks. Figure 12-12 shows a similar trend to the case of Stirling engines with the load size having a large impact on NPV.

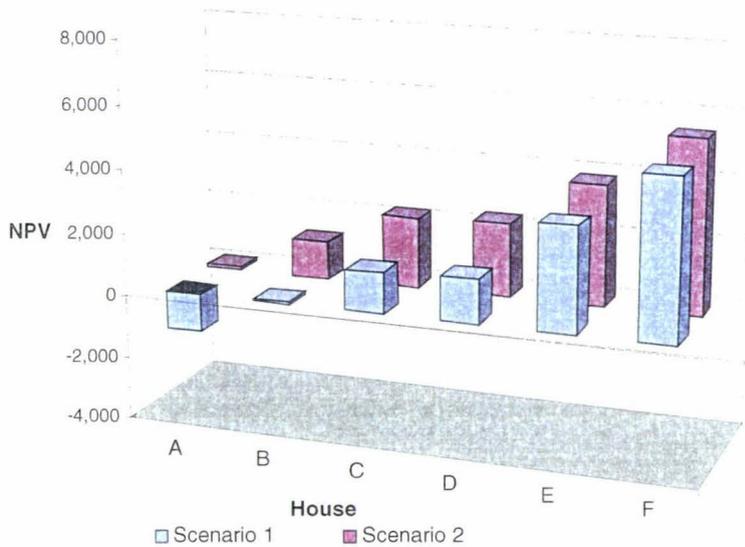


Figure 12-12: Heat Pump Results: Profitability vs House Type

There was a less pronounced difference between the two scenarios because the difference in gas price did not have an effect on the NPV as gas did not provide any of the energy requirements. The heat pump algorithm currently allows for any thermal load to be met (which was identified previously as a major limitation to the current model) whereas in practice there would be upper bounds to the heat capacity. The analysis assumes the initial cost of a HP is the same irrespective of the served load i.e. the HP is effectively over sized for houses with small loads. Only a single size-capital cost combination of HP was examined, which favours high load households. Figure 12-13 shows the close correlation of the percentage of captured thermal energy with the NPV.

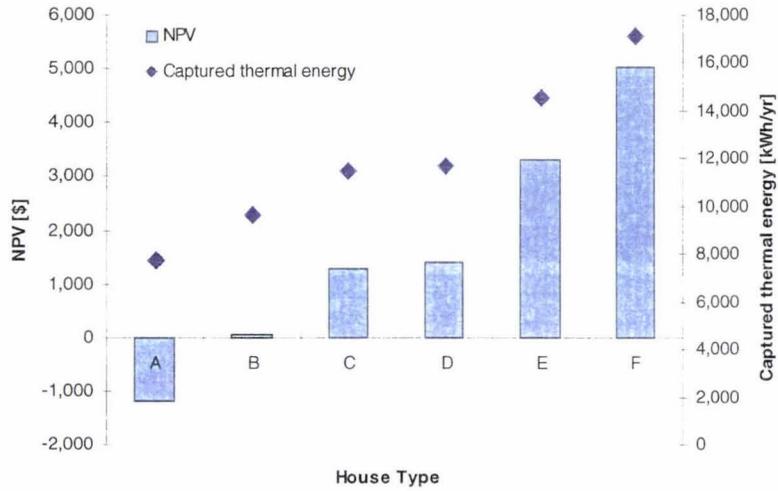


Figure 12-13: Scenario 1: Heat pump Operational Indices

### Network impact

The impact of heat pumps on the hypothetical network is even more pronounced than that for the Stirling engine, with over 48 MWh of energy supply being removed during a winter week-day (Table 12-9). The reduction in peak load of over 2 MW is also significant (Figure 12-14) due to the continuous operation of the heat pump and subsequent consistent reduction in demand.

	Winter			Summer		
	Hypothetical	Hybrid	Net	Hypothetical	Hybrid	Net
Total [kWh]	305,342	256,566	48,776	191,576	178,004	13,572
Average [kW]	6,362	5,346	1,016	3,992	3,708	282
Min [kW]	3,108	2,754	356	1,780	1,648	130
Max [kW]	130,34	10,696	2,338	6,602	6,084	518

Table 12-9: Residual Load on the Network for Scenario 1 with 500 Heat Pumps Installed

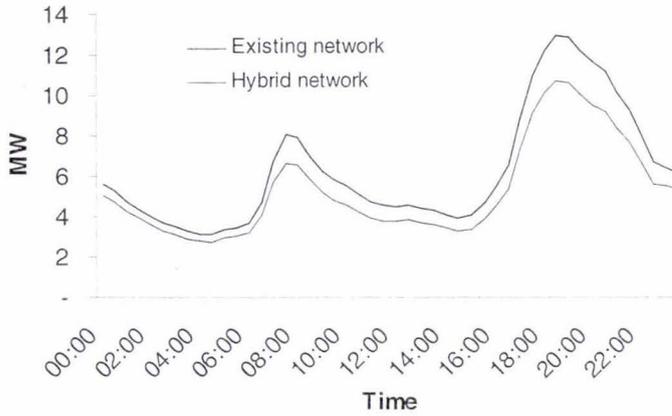


Figure 12-14: Impact of 500 Heat Pumps on the Network During a Weekday Winter

An additional case study is shown in Appendix C.4. It is similar to case study 2 but examines a fuel cell being operated in a Wellington house.

### 12.3 Case Study 3 - Individual Variables

#### 12.3.1 Introduction

The objective of this case study was to examine the sensitivity of the model's results to the value of specific variables. Each parameter was adjusted individually to gauge its own impact on NPV. This case study was based on Case study 2 with the heat pump as the example technology.

#### 12.3.2 Independent Variables

The following variables were adjusted by 20% in the direction that they are most likely to change.

Parameter		Base case	Adjusted value
Load size	[kWh/yr]	14,000	17,000
Capital cost	[\$/unit]	3,000	2,400
Carbon tax	[\$/tCO <sub>2</sub> ]	0	25
Heating season	[months/yr]	4	5
Discount rate	[%]	9	10.8
COP		3.4	4.2

Parameter		Base case	Adjusted value
Diversity <sup>43</sup>	[kWh/yr]	0	115
Profile shape	-	Class 3	Class 2
Electricity price	[\$/kWh]	0.130	0.156

Table 12-10: Base Case and Adjusted Value Data

### 12.3.3 Results

The results are shown using Tornado graphs (Figure 12-15 for NPV and Figure 12-16 for payback period). For the base case the NPV is \$50 and the payback is 10 yrs.

#### NPV

Figure 12-15 shows how the load size strongly influences the feasibility of a heat pump. An increase of 3,000 kWh/year energy load increased the NPV over the 10 year period from around \$50 to \$1,300. Capital cost also has a significant impact on NPV. Most other variables had low impact on the NPV. Caution must be stressed in interpreting this Tornado Diagram. It is specific to this particular combination of technology parameters and load characteristics. The electricity price sensitivity is attenuated, as 50% of the space heating requirement is met by wood. If it was 100% electricity supplied, the dependency of the NPV towards changing electricity price would be greater.

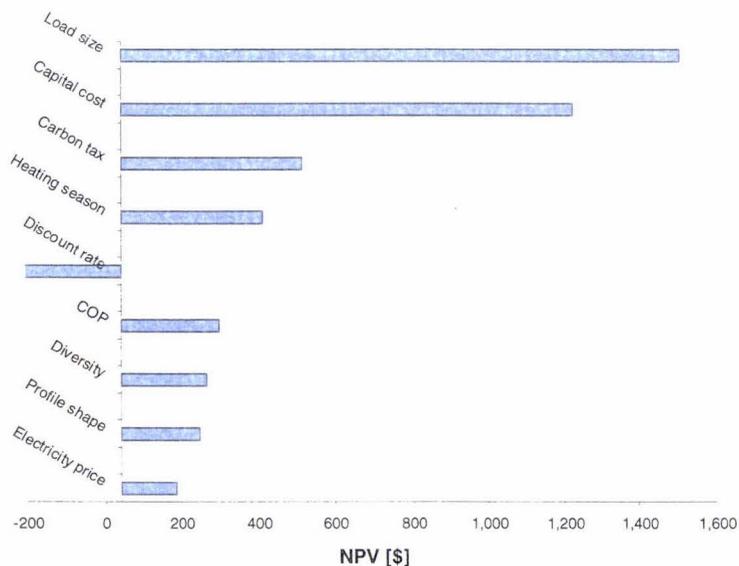


Figure 12-15: NPV Sensitivity for a Heat Pump

<sup>43</sup> The diversity category represents the change in NPV due to the variation in individual house load profiles. This variability is inherent in the model and can be viewed as its sensitivity limit.

### Payback

Figure 12-16 shows the payback period is also affected most strongly by the capital cost and load size. There was a strong correlation with the NPV results as expected.

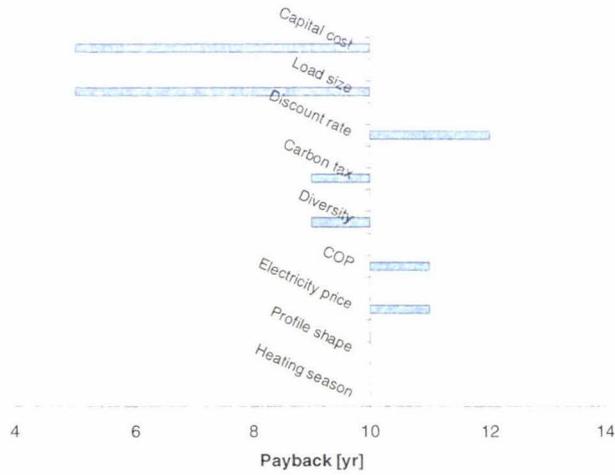


Figure 12-16: Payback Sensitivity for a Heat Pump



## Chapter Thirteen

# Conclusions & Recommendations

*This Chapter provides a summary of the conclusions reached in the thesis and makes recommendations for further analysis.*

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### 13.1 Overview

The overall purpose of this work was to develop:

- *an aid* in assessing the business opportunity for residential DG.
- *greater understanding* of the residential market and the factors that affect domestic energy use.
- *awareness of the new and emerging technologies* that may be used in this market.
- *a base* on which further and more detailed analysis can be carried out.

These objectives were addressed by developing a DG evaluation decision tool or model. The main modules each incorporated key aspects of residential distribution in New Zealand. Figure 13-1 gives an overview of the modules in the model and the variables analysed.

Module	Load Profile						
Objective	1) To identify the constituents of demand		2) To identify factors which affect demand			3) To reflect profile uncertainty	
Analysis	End-use	Other	Size	Insulation Category	Climate	Diversity of individual house	
Detail	<ul style="list-style-type: none"> <li>SH</li> <li>SC</li> <li>Hot water</li> <li>Residual</li> </ul>	Total use: thermal use ratio	<ul style="list-style-type: none"> <li>Small</li> <li>Medium</li> <li>Large</li> </ul>	<ul style="list-style-type: none"> <li>A</li> <li>B</li> <li>C</li> </ul>	<ul style="list-style-type: none"> <li>Christchurch</li> <li>Dunedin</li> <li>Wellington</li> <li>Auckland</li> </ul>	<ul style="list-style-type: none"> <li>Residual</li> <li>Thermal</li> </ul>	
Level of disaggregation	½ hourly		Seasonal				½ hourly

Module	Technology Selection						
Objective	Available technology			Climatic conditions			
Analysis	Heat engine		Renewable	Other	Wind	Solar radiation	Temperature
	<ul style="list-style-type: none"> <li>Stirling engine</li> <li>Micro-turbine</li> <li>Reciprocating engine</li> <li>Fuel cell</li> </ul>		<ul style="list-style-type: none"> <li>Solar hot water</li> <li>Photovoltaics</li> <li>Wind turbine</li> </ul>	<ul style="list-style-type: none"> <li>Heat pump</li> </ul>			
Detail	<ul style="list-style-type: none"> <li>Power output</li> <li>Heat output</li> <li>Usable heat efficiency</li> </ul>		<ul style="list-style-type: none"> <li>Fuel conversion efficiency</li> <li>Maintenance costs</li> </ul>				
Level of disaggregation	½ hourly						

Module	Operation Control	
Objective	Explore effects of different control regimes	
Analysis	Mode of operation	<ul style="list-style-type: none"> <li>Peaking (heat led)</li> <li>Peaking (electricity led)</li> <li>Continuous</li> <li>Renewable (resource limited)</li> </ul>
	<ul style="list-style-type: none"> <li>Base load</li> <li>Load following (heat led)</li> <li>Load following (electricity led)</li> </ul>	
Detail	Imported / export energy requirements, performance characteristics (run hours, fuel usage)	
Level of disaggregation	½ hourly	

Module	Costing						
Objective	Fuel			End use			
Analysis	Electricity	Reticulated gas	Wood, LPG	Residual	Space heating	Space cooling	Domestic hot water
Detail	TOU, tariff	TOU (limited), tariff	Single				
Level of disaggregation	½ hourly, Seasonal, Annual						

Figure 13-1: Main Modules and their Scope of Analysis

The Load Profile module analysed the factors that affected domestic energy use. It categorised them into three parameters of house size, insulation level and geographic location and included 5 different profiles shapes. Four end uses were included in the profile, SH, SC, DHW and residual.

The Technology Selection module is essentially a database with numerous DG technologies including heat engine, fuel cell, reciprocating engine, heat pump, SHW, WTG and photovoltaic and their key performance attributes such as heat and power outputs.

The Operation Control module allows the comparison of the demand profile and the DG supply profile under various control regimes to determine the optimum operating conditions for a particular technology type and load profile.

The Costing module provided a economic platform to compare the BAU case with the DG case. A discounted cash flow was used to yield NPV and other economic indicators.

The model provides a comprehensive account of end use costs as well as fuel costs on a seasonal and annual basis. Key features of the model include its modular structure with a centralised calculation engine. The model was implemented using Visual Basic in Excel to facilitate further development. This allows for separate development of areas within each module. The model has the capability to simulate DG either at a single household level or perform a network simulation where up to 2,000 houses can be analysed. The model however does not consider power flow issues at either level. The model accommodates diversity between houses to more accurately simulate the matching of a DG output with the demand profile.

In the first case study a number of DG technologies were compared for a typical home in Christchurch under a scenario representing the current situation. The case study showed that technologies such as fuel cells are not yet economic, but that Stirling engines and heat pumps display promise, especially if capital cost can be reduced by at least 30%. The second case study demonstrated the impact of 500 Stirling engines and heat pumps on the distribution network, indicating their potential application for managing peak demand. The other case studies demonstrated the importance of the size of the load profile and capital cost as being the most significant drivers affecting the profitability of DG.

## 13.2 Recommendations

The Load Profile module is an area that warrants the greatest scope for further development. The thermal component is currently estimated as a constant percentage of the total load. This means thermal and residual loads must be coincident which is often not realistic and leads to over-estimation of the utilisation of DG output, under-estimation of import and hence DG technologies, that utilise CHP operation, appear more attractive than they should. It is recommended that the load profile module be modified such that the thermal components of SH, SC and DHW are all independently derived. In addition, diversity within the ½ hour should be incorporated into the load profile so that the export and import profile of a DG unit is more accurately estimated. Multi-unit analysis is a functionality that urgently needs to be developed as multi-unit accommodation has load characteristics better suited to many residential sized DG technologies and is become more popular. Lastly, demand management using DG is an area of future development which could become an likely option as networked intelligent appliances allow greater control of load within a home.

The technology selection module has a number of areas that warrant further development. For the heat pump technology, it is recommended that the method to estimate COP is improved and that variation with operating capacity is incorporated. The storage module needs further development to enable stored thermal energy to be used on subsequent days. WTG are not a technology option that is currently at a sufficient stage of development to conduct a case study. Further work is needed determining the ½ hour wind speed and its distribution to estimate the variability of power available for a ½ hour period. The model has the structure to analyse hybrid technology options but this should be further developed so that situations like remote are power supply [RAPPS], where having more than one technology type is necessary can be assessed.

An operational mode incorporating a cost reflective message should be included to allow analysis of real time pricing and its impacts and potential for encouraging DG. In addition, a timed operation mode could be introduced to model system or network peak periods. Network analysis to allow greater flexibility in the network housing composition (i.e. different house sizes and insulation levels) could also be included to give a more realistic network.

Net metering and the price of export electricity is a critical issue for DG. It is recommended that further work be done in the area of analysing how this cost may be equitably determined

by analysing different tariff structures. For example, the price of export could increase during peak periods, or provide a reward for reactive power generation.

Lastly there is considerable scope to consolidate the code and its structure. To simplify the code and make future expansion easier it is recommended that a centralised worksheet is used to define all variables used and that greater use of code modules is included.



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# Glossary and Notation

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Term	Description	Unit
$A_c$	Area of collector	$m^2$
$AEC$	Annual energy consumption	KW/yr
$C$	Cost profile	\$
$C_c$	Capital cost	\$
$CM$	Cost of maintenance unit	\$/service
$COP$	Coefficient of performance	-
$C_v$	Yearly cost	\$
$F$	Operating efficiency	%
$G$	Geographic factor	-
$H$	Usable heat %	%
$H_{op}$	Hours of operation	hrs
$I$	Insulation factor	-
$I_c$	Installation cost	\$
$I_n$	Incident radiation	$KW/m^2/0.5hr$
$J$	PV efficiency	-
$K$	Displaced $CO_2$	tonne/yr
$Mc$	Maintenance costs	\$/ service
$MI$	Maintenance frequency	Service / hrs of operation
$N$	Normalised heat/electric output	-
$N_c$	Net storage capacity	kWh
$O$	Fraction of full load	%
$OC$	Operating capacity	-
$Of$	Operating efficiency (electrical)	%
$Q$	Energy collected	kW
$R$	DG unit rating	kW
$RC$	Residual component factor	-
$S$	House size factor	-

<b>Term</b>	<b>Description</b>	<b>Unit</b>
$S$	Storage capacity	kWh
$S_{D,t}$	Storage cumulative discharge	kWh
$S_{CS}$	Cumulative storage	kWh
$S_{D,t}$	Storage discharge	kWh
$S_{DR}$	Storage discharge rate	KW/hr
$S_{EF}$	Storage efficiency	%
$SF$	Scaling factor	-
$S_{min}$	Minimum storage capacity	kWh
$S_{max}$	Maximum storage capacity	kWh
$TC$	Thermal component factor	
$v$	Velocity	m/s
$\lambda$	Demand profile	kW
$\gamma$	Supply profile	kW
$\gamma_{amb}$	Fraction of DHW / total thermal	%
$\gamma_e$	Fraction of electricity / total residual	%
$\gamma_{LPG}$	Fraction of LPG / end use	%
$\gamma_{NG}$	Fraction of NG / end use	%
$\gamma_{SC}$	Fraction of SC / total thermal	%
$\gamma_{SH}$	Fraction of SH / total thermal	%
$\gamma_w$	Fraction of W / end use	%
$z$	Unit cost	\$/kWh

#### **Subscripts**

<b>Term</b>	<b>Description</b>
$Amb$	Ambient
$b$	Base profile (storage calculations)
$c$	Class profile
$d$	Day type
$E$	Electricity
$ind$	Individual house
$LPG$	Liquefied petroleum gas
$m$	Season type
$ms$	Month-season
$n$	Nth period of the day

<b>Term</b>	<b>Description</b>
<i>NG</i>	Natural gas
<i>p</i>	Power component
<i>r</i>	Residual component
<i>t</i>	Thermal component
<i>T</i>	Technology type
<i>va</i>	Variability
<i>W</i>	Wood



# Appendix A

## Model Input Data Validation

*This Appendix provides a check on the validity of the data inputs used, intermediate results and final outcomes. The aim is to provide an estimation of how accurate the data used is and to illustrate some issues about data comparison.*

---

### A.1 Introduction

This Chapter discusses data either raw or processed, generated by the model or published elsewhere. The objective is to highlight many of the issues that must be considered when comparing and using data, particularly from a wide range of data sources. Model comparison can be separated out into 3 distinct levels. Figure A-1 shows these three levels and typical

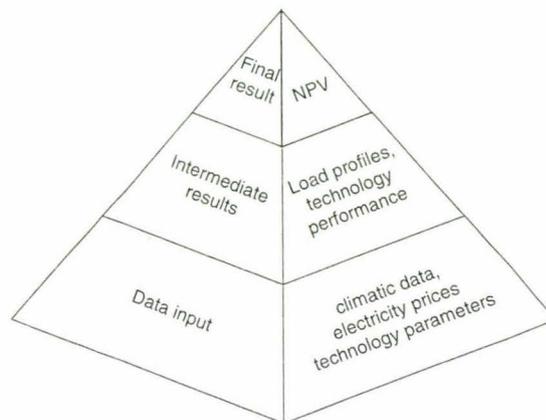


Figure A-1: Different Levels of Data Comparison in the Model

data found in each category. A thorough and complete review of all data used and subsequent results is what the ideal model comparison would involve. Chapters 7 to 10 highlights the present assumptions that are being used and possible future provisions that are required to improve the accuracy of the model. That is, it provides a descriptive assessment of the areas that are of concern in terms of accuracy. Unfortunately, it is not possible to accurately quantify all of these, as there does not exist external data that can be used for comparison sake.

Therefore two criteria were used to assess which areas were the subject of a model comparison process. They were:

1. What areas, parameters or data-sets have significant impact on the outputs produced by the model? (i.e. sensitivity analysis)
2. What areas have suitable and reliable data for comparison?

The three levels of comparison are each addressed by these two questions. Figure A-2 shows a sensitivity analysis for a Stirling Engine operating base-loaded, with an increase 10% for each variable.

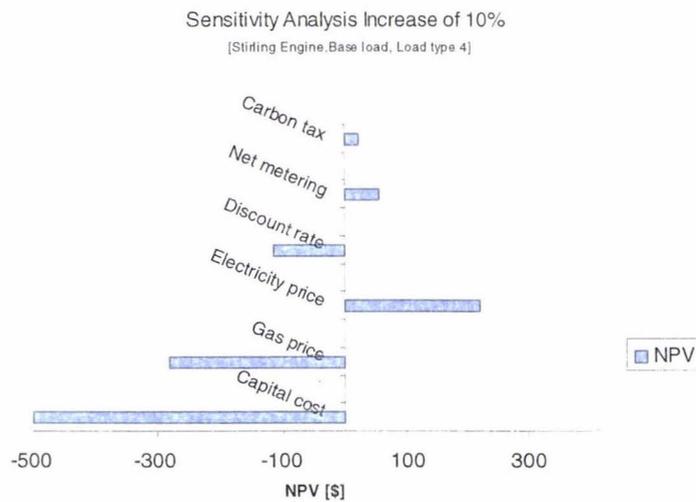


Figure A-2: Tornado Sensitivity Diagram

This Tornado can be compared to Figure 12-15 where load size (not examined here), and capital cost are highly sensitive, whilst changes in electricity price have insignificant impact on NPV. Given the variability in sensitivity, it was concluded that input data comparison be done on a case by case basis.

## A.2 Data Input

Because of the nature of 'raw' data it is generally freely available and has little added value to it. This can lead to two extremes. The data can be found from multiple sources and hence a range of reasonable values can be gauged or either, the data is so adequately provided for that there is only one source, this is often the case with meteorological data. Another important aspect of raw data is that it is easy to change in the model. This is particularly relevant for quoted capital costs of different technologies that often vary wildly.

### A.2.1 Capital Cost

Table 4-6 shows some typical capital costs. These have been sourced from a wide range of materials and given the model's ability and one of its stated uses, to discover the capital cost entry point for technologies, no additional verification of this parameter is required. Care must be taken to include installation costs, which include permitting and to use NZ dollar values as the majority of quoted costs are in US\$ terms.

### A.2.2 Electricity price

There are two types of electricity prices used. Firstly the cost to provide the electricity to a customer, which includes a break-down of its various components or else a simple retail tariff. As expected there are some differences in the constructed costs compared to the retail tariffs (Table A-1).

Area		Meridian Retail Tariff		Constructed cost
Wellington	Variable [c/kWh]	Anytime	10.3	10.9-15.1
		Controlled	8.75	
		Economy	9.78	
	Fixed [\$ /yr]	275		280
Christchurch	Variable [c/kWh]	Anytime	15.08	10.9-16.3
		Economy	11.14	
		D/N (n)	6.35	
		D/N (d)	12.04	
		Fixed [\$ /yr]	162	

Table A- 1: Energy Cost Comparison between Tariff and Constructed Options

Constructed cost variation is due to seasonal and daily movement in spot. Theoretically for profitable customers these constructed costs should be lower than the retail tariff. Spot prices are based on a single year's (2000) values which may not represent an average year. Retail

tariffs are based on forward<sup>44</sup> prices which tend to average out spot price variability. For the case studies only tariff prices were used.

### **A.2.3 Gas Prices**

Gas prices used are taken directly from tariff rates for typical residential customers and as such are assumed to be correct. Since Meridian does not have any direct gas interests, a customer of theirs would be charged the going tariff rate of the gas company in the area.

### **A.2.4 Climatic data**

Whilst meteorological data is sourced from reputable organisations such as NIWA and the Met Service, uncertainty comes about because of its spatial and time variability. In order to minimise this, as many different sites as possible should be used. However due to the cost, time constraints and uncertainty of impact only 4 regional sites were used to provide data. Substantial variability can occur even between sites that are spatially close (>1km). This is particularly true for wind and solar where the 'lie of the land' can have tremendous impact on these natural resources.

## **A.3 Intermediate Results**

By virtue of where they sit in the calculation chain, intermediate results have a greater uncertainty associated with them as a result of error propagation. Comparison with other intermediate results has the difficulty of unknown data inputs and assumptions, making comparisons less reliable.

### **A.3.1 Renewable Energy Resources**

Of particular note is the calculation of available solar energy falling onto a flat surface. The accuracy of this semi-raw data is important as it is used for both the PV model and SHW. Table A-2 shows solar resource data from various sources and for different locations. There is only about a 3% difference in these values compared with the model.

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<sup>44</sup> <http://www.meridianenergy.co.nz>

Location	NZPVA	Model	RET Screen	EECA
	Solar radiation, flat surface [kWh/m <sup>2</sup> /yr]			
Christchurch	1360	1377	1340	-
Wellington	-	1352	1390	-
Paraparaumu	1400	-	-	-
Average for NZ	-	-	-	1333

Table A- 2: Solar Resources Comparison

The functionality of the model allows for a natural resource to be *tuned* to provide flexibility in its magnitude as a function of the season of the year. If data is available or is calculated monthly it is averaged out to become seasonal averages. The seasonal averages are used then to calculate a particular yearly resource amount by multiplying out the number seasonal days for each season. This is used to calibrate the model to other studies so a more meaningful comparison of results can be done.

### Photovoltaic technology

Once the solar resource is determined the question becomes how much of it can be transformed into useful energy<sup>45</sup>? PV panels differ in their efficiencies and sizes making comparison with each other (through different studies) difficult, even given the same input (resource) data. Table A-3 shows the results for 2 major cities in NZ. In Wellington's case, the model produces a 16% smaller estimation of received solar input onto the tilted surface, this compared with only a 3% difference in input data. The reason for this lies in the way the model treats seasons and the non-linear relationship between time of year and solar radiation.

Location		RET Screen	Model	Notes
Wellington	Solar radiation on tilted surface [kWh/m <sup>2</sup> /year]	1530	1320	180° orientation, 30° tilt
	Annual energy delivered [kWh/m <sup>2</sup> ]	107	89	6.7% efficiency of panel
Christchurch	Solar radiation on tilted surface [kWh/m <sup>2</sup> /year]	1670	1442	180° orientation, 30° tilt
	Annual energy delivered [kWh/m <sup>2</sup> ]	116	97	6.7% efficiency of panel

Table A- 3: Performance Comparison of Photovoltaic Collectors

<sup>45</sup> Useful energy is differentiated from used energy. For example, a SHW system operating with minimal storage might not fully utilise the useful energy (hot water) that it produced.

### **A.3.2 Non-renewable Energy Resource**

There is not the same scope here for error propagation as the energy supply i.e. fuel, can be known far more precisely as it does not vary to the same extent as natural resources do.

#### *Heat engine technologies*

The heat engines examined fall into two categories. The reciprocating engine, although a proven DG technology on one hand has not been widely considered for residential DG and hence little data is available. Alternatively, the emerging technologies such as fuel cells, Stirling engines and micro-turbines are so new that useful and accurate performance data is not readily available.

#### *Heat pump technology*

The performance of heat pumps are closely aligned to the estimation of COP (See Section 8.2.2). A comparison between published COP figures and those produced by the model is difficult as they are temperature and load dependent, parameters which are often excluded in the reports. The methodology of determining COP however does warrant further development.

### **A.3.3 Demand Characteristics**

As discussed in Chapters 4 and 7 the estimation of demand is difficult due to its many contributing factors. In order to ascertain how accurate the demand side of the model is comparisons are needed to be made with available data. However, because of the lack of statistically accurate data in the first place only broad trends were used to model some of the variability due to house size, location and insulation level. The basis for these trends comprise much of the available data for comparison and obviously there is little point in doing this as the data is the same, i.e. a circular argument. What can be done however is to compare energy use for different end uses and total energy use for specific cases where comparable data exists.

#### *Energy usage*

Energy usage is possibly the most difficult to compare as data quoted from most sources are incomplete in terms of listing the parameters they relate to. As mentioned previously many variables have a pronounced effect on energy use and not being aware of them lends little credibility to results. However every effort was made to compare the values generated by the model with any reasonable source.

Table A-5 shows values from the RiNo<sup>46</sup> Software (Austral EA Ltd, 2001) and those of the HEEP study for total daily energy use. The values for all sources are reasonably similar. The model's values relate to a medium house with retrofit insulation, i.e. an average house. It appears unusual though to note that RiNo has a higher energy usage in the warmer climatic region of Auckland.

Region	RiNo	Model	HEEP
Auckland	29.8	27.0	-
Dunedin	27.8	30.3	-
New Zealand	-	-	25.1

Table A- 4: Daily Residential Consumption [kWh/day] as Reported by 3 Sources

#### *Domestic hot water*

Table A-6 indicates that the model's estimates of DHW use are too high. The DHW use as a percentage of total energy is around 42%, compared to 38% for the average NZ household. As explained in Section 7.10, the thermal end-use determination is affected by a number of constraints which contribute to this discrepancy. Of particular note is the increasing energy the further south the location is and hence cooler climate. This would seem logical and it is this premise that the model is based on. The EERA data however has the highest energy consumption in Auckland, the warmest zone. Their figures are not temperature corrected. The reason could be that the EERA figures are based on electricity use which may decrease the further South you go, as even though water temperature is lower (and thus required energy higher), a higher proportion of DHW energy is served by non-electricity sources such as wet-backs. The model calculates DHW as a function of total energy, it therefore increases as total energy increases. However in reality this increase in total energy would be more due to an increase in space heating.

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<sup>46</sup> A stochastic point load simulation in a constant current power flow analysis

End-use	HEEP	EERA <sup>47</sup>	Model <sup>48</sup>	Baines & Wright	
Domestic Hot water [kWh/yr]	NZ average	3160	3967	4700	4000
	Fuel supplementation <sup>49</sup> (Nth Island)	-	-	2947	3300
	Fuel supplementation (Sth Island)	-	-	4034	2950
	Auckland	-	3484	4153	-
	Wellington	-	3460	4700	-
	Christchurch	-	3324	5513	-
	Dunedin / Invercargill	-	3348	5984	-

Table A- 5: DHW Energy Comparison

### Space heating

Table A-6 illustrates the comparison in space heating requirements from three different sources. Space heating varies substantially and this concept is shown in the data from Baines & Wright with a 350% increase from Auckland to Dunedin. Model results increase by only 30% between these geographic regions. A possible cause in the difference may be that the model uses lines company data, region specific, to account for the geographic (climatic) variation. There may be disproportionate increase in the use of other energy sources which may be unaccounted for. This impact could substantially increase SH usage if the efficiencies of the other fuel sources are lower.

End-use	HEEP	Model <sup>50</sup>	Baines & Wright	
Space heating [kWh/yr]	Auckland	-	3221	1520
	Christchurch	-	4080	5130
	Dunedin	-	4153	7260
	NZ average	3484	3432	-

Table A- 6: Space Heating Comparison [kWh/year]

<sup>47</sup> EERA: Energy Efficiency Research and Assessment

<sup>48</sup> Model: Energy Modelling Software (Energy Modelling Software Ltd)

<sup>49</sup> Fuel supplementation: Fuel supplementation is used to account for the difference in energy requirements between the model and the actual data. It is used to account for the difference in energy requirements between the model and the actual data.

<sup>50</sup> Model: Energy Modelling Software (Energy Modelling Software Ltd)

### Annual Loss Factor (ALF) Model

BRANZ have produced the ALF 3, a product to evaluate energy behaviour in residential buildings. This program evaluates a building as a thermal envelope and was designed to primarily reflect changes in the physical construction of the building and how these affect energy flows into and out of the building. ALF 3 was used to compare the scaling factors ( $G$ ,  $I$  and  $S$ ). Table A-8 shows the comparison between the relative change in energy consumption from a simulation run on ALF and the corresponding changes used by the model. The comparison was made using a medium sized house, with retrofit insulation in Christchurch. Appendix I lists the details of the house used in the ALF simulation.

End-use	ID	Description	ALF 3	Model
Insulation level	A	None	1.3	1.2
	B	Retrofit	1.0	1.0
	C	Full	0.8	0.8
Climatic Zone	1	Nth North Island	0.9	0.8
	2	Sth North Island	0.9	0.9
	3	Nth South Island	1.0	1.0
	4	Sth South Island	2.0	1.1
House Size	A	Large	1.5	1.5
	B	Medium	1.0	1.0
	C	Small	0.2	0.5

Table A- 7: Comparison Between ALF and the Model Scaling Factors

The results overall correspond well, apart from the impact of climatic zone, particularly in the Sth South Island (Dunedin). ALF figures are 90% greater than the models which, along with results shown in Table A-7, suggests that this component of the model requires further analysis.

### Costs

Table A-9 represents the classic difficulty in comparing energy use data, as a considerable number of hidden factors can have a substantial impact on the bottom line.

Region	Annual expenditure on fuel and power [\$/yr]		
	EECA <sub>2000</sub>	Model	
		Electric	Supplement
Auckland	918 (1034)	1451	1359
Wellington	1092 (1230)	1473	1352
Christchurch	998 (1240)	1899	1735
Otago	1003 (1130)	1899	1735
Average	1284 <sup>31</sup>	1707	1560

Table A- 8: Regional Energy Expenditure

EECA's regional figures do not include 'free' energy such as firewood, which is considered to be a substantial source of home heating in the winter, particularly in the South Island. The model values shown are for a 100% electricity, medium sized house with a retrofit insulation. EECA figures are presumably an average of all houses. Since electricity is more expensive than gas this would push up expenditure in the North Island. Whilst in the South Island free firewood again reduces recorded expenditure. However with supplemental energy sources displacing some electricity, the model still overestimates expenditure somewhat. However the regional EECA figures are for the period 1993/1994. Assuming inflation at 2% per annum and constant demand, the present expenditure is shown in brackets which more closely resemble the models' results.

#### A.4 Final Results

Certainly for overall impression of the accuracy of the model the final result provides a reassuring answer. However it tells you little about the accuracy of the intermediate steps, which may be of concern especially if poor agreement is discovered. The term 'final result' is unfortunately an arbitrary stake in the ground. For example an estimation of the number of houses that may suit a particular technology would be considered a final result, but the economic criteria applied to make this decision is subjective. Therefore, results at a tier down from that example are assessed. This would mean for example looking at payback years as a major comparative value. Alternatively NPV can be considered but often the discount rate and period of analysis is not quoted with published figures.

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<sup>31</sup> See also Statistics New Zealand Housing of Household in 2000.

For example Table A-10 shows a range of payback periods for SHW as a function of location and DHW tariff. As can be seen good agreement is reached between the model's results and those published by EECA. Even though this appears satisfactory caution must be noted as the model treats DHW and SH as common thermal entities. Therefore the system savings and consequent annual savings refer to thermal reduction and not just DHW as is the case with the EECA studies.

Source	Payback Years	Location	Marginal capital cost <sup>52</sup>	DHW tariff	System savings	Annual savings
			\$	c/kWh	kWh	\$
Energy Wise News (EECA, 2001 <sub>a</sub> )	12.5	Dunedin	2700	10	2700	270
	9	Auckland	2700	11	3000	330
Energy Wise Renewables (EECA, 2001 <sub>b</sub> )	12.4	Auckland	2750	12.5	1776 (74%)	222
Model	11	Dunedin	2700	10	1604	328
	9	Auckland	2700	11	2327	330
	11	Auckland	2750	12.5	2327	391

Table A- 9: Payback Period for SHW Heating System

<sup>52</sup> Cost in addition to a comparable sized electric hot water cylinder

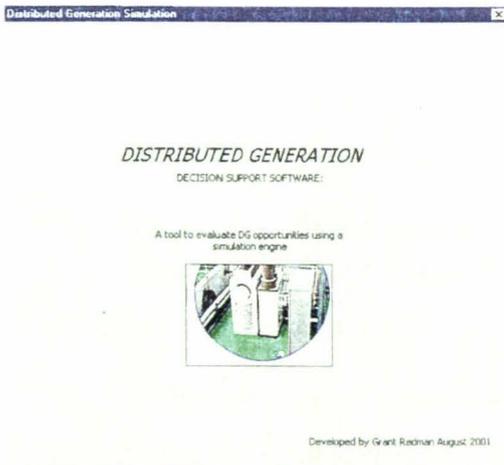


## Appendix B

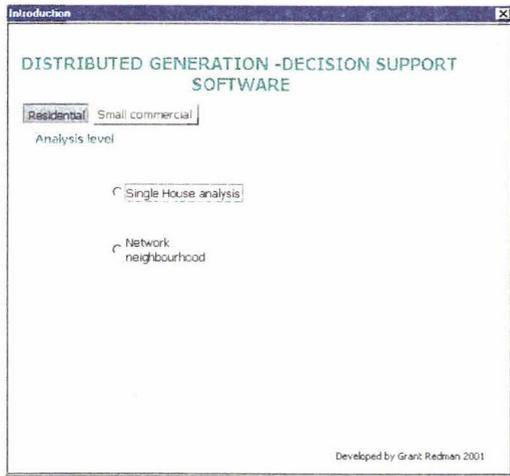
# Users Manual

*The user manual was intended to allow for the basic operation of the model. It takes the reader through the progression of screens that the model operator would work through as well as the alternative options and briefly describes the input required. It is assumed that the operator is computer literate, it is not a developer's guide.*

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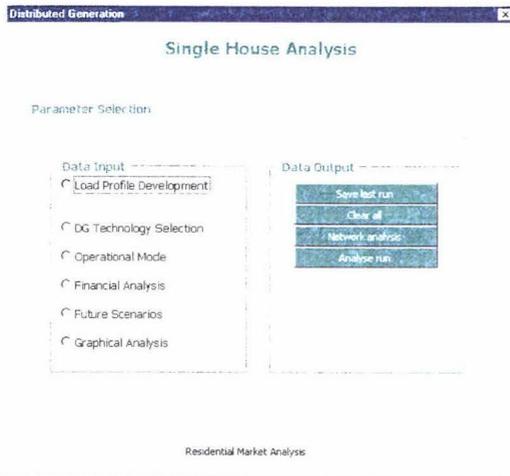


Welcome Screen



The 1st interface screen

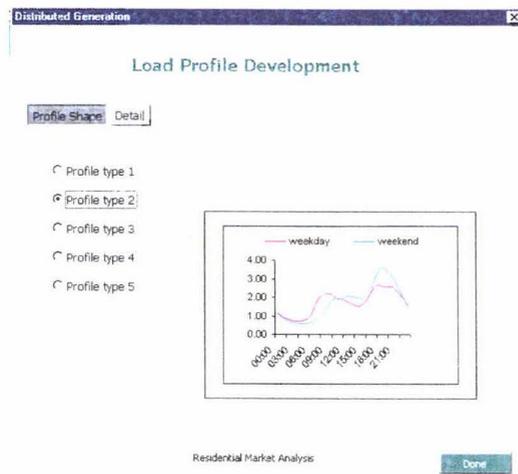
The user can select to analyse a single house or look at a neighborhood situation



The 2nd interface screen

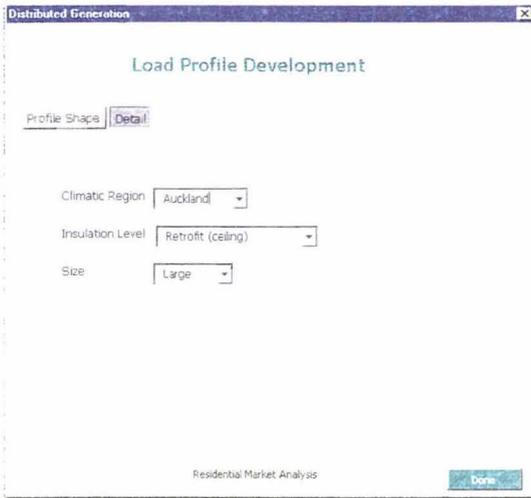
The central screen for a single house analysis. This screen provides the pivot point from which to drive the modules from.

The first module is the load profile development



The 3rd interface screen

The first load profile screen. Here the user can select the profile shape they wish to analyse



The 4<sup>th</sup> interface screen

The second load profile screen. The shape that was previously selected is transformed to the final profile by selecting values for:

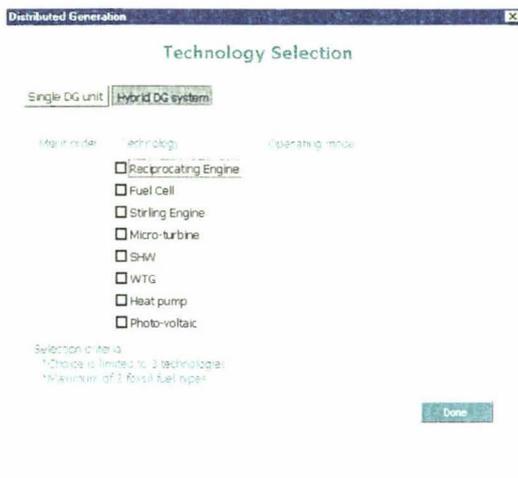
- Climatic region
- Insulation level
- Size

The second module is Technology Selection



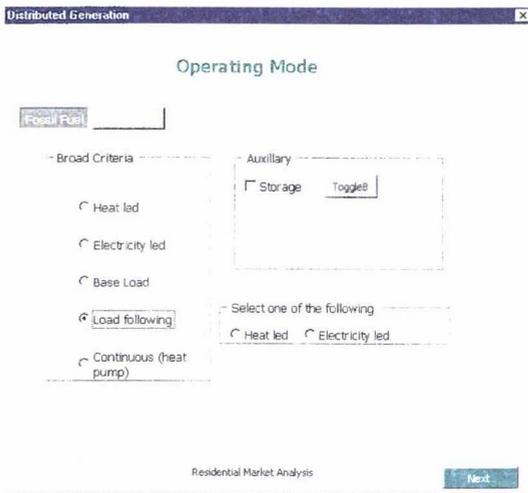
The 5<sup>th</sup> interface screen. (option 1)

The first technology selection screen. The technology type is selected for a single unit system.



The 6<sup>th</sup> interface screen (option 2)

The second technology screen. The combination of technologies for the hybrid system is selected.



The 7<sup>th</sup> interface screen (option 1)

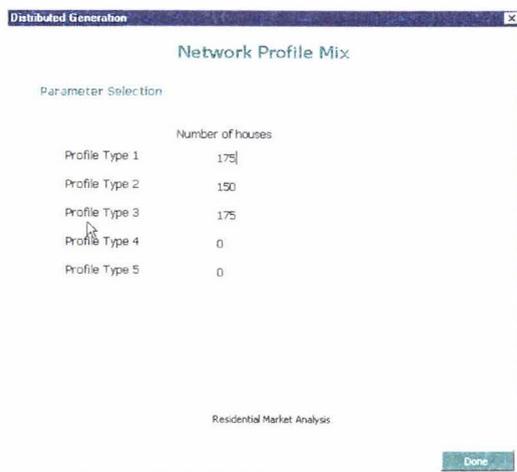
The first operating mode screen. Here load following, either heat or electricity led is being selected.



The 8<sup>th</sup> interface screen (option 2)

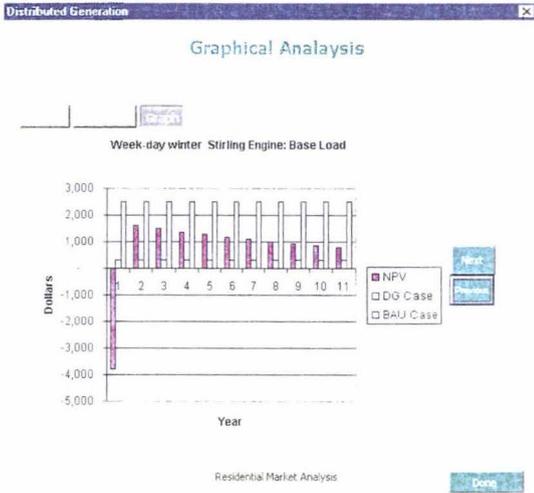
The second operating mode screen

Applies only to renewable technologies



The 9<sup>th</sup> interface screen

Hybrid network selection. If a network analysis is required, its composition is determined here.



The 10<sup>th</sup> interface screen

Output screen

There are numerous graphs that can be toggled through to provide a quick check as the validity of the results.

Data relating to specific technologies, pricing, fuel composition and end-uses is changed directly in the Microsoft Excel spreadsheets, primarily 'Engine'.



# Appendix C

## Case Studies

*This Appendix summarizes the data used for the three case studies*

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### C.1 Case Study 1 - Broad Overview

#### C.1.1 Load Profile Shape

Figure C.1-1 shows the individual load profile based on Profile Class 2. It is for a week day winter

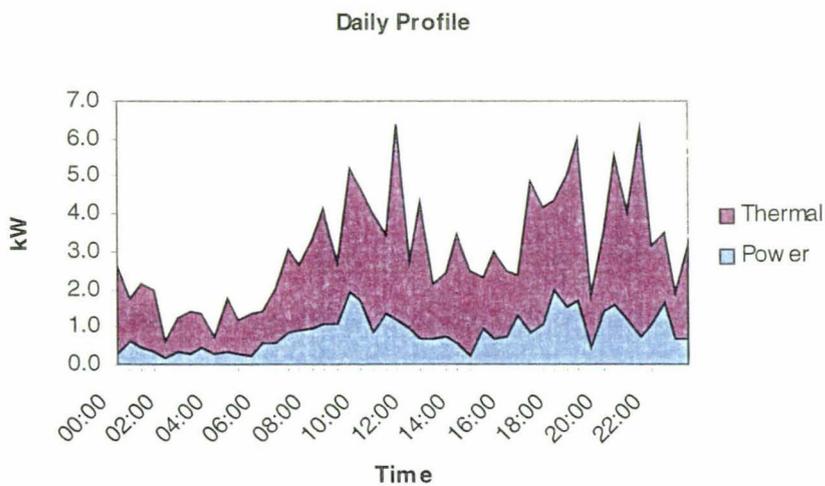


Figure C-1: Load Profile for Case Study 1

### C.1.2 Load Profile - Energy Provision

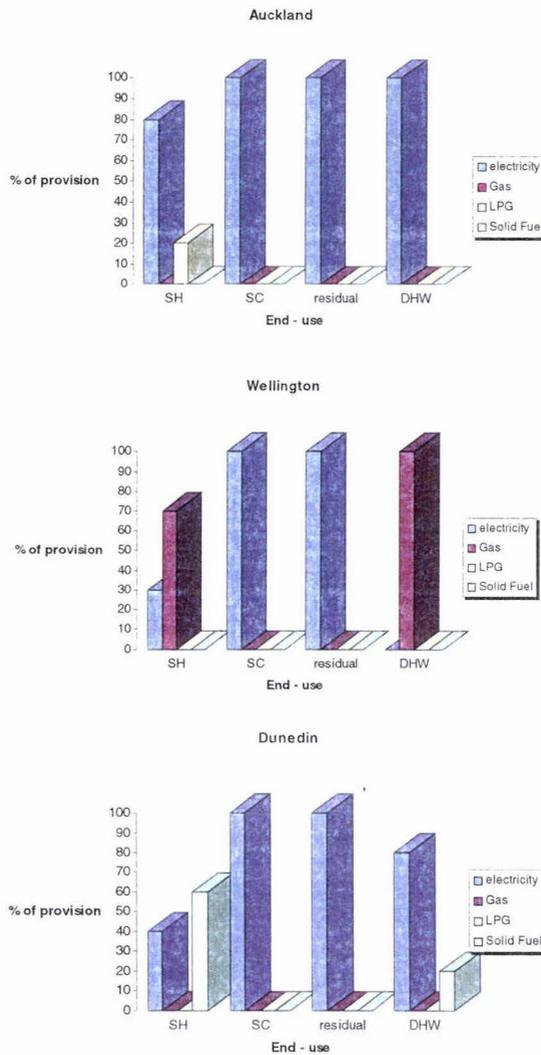


Figure C- 2: The 3 Houses and their Energy Provision used in Case Study 1

The three houses were chosen to have a fuel mix based on what you might find in a typical house in that region. The Auckland house had electricity as the dominant energy provider plus a small LPG heater to supplement space heating. The Wellington house had a reticulated gas connection supply a gas hot water cylinder and a large space gas heater. Conversely the Dunedin home had a solid fuel burner (including a wet-back).

### C.1.3 Load profile - End-use Efficiency

Thermal		Residual	
Electricity	90%	Electricity	100%
Reticulated gas	70%		
Solid fuel	30%		
LPG	70%		

Table C-1: Fuel Conversion Efficiencies

### C.1.4 Financial

Exchange rate	1NZD to USD	0.41
Discount rate	%	8
Period of analysis for NPV	Years	10

Table C- 2: Financial Parameters used in Case Study 1

The exchange rate is stipulated here to primarily convert capital costs of equipment into New Zealand dollar equivalents and to allow expansion of the model to incorporate the impact of the exchange rate on DG project feasibility.

### C.1.5 Climatic -Seasonal Lengths (months)

Table C-5 shows the seasonal lengths of the 3 regions used in Case study 1.

Season	Auckland	Wellington	Dunedin
Winter	3	3	4
Summer	3	3	3
Autumn	3	4	3
Spring	3	2	2

Table C- 3: Seasonal Lengths for the Main Centres in Case Study 1

As mentioned earlier the year is represented by 8 day different days. The relative weightings of these days are determined by the seasonal lengths that they relate to. This can be adjusted to simulate the impact of 'weather'. The data above was chosen to emphasise the difference in weather patterns between these major centres.

### C.1.6 Thermal Component Factor

Table C-5 shows the final values of TC used in the model.

Month	$TC_{DHW}$	$TC_{SH}$	$TC_{SC}$
July	0.04	0.96	0.00
August	0.06	0.94	0.00
September	0.11	0.89	0.00
October	0.23	0.77	0.00
November	0.42	0.58	0.00
December	1.00	0.00	0.00
January	1.00	0.00	0.00
February	1.00	0.00	0.00
March	0.99	0.01	0.00
April	0.37	0.63	0.00
May	0.09	0.91	0.00
June	0.04	0.96	0.00

Table C-4: Thermal Component Factors Used in Case Study 1

## C.2 Case Study 2 – Christchurch

Except for the following the same data for Case study 1 was used:

### C.2.1 Load profile - Energy Provision

Figure C-3 shows the fuel mix for the four end-uses for the house used in Case study 2.

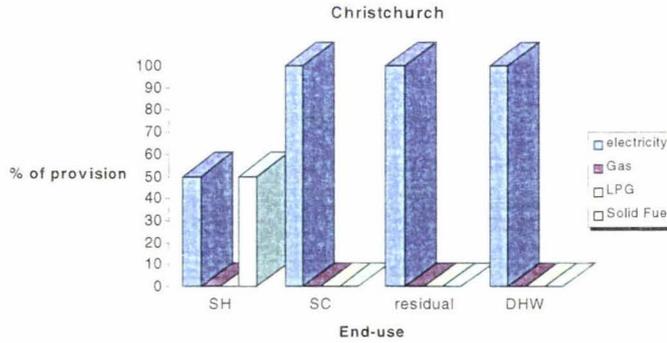


Figure C- 3: Make of Energy Provision for House in Case Study 2

In this case study 6 houses were modelled, corresponding to the permutations of three insulation levels and 2 (medium and large) size categories.

### C.2.2 Climatic -Seasonal Lengths (months)

Season	Christchurch
Winter	4
Summer	3
Autumn	3
Spring	2

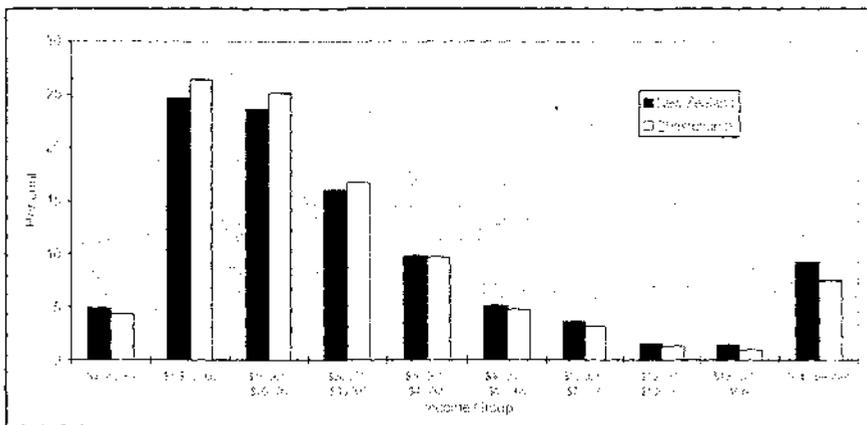
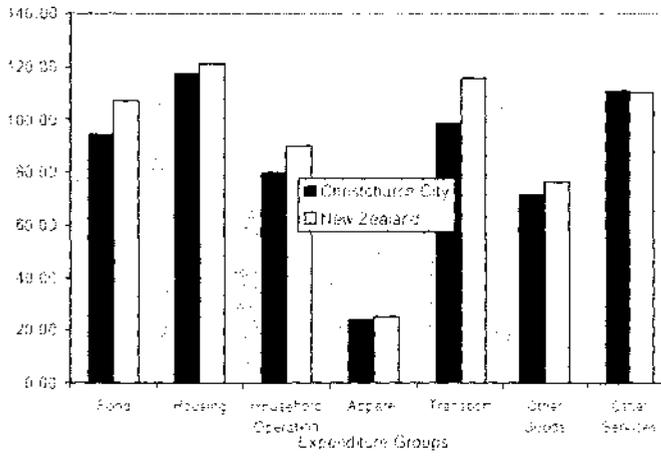
Table C- 5: Seasonal Lengths for Christchurch

### C.2.3 Other Data

Fixed electricity charges - \$200/yr

### C.2.4 Miscellaneous Figures

Figure C-4 shows how Christchurch compares with the rest of New Zealand in house hold expenditure, annual income and heating fuel.



Source: Statistics New Zealand, Census of Population and Dwellings, 1996

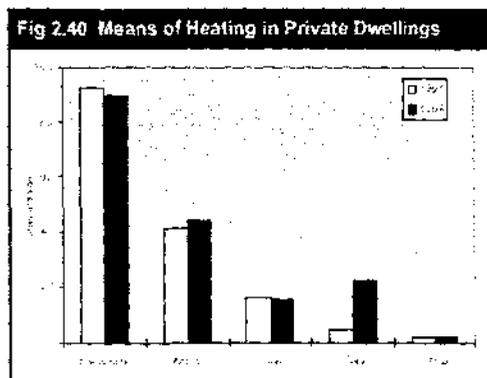


Figure C-4: Christchurch Housing Statistics

### C.3 Case Study 3 - Individual Parameters

Except for the following, the same data used in Case study 2 were used.

#### C.3.1 Load Profile Details

House description: Medium size house with retrofit insulation

#### C.3.2 Load Profile Class

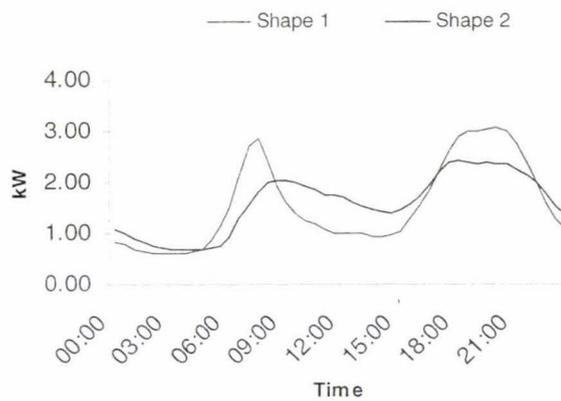


Figure C- 5: The 2 Profiles Classes Used in Scenario 1 & 2

Note that both shapes<sup>53</sup> have the same yearly consumption

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<sup>53</sup> Shape and class are used interchangeably

## C.4 Case Study 4 – Wellington Area Study

### C.4.1 Introduction

This case study is essentially a replica of Case Study 2 but with a fuel cell being the technology that was examined in the Wellington region.

Technology type: Fuel cell, operating in load following (heat) control

Load type: Large Wellington home with retrofit insulation.

### C.4.2 Load Profile - Energy Provision

This house in Wellington represents one that has a gas connection added to it for the purpose of perhaps replacing a solid fuel burner. This gas heater would provide half of the space heating requirements as shown in Figure C-6.

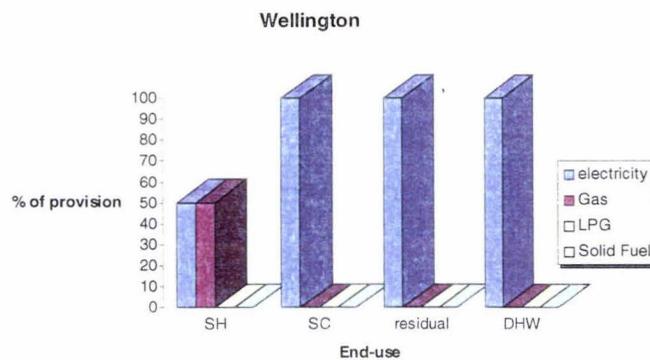


Figure C- 6: Energy Provision for House in Case Study 5

### C.4.3 Technology Specifications

Table C-5 shows specifications for the fuel cell used in case study 4.

Parameter		Value
Power output	[kW]	2
Heat output	[kW]	2
Usable heat	[%]	75
Fuel conversion efficiency	[%]	35
Maintenance	[event / hrs of operation]	8,000 (\$150)

Parameter		Value
Capital cost	\$	5,000
Installation cost	\$	500
Export electricity price	\$/kWh	0.0

Table C-6: Fuel Cell Characteristics Used in Case Study 5

This fuel cell is hypothetical and is sized at a more appropriate level for New Zealand houses than that considered in Case study 1.

#### C.4.4 Capital Cost

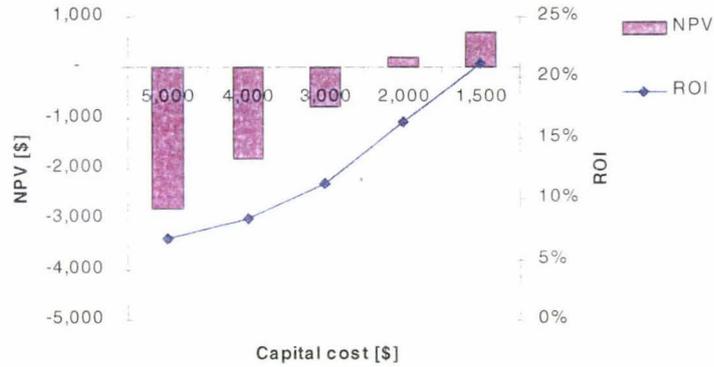


Figure C-7: Impact of Capital Cost on NPV and ROI

Capital cost is perhaps the dominant variable in terms of its impact on the profitability of most technologies. Figure C-7 shows the effect of decreasing capital cost from \$5,000 to \$1,500. This drop may not be realistic but the impact on the NPV is clear. A 70% drop in capital cost results in a NPV increase of 124%

#### C.4.5 CO<sub>2</sub> Tax

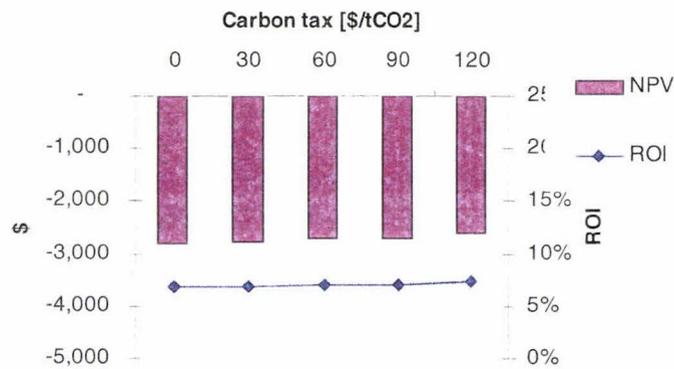


Figure C-8: Impact of Carbon Tax on NPV and ROI

As Figure C-8 shows, carbon tax has little impact on the overall profitability in this case. This is largely due to the gas consumed by the fuel cell. Whether this produces CO<sub>2</sub> or not is not important as the CO<sub>2</sub> is calculated on a fuel content basis and not on the type of energy conversion process.

#### C.4.6 Gas Price

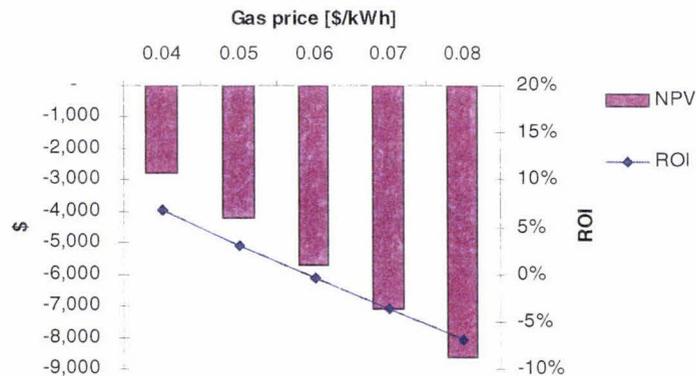


Figure C-9: Impact of Gas Price on NPV and ROI

Figure C-9 shows that a 100% increase in gas price leads to a 200% drop in NPV. Obviously this fuel cell operating in this regime is very sensitive to the price of gas. The fuel cell is sized small enough to be called to run over 84% of the time.

### C.4.7 Electricity Price

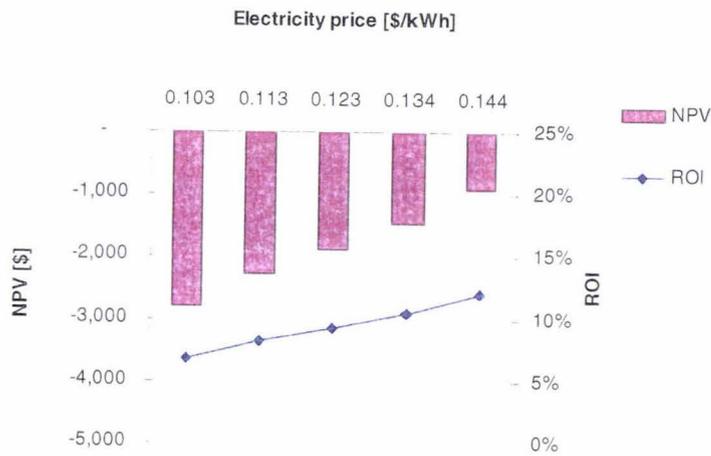


Figure C-10: Impact of Electricity Price on NPV and ROI

Figure C-10 shows a 40% increase in the price of electricity results in a 67% increase in the NPV. The impact of an electricity price rise is shielded somewhat by the 50% use of gas for the space heating requirements in the home.

### C.4.8 Load Size

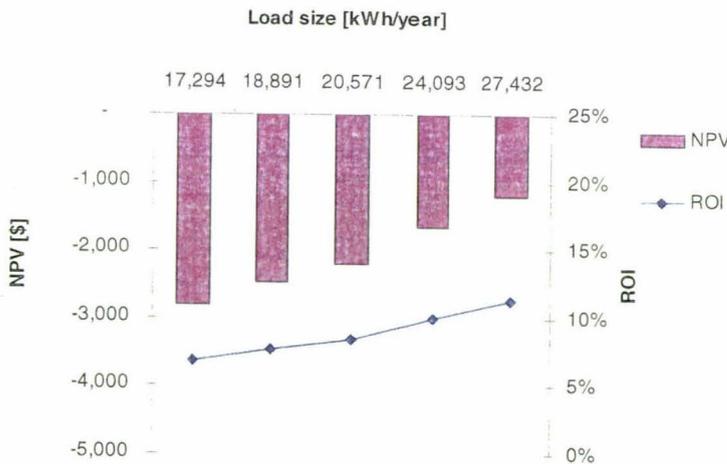


Figure C-11: Impact of Load Size on NPV and ROI

Figure C-11 shows that increasing the annual energy consumption by 58% had a proportionate increase in the NPV.

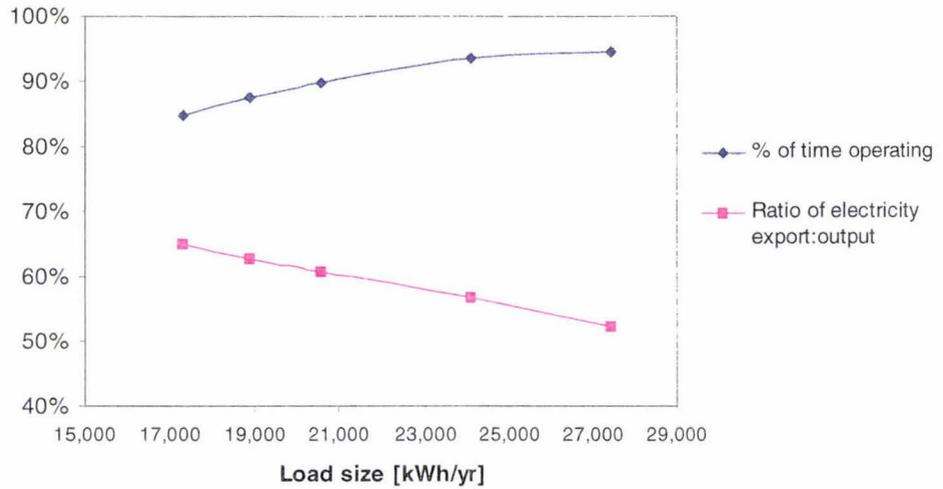


Figure C-12: Operating Characteristics of a Fuel Cell with Increasing Load

Figure C-12 shows that as the load size increases the 'fit' of the fuel cell becomes better. (i.e. it runs a greater percentage of the time). Another consequence of a larger load is that more of the power (residual) produced could be used on site and not exported. This only improves the NPV (as it does in this case) if the value of export is less than the value of imported power.

#### C.4.9 Discount Rate

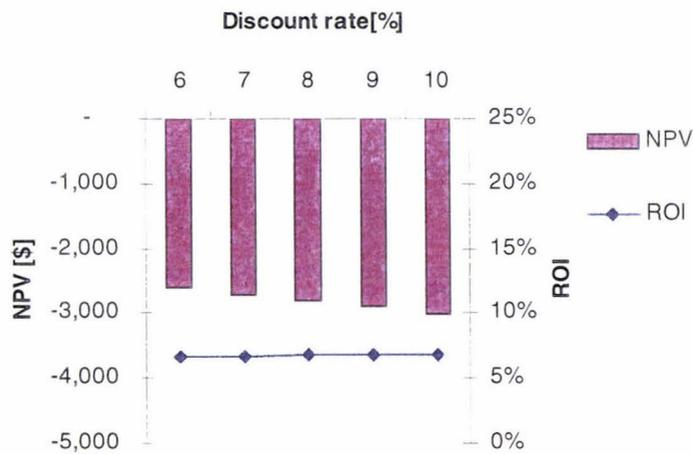


Figure C-13: Impact of Discount Rate on NPV and ROI

Figure C-13 shows that the effect of discount rates on NPV was minimal. Meridian Energy use a nominal post tax discount rate of 9.9% and a real post tax discount rate of 8%. If the NPV was being calculated for an individual household's perspective a slightly lower discount rate would generally be employed.

### C.4.10 Operating Efficiency<sup>54</sup>

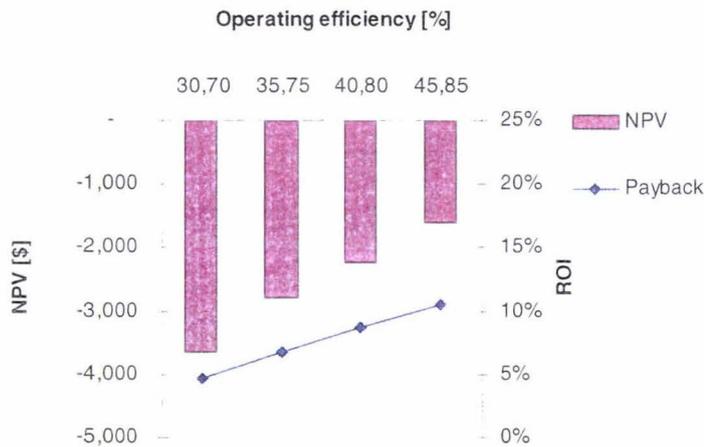


Figure C-14: Impact of Operating Efficiency on NPV and ROI

Figure C-14 shows the effect of a concurrent increase in both the fuel-to-power conversion and heat recovery efficiency. Obviously such a dramatic increase in efficiency is likely to occur in the foreseeable future. However the effect on NPV is large (for an efficiency increase from 30% to 35% LHV the NPV rises by 23%). Further analysis though is required to determine the appropriate relative weighting due to the thermal recovery and electrical efficiencies.

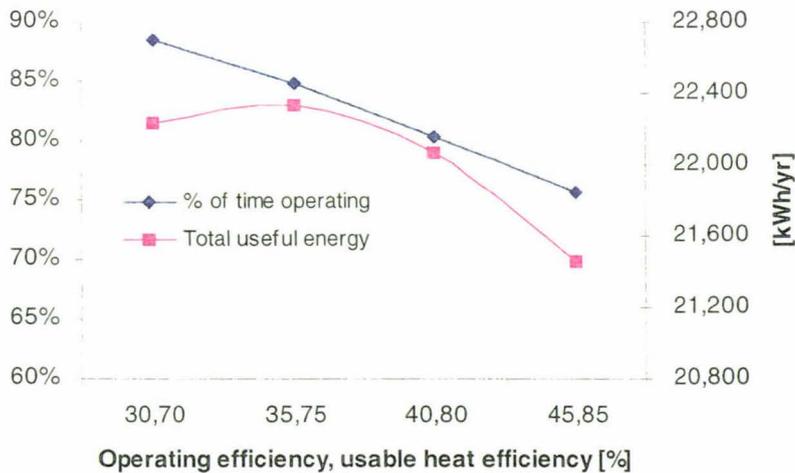


Figure C- 15: Impact of Operating Efficiency on Operating Time and Energy Output

Figure C-15 shows that the fuel cell actually operates a fewer number of hours as the operating efficiency increases. This is due to the higher effective thermal output, essentially creating a larger engine. Even though the engine runs less, when it does run there is a

<sup>54</sup> For example 30,70 refers to 30% [70] fuel to power conversion and 70% [7] use of heat produced

significant amount of more useful power and thermal output, meaning that overall the total energy supplied remains fairly constant (4% variation in kWh/yr). However it does suggest that for this particular house there is an optimum effective heat output (as impacted by operating efficiency). This though does not necessarily correspond to the highest NPV due to no value being obtained from exported electricity.

#### C.4.11 Profile Shape & Diversity

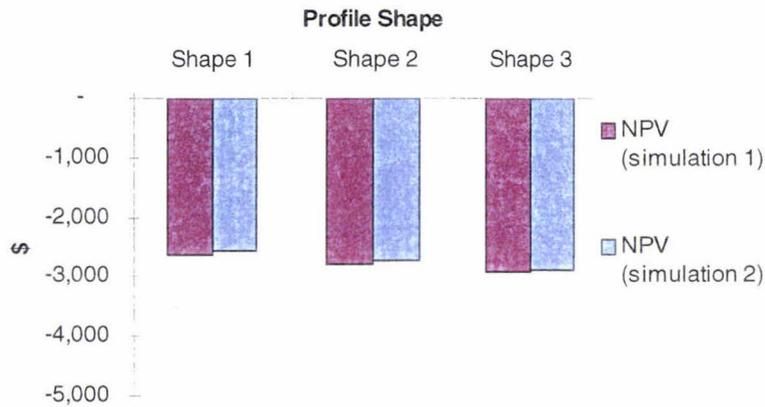


Figure C-16: Impact of Profile Shape Diversity on NPV

Figure C-16 shows how little sensitivity there is towards load profile shape<sup>55</sup> and diversity. This is not unexpected as the generic shapes are reasonably similar in the first place. The second series represents a second simulation and shows that uncertainty (diversity) has little effect.

#### C.4.12 Export Electricity Price

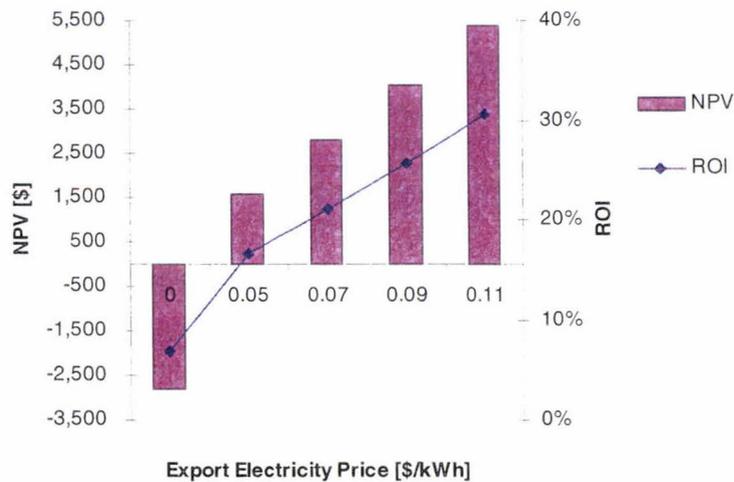


Figure C-17: Impact of Export Electricity Price on NPV and ROI

<sup>55</sup> Shapes 1-3 have an equal AEC

Figure C-17 shows that export electricity price has a significant impact on this proposition. The reason is that around 65% of the power generated is available for export, so naturally an increase in its value will lead to an improvement in the NPV.



## Appendix D

# Gamma Distribution

*This Appendix gives a graphical description of how the random number generator was used to generate a load  $[X]$  with a cumulative probability between 0 and 1.*

---

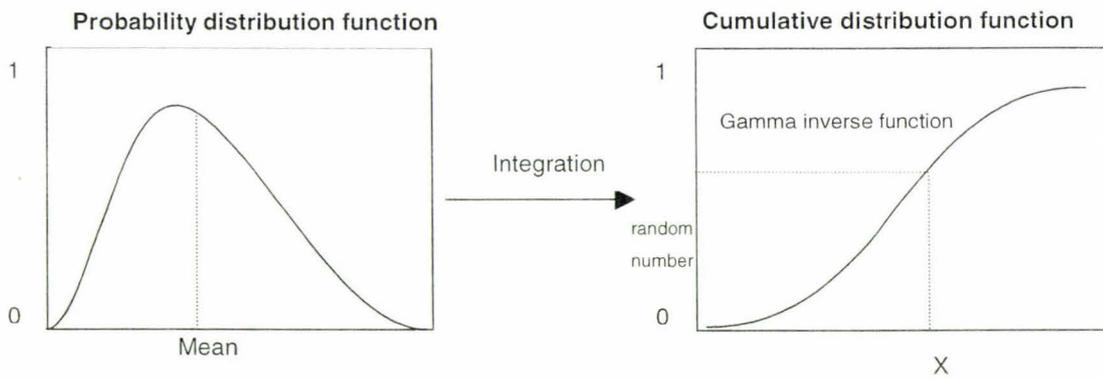


Figure E-1: Gamma Distribution

Figure E-1 graphically shows the process used to generate the random values that have a Gamma distribution. The Gamma function described in Section 7.9 uses a random number, generated between 0 and 1, to calculate a demand value.



## Appendix E

### Code

*A listing of the code that was written in the Visual Basic Editor is included as a Microsoft Word document (available on attached CD-ROM). The code was included as it is a significant aspect of this thesis. Not only in terms of the time spent writing and debugging the code but its intrinsic value, i.e. it is the physical representation of the conceptual development and implementation of the model.*

---



## Appendix F

### Presentation Work

*This thesis was conducted in a commercial setting and hence additional reporting and interaction with Meridian Energy was required that is outside the scope of a traditional academic criteria. This work was important though in maintaining the correct commercial direction in ensuring a result that could be used to add value to the business of Meridian Energy. Following is an example from a presentation given to the Knowledge and Innovation team at one of their planning days. Also included is a poster submitted for the annual TIF Awards.*

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# Distributed Generation

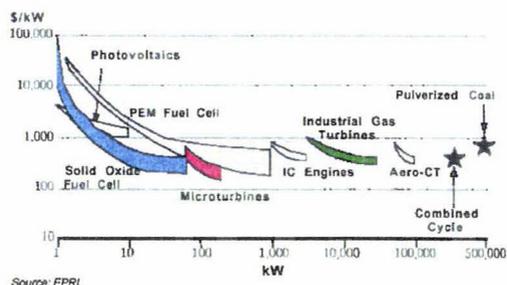
## Decision Support Software to Evaluate Opportunities in the New Zealand Market

Grant Redman

### What is DG?

- Generation:
  - Situated close to load
  - Embedded in the distribution network, or
  - On the customer side of the meter
- New term for an old way of providing energy
- Half all installed generation in NZ in the last 5yrs
- Energy provision including electricity + thermal

### Technologies: size vs cost



## DG Positives

Utilise low cost fuel  
Utilise gas line capacity  
CHP efficiencies  
Bundled energy solutions

### FACTORS AFFECTING THE UPTAKE OF DG

Environmental Issues  
Deregulation and privatisation  
Power quality  
New Technologies  
T&D upgrade costs  
Increased electricity demand

## Project Objectives

- Explore: Combinations of DG technologies  
Different operating regimes  
Future scenarios
- "To identify which technology blends best fit the NZ residential market's requirements"
- Solution focused and not 'technology vendor' focused

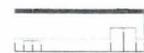
## Scope



- Single dwelling mass market residential



- Neighbourhoods & apartment complexes



- Small business & commercial

## DG for buildings

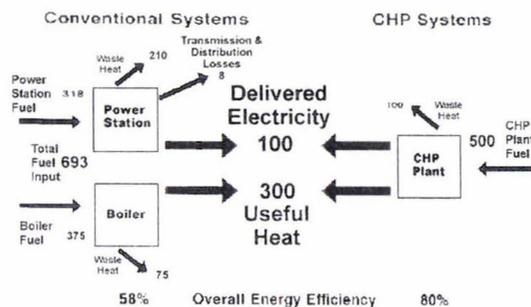
**“Shift in paradigm of energy supply leads to new opportunities if prepared to embrace innovative technologies and approaches”**

**Value for building owner, occupier**



**Total energy provision  
Cost benefit  
Green and premium power  
Increased comfort levels**

## Combined Heat & Power



## Residential market - Growing opportunity

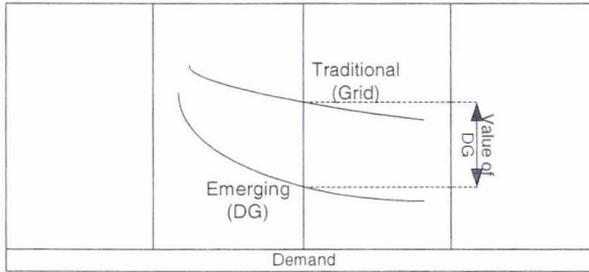
- 13.3% of consumer energy in NZ (57 PJ)
- 35% of electricity generated in NZ (39 PJ)
- 22% stock increase (estimated number of households):
 

2001	1,377,000
2021	1,676,000
- Sector energy increase '91 to '99
 

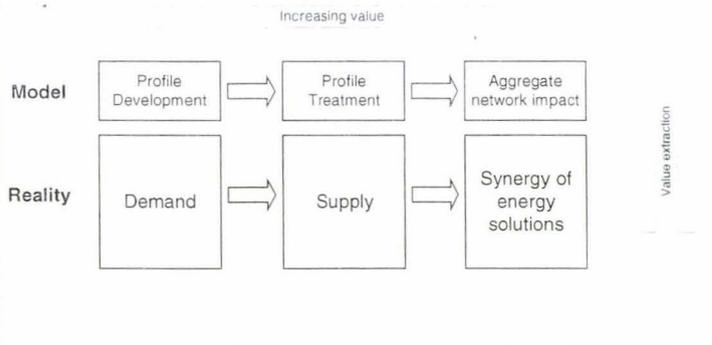
Residential	7.3%
Industrial	-2.92%
Commercial	-0.52%
- Lowest space heating intensity of 13 OECD studied

## Supply vs demand

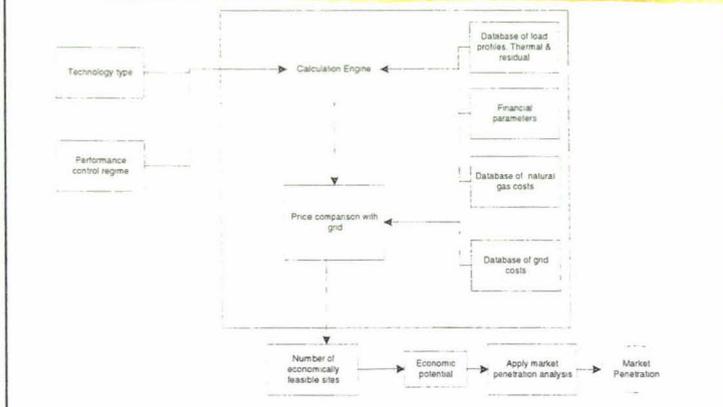
Cost of meeting demand



## The value of DG

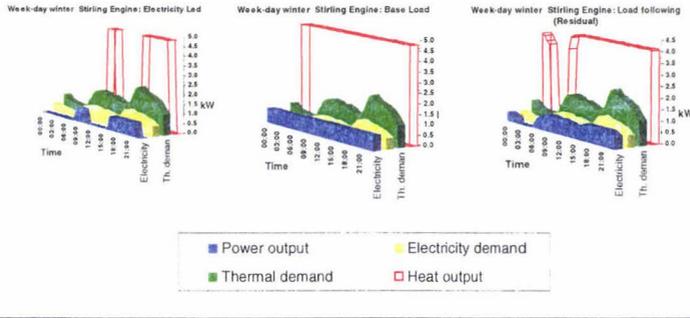


## Project Environment- overview



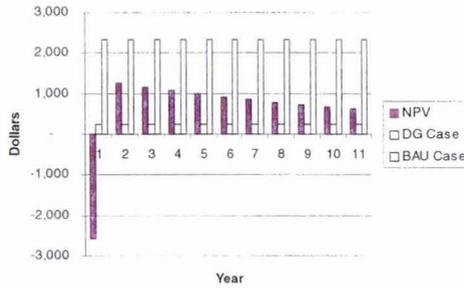
# Operating Regimes

- Peaking mode heat/electricity led
- Base load
- Load following heat/electricity led

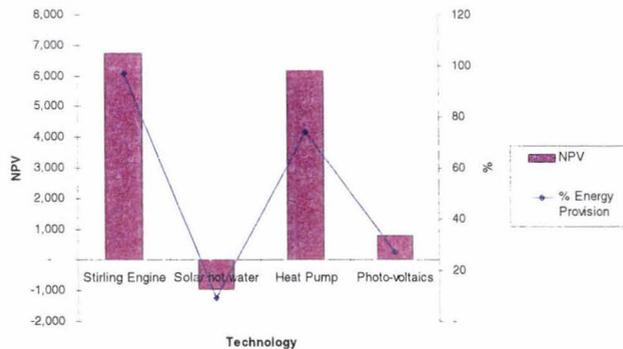


# Cash flow

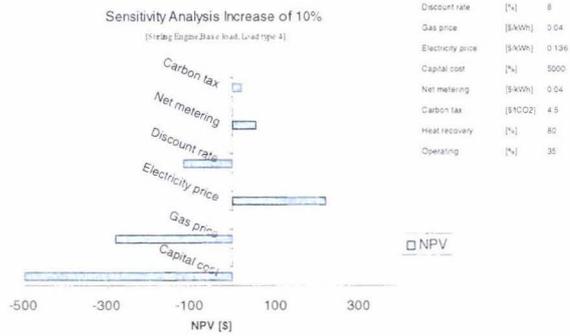
Week-day winter Stirling Engine: Base Load



# Technology comparison



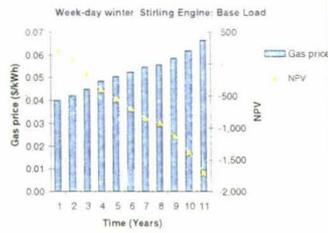
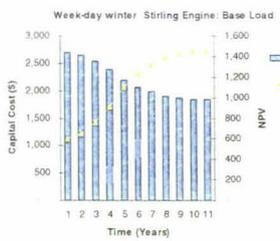
# Sensitivity Analysis



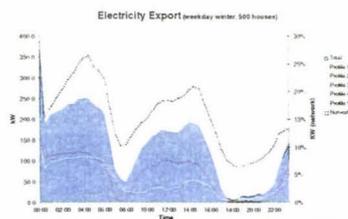
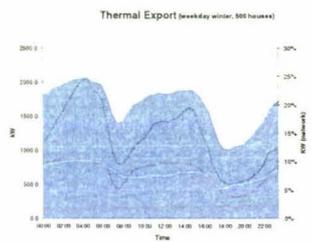
# Projected costs

■ Capital cost decrease

■ Gas price increase



# Network Impact Stirling Engine: Base load (20% penetration)



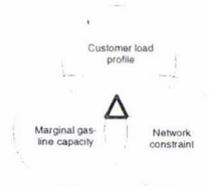
## MEL's investment in DG

- New technology development fund (CFCL, Whisper Tech, Nth Power)
- CHP applications through Meridian Solutions
- Network capacity alleviation
- Developing a DG strategy

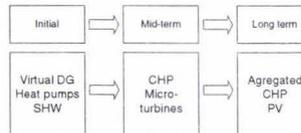
Next step?

## Way forward

- Identify opportunities



- Establish an energy provider presence

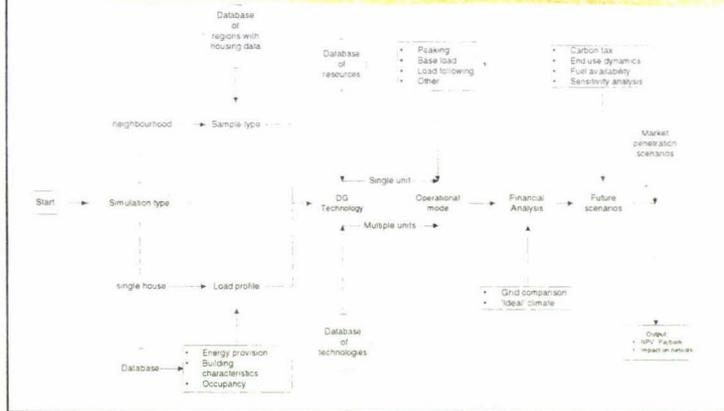


## Project benefits to MEL

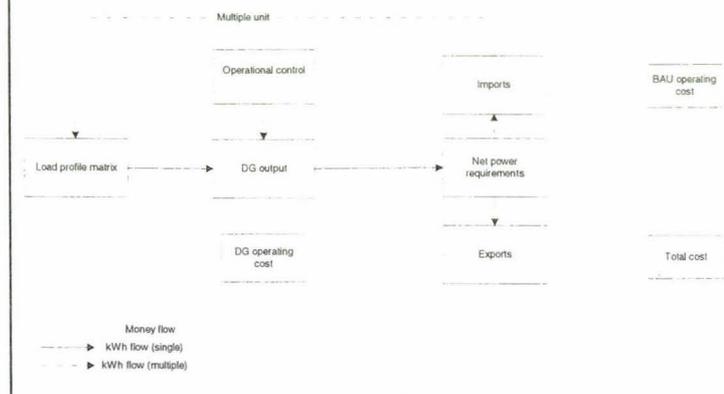
- Identify which regions in NZ are suitable for particular technologies
- Identify the capital cost entry point for certain technologies
- Examine the effect of regulatory regimes such as CO<sub>2</sub> levies, green pricing schemes on the feasibility of DG
- Examine the effect of changing demand patterns e.g. trend towards increase in space heating
- Identify 'smart' operating regimes to maximise benefit of DG
- Energy management -project evaluation for MS

# Comments & questions

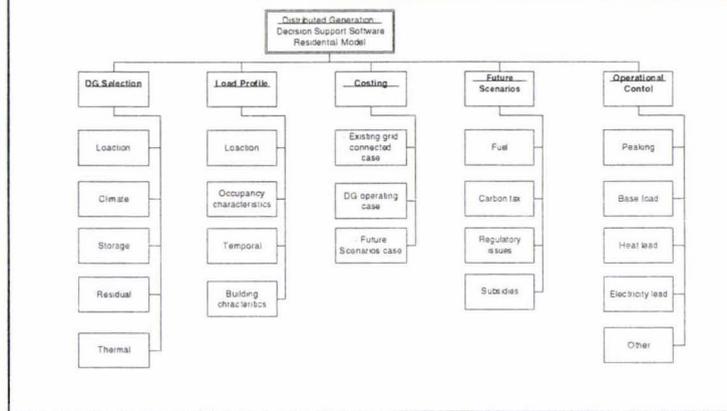
# How it works



# Calculation Engine



# Modules



# DISTRIBUTED GENERATION



Distributed Generation [DG] is a new term for an old way of delivering energy to end-users. A shift in the paradigm of energy supply leads to new opportunities if we are prepared to embrace innovative technologies and approaches. Meridian Energy are poised to take advantage of this new way of providing energy to its customers. A total solution to a customer's power, heating and cooling requirements will be the domain of 'smart' generating units and control systems.

**WHAT IS DG?** DG is the generation of energy (electricity and heat) that is sited close to the load source. It can be embedded into the distribution network or on the customer side of the meter. DG technologies are often leading edge and include renewable technologies. Some produce either electricity or heat and store both.

**PROJECT BACKGROUND** Meridian Energy is both a generator and retailer in the NZ electricity market. Their main generation capacity is located in the South Island in the Waitaki hydro systems and the Mangonui power station. They have a relatively small customer base that, apart from Tokelau, is remote from its generating base and on the other side the HVDC link, a major

transmission constraint. This, combined with predicted load growth being mainly in the North Island, means that Meridian is exposed to significant transmission and distribution costs and runs the risk of becoming a 'stranded generator'. Meridian's customers are primarily price-driven and DG technologies offer Meridian an innovative way to minimise transmission and distribution costs. Strategic placement of generation capacity can overcome cost penalties incurred in supplying energy to specific locations within local electricity grids. It will allow Meridian to decrease costs associated with the delivery of electricity to customers through expensive transmission and distribution networks thus giving Meridian a greater capacity to both retain its present customers and acquire new customers.

**PROJECT SCOPE** The title of the project is Distributed Generation Decision Support Software to Evaluate Opportunities in the Residential Market. The primary focus is on the production of a 'smart' model that would allow for the determination of the best technology, blends that best fit the market's requirements, i.e. solutions focused.

**COMBINED HEAT AND POWER (CHP)** CHP is often associated with DG applications. It involves the simultaneous production of both electricity and heat. Since DG is sited close to the load, it allows for the use of this heat for industrial processes or water and space heating in the home.

**PHOTO-VOLTAIC (PV)**

Each day, more energy falls onto the earth from the sun's rays than the total amount of energy that the planet's entire population would consume in 27 years. Despite their presently high costs, advances in micro-inverters and PV integrated roof tiles are increasing their use for domestic housing.



**SOLAR HOT WATER HEATER (SHW)**

Using the sun's energy to heat your hot water can save between 50% and 85% annually in your electricity bill. A collector mounted on your roof-top absorbs solar energy to heat your hot water directly in an open system or indirectly in a closed loop system.

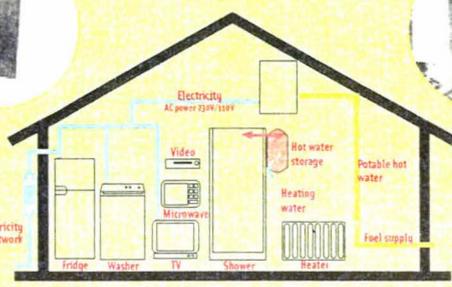


**Heat pumps**

Heat pumps are the essential device to redistribute solar energy. It uses solar heat stored in either the ground or ambient air and delivers the heat next to the load. As their technology improves, their characteristically high operating efficiencies (between 120% to 500%) could be felt by more and more residential customers.

**RECIPROCATING ENGINES**

Traditional diesel engines are giving way to gas fired units that require less maintenance and have far reduced emission levels. Given their already established support infrastructure these engines may be the lead in technology for DG, although possibly in industrial settings and operating in peaking mode.



**FUEL CELLS**

Fuel cells use an electro-chemical reaction to produce both electricity and heat. Since there is no combustion, emissions are extremely small making the ideal for high-density urban housing.



**STIRLING ENGINE**

An external combustion engine based on the Stirling cycle. These low maintenance engines can run on virtually any heat source and are being developed commercially around the world, notably including New Zealand's own Whisper-Tech.

What issues are we interested in examining. They include:

- \* Identifying which regions in NZ are suitable for particular technologies
- \* Examining the effect of regulatory regimes such as CO2 levies, green pricing schemes on the feasibility of DG
- \* Examining the effect of changing demand patterns e.g. trend towards increase in space heating
- \* Identifying 'smart' operating regimes to maximise the benefit of DG

**PURPOSE**

The purpose of this project was to examine the value proposition of residential buildings with respect to the provision of their energy requirements. This meant approaching both the demand side and supply side of the equation. Ways in which to extract this value needed to be identified and a process developed to assess the magnitude of them. Demand side measures include demand side management and supply side relate to energy provision, either the traditional grid or a DG unit. Residential DG is possibly a number of years away and as such, an important objective of the model development was to ensure that it could simulate future trends.

**ACHIEVEMENT**

The tangible product developed was a software based decision tool. It consists of a series of Microsoft Excel files controlled by Visual Basic for Applications code. It was built in a generic and modular fashion to enable future upgrades to certain modules to allow for more in depth analysis of demand and supply side issues. In addition there is a user friendly interface to allow for easier operation of the model. Simulations can be run on two levels:
 

- single house - hold
- neighbourhood / apartment block

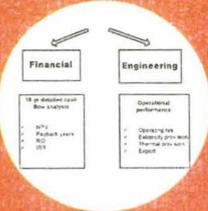
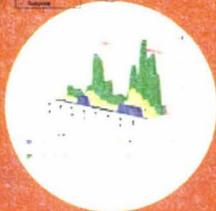
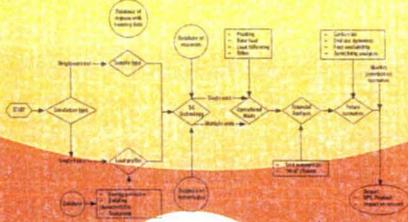
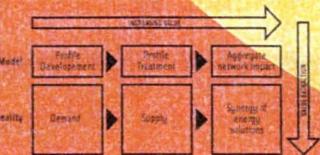
 There is both a financial and engineering component to the model's output.

**BENEFITS**

The benefits to Meridian Energy were a qualitative description and a greater understanding of the issues facing the residential market and a means of quantifying them. This all goes to helping to develop a successful DG strategy by predicting future trends both in technology and demand patterns and being able to position themselves to take maximum advantage. The residential market is a growing opportunity:
 

- 22% increase in the number of households in the next 20 years
- 13.3% of consumer energy in NZ (\$7 PJ)
- 35% of electricity generated in NZ (\$9 PJ)

 By using the model to run various scenarios, what technologies, where in New Zealand and when they will become economically viable can be predicted and used to give Meridian the competitive advantage to capture more of this opportunity.

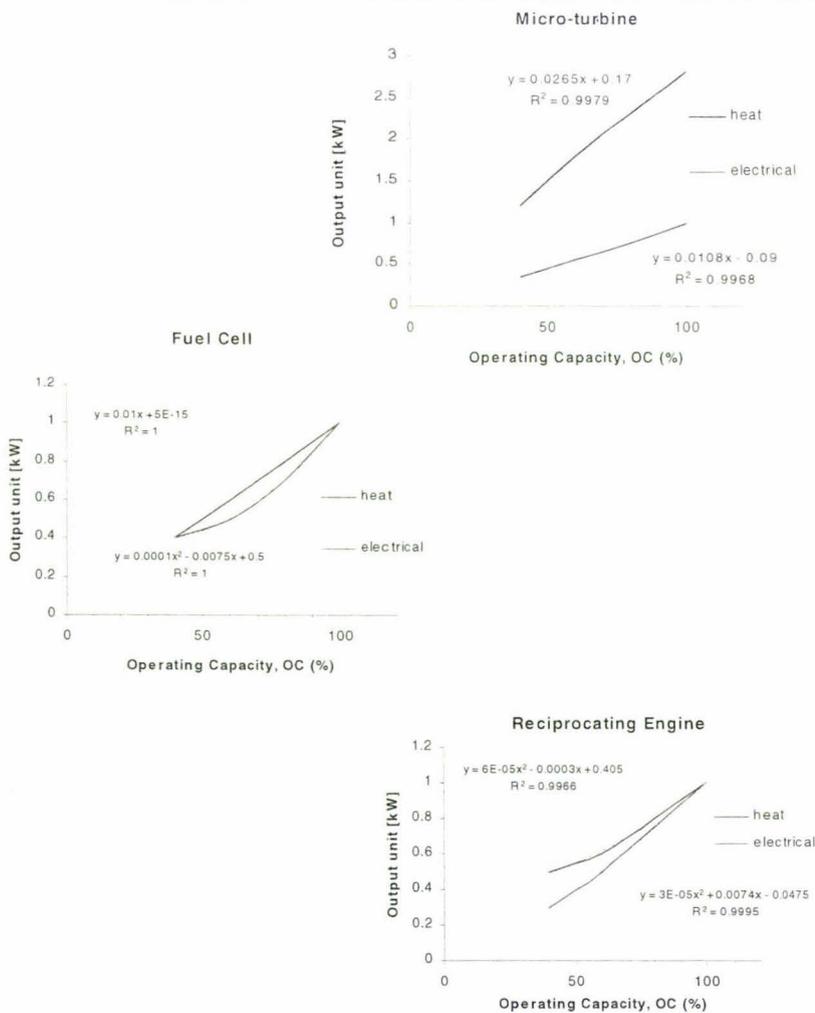




# Appendix G

## Performance Curves

The performance curves shown below are used to calculate the heat and electrical output for the heat engines when operating in a load following manner. Note the corresponding partial loading curves are not shown.





## Appendix H

# ALF Simulation

*This appendix gives the parameters for the ALF simulation. The simulation was used to obtain scaling factors for the load profile development module.*

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Category	Default	Insulation			Location				Size			
		A	B	C	1	2	3	4	Small	Medium	Large	
Climate and Heating	Climate	Lower Nth Island				Upper Nth Island	Lower Nth Island	Upper Sth Island	Lower Sth Island			
	Heating Schedule	Morning & evening										
	Heating level [°C]	16										
Floors	Area [m <sup>2</sup> ]	110	Un-insulated timber floor	Suspended timber + perforated foil (sag 50mm)	Lining with draped foil					55	111	165
Walls & windows	Orient.	N										
	Height	1.5								1.5	1.5	1.5
	Construct R	1.47	1.2	1.47	1.93							
Roofs & Skylights	Length	2								1	2	4
	Width	22								15	22	24
	Construct R	5								4	5	7
Air leakage	Average, medium sheltered	2.10	0.5	2.10	2.10							
# of occupants	[m]	3								2 (2)	3x-6 (4)	3-6 (6)
Room height	[m]	2.4										
Thermal mass	Exposed timber [m <sup>2</sup> ]	floor %	100	50	0							
Heating	[kW/yr]		3620	2992	2424	2608	2698	2992	5836	1408	2893	4425
<u>Relative heating</u>			<u>1.29</u>	<u>1</u>	<u>0.84</u>	<u>0.9</u>	<u>0.9</u>	<u>1</u>	<u>1.95</u>	<u>0.21</u>	<u>1</u>	<u>1.48</u>

Table I- 1: Values of the Parameters Selected in the ALF Model