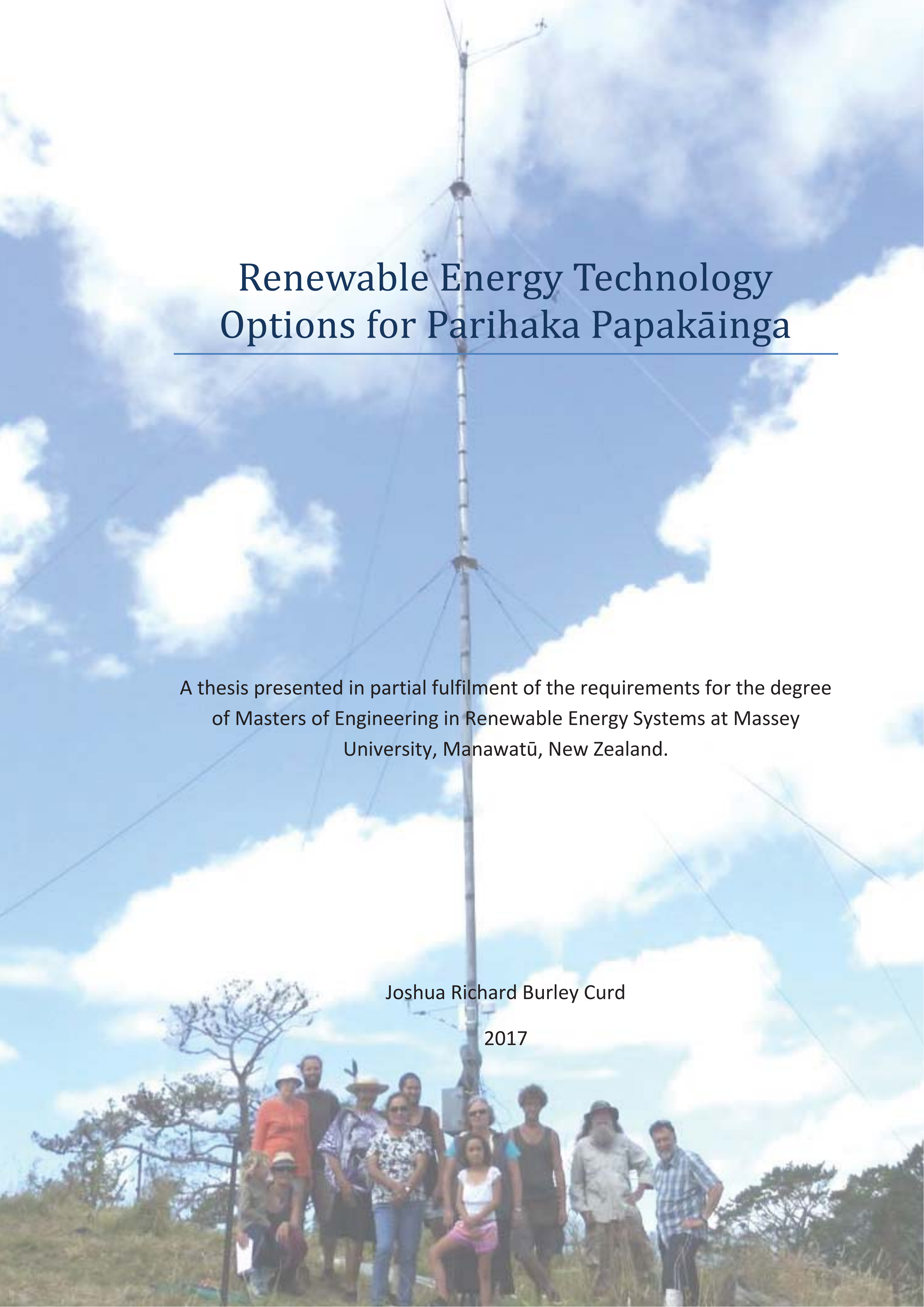

Renewable Energy Technology Options for Parihaka Papakāinga

A thesis presented in partial fulfilment of the requirements for the degree of Masters of Engineering in Renewable Energy Systems at Massey University, Manawatū, New Zealand.

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Abstract

The Parihaka Papakāinga Trust - the administering body of communally owned Māori land at Parihaka, Aotearoa New Zealand - initiated university research into sustainable energy practices and technologies within a context of community and infrastructure development. As one part of this wider research topic, various renewable energy conversion technologies were compared in terms of cost, effect on increasing the energy independence of the papakāinga (excluding transport, covered elsewhere), and reducing papakāinga greenhouse gas (GHG) emissions.

Consumption of electricity, LPG and firewood was assessed in 14 study buildings over 12 months. Energy demands both now and also for hypothetical scenarios 20 years in the future were proposed, taking into account energy efficiency opportunities, low energy housing design and potential electric vehicle charging loads from parallel research.

The local solar, wind and hydro potentials were assessed over 12 months, and estimations of the long-term resources were made using long-term reference data from the region. An estimation was also made of land area requirements to support a short rotation coppicing (SRC) fuelwood plantation.

The technical and economic performance of a range of electricity and heat generation technologies was modelled, both on an individual building basis and on a community-wide basis.

The technologies with the largest expected economic benefits (after energy efficiency and building design) were a grid-connected community solar PV array with output available for consumption by as much of the papakāinga as possible, and wood-burners for space and water heating in new homes. However further study is required into the design and costs of a feasible metering and billing solution to allocate the benefits of community owned distributed electricity generation.

The technologies with the largest expected effect on energy independence include combining solar water heaters with wood-burners and wetbacks for space and water heating, and producing firewood locally with an SRC plantation.

Based on the household study, transport behaviours or technologies are expected to have a larger effect on GHG emissions than papakāinga infrastructure.

Recommendations include a billing/metering feasibility study potentially followed by a community PV array, an SRC trial, and solar water heaters and wood-burners with water heating for new homes.

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I would also like to acknowledge that the conclusions and recommendations here fall far short of the vision of self-sufficiency at Parihaka, but hope that they inform some initial practical steps as part of a larger journey in that direction.

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1. Introduction

This thesis forms one component of a larger research project named *Taiepa Tiketike*, which has been undertaken as a partnership between the Parihaka Papakāinga Trust and Massey University, funded by the New Zealand Ministry of Business, Innovation and Employment (MBIE). The Parihaka Papakāinga Trust (PPT) administers the Parihaka papakāinga, a home village on communally owned Māori reservation land. *Taiepa Tiketike* was formed to investigate opportunities for incorporating sustainable energy technologies and practices into the papakāinga.

For the complete findings of the *Taiepa Tiketike* project, refer also to:

- Energy Efficiency Gains in the Parihaka Community (Hernandez Pacheco, 2016).
- Low Energy House Design for Parihaka (Lambert, 2015).
- Low Carbon Transport Options for Residents of the Parihaka Papakāinga (Mohan, 2016).
- Opportunities and Barriers to, and Benefits and Impacts from Papakāinga Owned Energy Systems: A Case Study of Parihaka (Quinn, 2017).

Within this wider project, this study provides technical and economic comparisons between various renewable energy conversion technologies which may be of benefit to Parihaka.

1.1. Background Information

Parihaka is located in the rural South Taranaki district of New Zealand, and was formed in the 1860s as a Māori settlement with an ideology and practice of peace and non-violence as a response to the New Zealand wars. Various historical reasons triggered the decline from a thriving self-sufficient community of thousands to its current much smaller and more dependent situation. However Parihaka as a community and as a philosophy has not ceased to exist, and there is at least one precedent of significant papakāinga restoration by those who supported the vision of Parihaka (including innovative street lighting powered by hydro-electricity by 1899 ("Parihaka To-day", 1899)). Planning is now underway to once again achieve aspirations of a vibrant and thriving papakāinga.

The reservation land is currently limited to around 20 hectares (Fig. 1), however much of the surrounding land is part of a farm associated with Parihaka.

During the course of research the population fluctuated significantly and continues to vary with usage of family homes, but at the time of writing is approximately 50. For the purposes of this study, homes south of Parihaka Rd (Fig. 1) were not included in the energy demand. The number of residential dwellings north of Parihaka Rd which were permanently occupied also varied, but at the time of writing is thought to be 11. Other buildings are used on an occasional basis, or are awaiting papakāinga infrastructure and services development prior to permanent occupation.

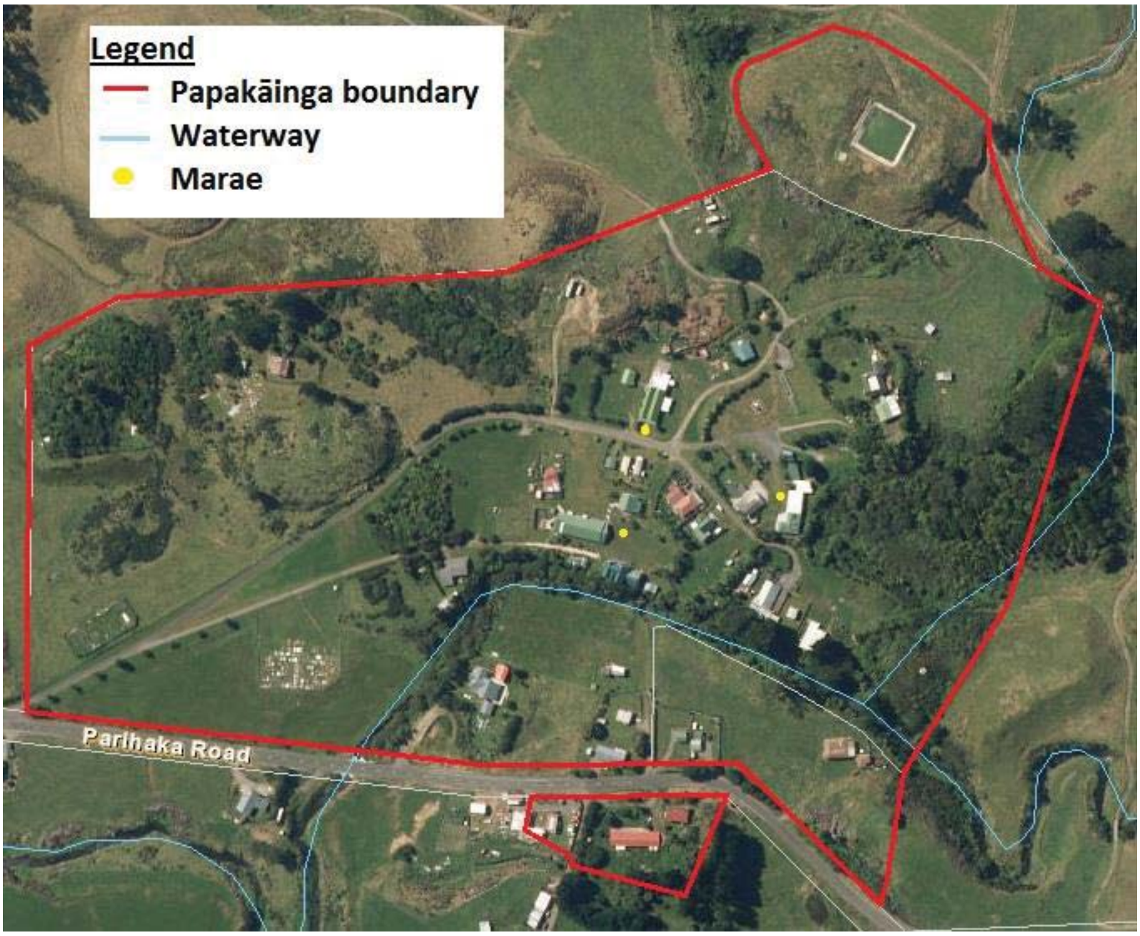


Figure 1: Current papakāinga boundaries[1]

There are three active marae at Parihaka: Toroanui (including Te Mahi Kūare meeting house and Te Rānui dining hall), Parāhuka (including Te Niho o Te Atiawa building), and Takitūtū (including Te Paepae o Te Raukura building). Another building, Te Whare Whakaruru, sees intermittent use as office and meeting space.

The current energy supply is a mix of grid electricity, bottled LPG, and firewood. Transport fuels are petrol and diesel. Liquid petroleum gas (LPG), a blend of butane and propane gases, is delivered in 45 kg capacity cylinders to buildings at Parihaka by truck as required. In some cases residents own 9 kg capacity cylinders which they take elsewhere to refill. Firewood is typically found from within the papakāinga or the nearby surrounds and processed at home.

The electricity supply to Parihaka is from a rural 11 kV supply which also services other nearby residential and farming properties (Silk, 2012). The papakāinga is bisected by the Waitotoroa river, and each side of the river is supplied by a different distribution transformer on the feeder. Those south of the river are supplied by a 50 KVA transformer (Chisholm, 2016). The north side of the river where most buildings are situated (Fig. 1), was supplied by a 50 kVA pole

[1] Reproduced from http://apps.geocirrus.co.nz/HTML5/Index.html?viewer=trc, accessed December 2016

mounted transformer at the start of the research. This was at capacity due to community peak loads, however has since been replaced by a 100 kVA pad mounted transformer.

Energy use within the papakāinga (i.e. excluding transport without) is dominated by typical daily residential energy use within homes, and the fluctuating energy use patterns of community facilities. Energy use of the marae in particular is characterised by periods of dormancy (where predominant energy use relates to refrigeration) punctuated by hui with high energy needs (related to catering and hospitality, often for hundreds of visitors). For example, on the 18th and 19th of every month the three marae are venues for Te Rā o Te Whiti o Rongomai and Te Rā o Tohu Kākahi – well attended days of discussion of matters pertaining to Parihaka which have been held uninterrupted for over 130 years.

1.2. Sustainable Energy for Community Development

The Parihaka Papakāinga Trust (PPT) is in the process of planning infrastructure to cope with significant potential population growth. Advisors have been providing input into this based on a planning scenario of 5-10 new homes being built each year over the next 20 years (Gawn, 2016).

The PPT commissioned the report *Parihaka Whakamua Parihaka Pūmou: Future-proofing Parihaka* to document papakāinga needs. This report conceptualised Parihaka community development in terms of the legacy laid down by the founders of the Parihaka papakāinga and movement, Tohu Kākahi and Te Whiti o Rongomai: a legacy of collectivism, empowerment and development with a vision of sustained and mutual peace (Ratima, 2015). This identified that renewable energy (RE) aligns with this legacy in many ways, including:

- being a community-based initiative which promotes collectivity, sustainability, self-sufficiency and innovative practice;
- providing education, training and employment options;
- providing an international example of community RE systems and raising visitors' and schools' awareness of RE;
- creating positive community action, tikanga (practice) and reo (language); and
- supporting environmental protection.

Although there are many expected benefits to sustainable energy technologies and practices at Parihaka - and many potential technologies and practices - the scope of this thesis is restricted to a few specific technologies, one social benefit and one environmental benefit: primarily increasing energy independence (by reducing the importing of energy) and also reducing greenhouse gas emissions.

1.3. Problem Statement

Although the uptake of sustainable energy technologies and practices has been clearly identified as a community development project which enhances the legacy of Tohu and Te Whiti, the problem is that details surrounding which mix of currently available technologies would be best to implement is not clear. This is because energy needs and renewable energy resource availability are very site and situation specific, and the Parihaka situation has not previously been quantified.

Comparisons between technologies depend on community preferences, local climate and geography, current technology costs (which can change rapidly) and technical limitations to RE penetration into the current supply mix. Community preferences to various technologies were analysed by Quinn (2017), and are not covered here.

The overall aim was to identify which renewable energy technologies might be most cost effective at increasing the energy independence (and reducing the greenhouse gas emissions) of Parihaka papakāinga.

The specific objectives of the study were to:

- assess energy use (excluding transport) within the papakāinga over 12 months;
- assess the solar, wind, hydro and biomass energy resources available at the papakāinga location over 12 months;
- develop two hypothetical scenarios for energy demand in 20 years time, incorporating findings from parallel research projects investigating:
    - opportunities for energy efficiency gains in the existing infrastructure,
    - low energy housing design for future infrastructure, and
    - sustainable transport systems;
- model the expected performance of various combinations of renewable energy conversion technologies (both now and in 20 years' time);
- evaluate:
    - the expected net present cost to the papakāinga over 20 years (based on approximate rather than detailed prices),
    - the expected percentage reduction of energy imports to the papakāinga, and
    - the expected percentage reduction of GHG emissions; and
- propose the most cost effective ways to reduce imports of energy (and reduce GHG emissions), taking into account potential population growth of the community.

1.4. Literature Review

Renewable energy is a topic of interest within many Māori communities; however academic literature is not necessarily the first port of call to keep abreast of developments. Some examples of proposed or existing renewable energy projects in Māori communities mentioned in the literature include:

- commercially growing Micanthus grass for liquid biofuel production (Tainui) (Bargh, 2014);
- building a wind farm at Kawhia harbour (Taharoa C Trust) (Bargh, 2014);
- various geothermal or wind farm joint ventures between state owned enterprises and Māori organisations (Bargh, 2014);
- Māori owned geothermal power stations (Tuaropaki Ahu Whenua Trust) (Bargh, 2014);
- investigating biofuel production options (Maniapoto Trust Board) (Bargh et al., 2014);
- investigating insulation, solar and methane biogas production from farms (Hauraki Māori Trust Board) (Bargh et al., 2014);
- energy efficiency education programmes (Hauraki Māori Trust Board, Ngātiwai Trust Board, Ngāi Tahu ki Murihiku, Ngāti Whakaue ki Maketu) (Bargh et al., 2014);
- investigating sustainable transport alternatives (Ngāi Tahu ki Murihiku) (Bargh et al., 2014);
- a micro-hydro powered Marae (Ngāti Kea/Ngāti Tuara) (Ford-Robertson & Lawley, 2014); and
- proposing a forestry-based biofuel industry, as Māori are significant owners of forestry assets in New Zealand (Steer, 2015).

Some of the points of difference between renewable energy projects within Māori communities and other renewable energy projects – but not unique amongst indigenous peoples – are mentioned by Bargh (2014). These include collectively owned assets; the enabling role of mahi aroha or volunteering; a concern that international demand for fossil fuel resources is driving oil exploration (particularly hydraulic fracturing) in their areas; and the number of Māori living in rental accommodation making it difficult to invest in energy saving technologies.

Bargh et al. (2014) suggested that many tribal organisations are now transitioning to becoming producers of their own food and energy needs as a response to specific local resources and contexts. They aligned this change to the call by Winona LaDuke (as cited in Bargh et al., 2014) to First Nations in America to develop "sustainable tribal economies" where energy and food are produced for local consumption and sale.

They also draws the distinction between renewable energies in general and renewable energy which fits appropriately with other Māori values, citing the example of Te Uri o Hau objecting to tidal turbines within the Kaipara harbour due to the intrinsic value of the harbour ecosystem (Bargh, 2014). Examples of opposition by indigenous peoples to renewable energy projects which do not align with indigenous values are found in the international context as well, such as the protest by the Saami people (on the grounds of resource sovereignty) against the Swedish state facilitating proposed wind farm development in traditional areas (Lawrence, 2014). The supposed “greater good” of renewable energy technologies was considered by the wind power industry and Swedish government to take precedence over traditional reindeer herding practices.

The use of renewable technologies by indigenous communities in general is more widely covered in the literature. Examples include:

- biomass combined heat and power, biomass heating , solar PV, solar water heating, and run-of-river micro hydro energy supplies for remote First Nation communities in British Columbia, Canada (Rezaei & Dowlatabadi, 2016);
- wind energy, wood energy and energy efficiency projects by Native American tribal governments (Shelby, Perez, & Agogino, 2012); and
- Solar PV and battery off-grid systems for remote Australian Aboriginal communities (Lloyd, 2000).

Rezaei and Dowlatabadi (2016) considered the growing interest in RE projects amongst First Nation communities in Canada. They contrasted the motivations and drivers for RE projects within these communities to the motivations and drivers of outside agencies installing RE projects into indigenous communities. Outside agencies tend to concentrate on economic cost savings and reducing GHG emissions, whereas the primary motivation for indigenous communities engaging in community energy projects is a desire for community self-sufficiency in the first instance, and also community development and environmental values.

Energy self-sufficiency is viewed within a broader interest in political autonomy and self-determination, and they proposed two dimensions to energy self-sufficiency for indigenous communities. The first relates to energy produced using locally available resources such as solar, hydro, biomass or wind; the second relates to community control of energy assets and service delivery. This second dimension resonates with the definition by Ariza-Montobbio (2015) that energy sovereignty is “the ability of a political community to have the authority to control, regulate and manage their own energy”.

These remote Canadian communities are typically powered by diesel generators, and there is a strong preference for a 100% renewable solution over saving fuel with a hybrid system, even though this entails a much higher cost. The motivation is to lose dependence on diesel, and the benefits are intangibles such as pride and independence as forms of community empowerment rather than a financial return on investment. However the high costs and financial risks associated with a system sized thus has unfortunately caused a number of projects to have stalled or be abandoned.

Lloyd (2000) found reliability of RE systems in remote Aboriginal communities to be a major concern, with little training provided to communities for maintenance and repair.

The themes of self-sufficiency, sovereignty and self-determination also feature in findings from a case study (Shelby et al., 2012) where the Community Assessment of Renewable Energy and Sustainability (CARES) team of the University of California, Berkeley partnered with the Pinoleville Pomo Nation (PPN) of Ukiah, California (a Native American nation) to co-design sustainable low energy housing. Four major aspects were found to frame sustainable development from the tribe's perspective: cultural sovereignty, tribal sovereignty, economic self-sufficiency and environmental harmony. The PPN were motivated to "evolve and share their culture and way of life with natives and non-natives as an independent self-sufficient community that utilizes the latest technological, political, and economic tools available to meet their needs and goals".

The interest in community RE projects as a tool for independence is of course not limited to indigenous groups. Nicholls and Patterson (2013) noted the strong desire for long-term sustainable energy solutions amongst communities in south east Alaska, and considered practical steps for communities to increase their energy independence by utilising local resources (particularly hydro). Sitka, a remote island community, in particular was identified as being renowned for grassroots community activism which can facilitate participation in and acceptance of community energy initiatives. Recommendations included energy conservation, reducing electricity demands using wood heating and solar water heating, appropriately scaled renewable energy project development, and the adoption of new technologies, including electric vehicles.

Some of these communities are already making use of electric vehicles and demand management systems which signal how much hydro resource is available. Community sustainable energy initiatives in Sitka have tended to generate media interest eager to showcase new developments, which can then influence other communities. Multiple community uptakes of RE technologies are considered to be able to weave together to help meet national GHG targets. However this does not necessarily translate directly to the New Zealand context. For example, Schwartfeger and Miller (2015) concluded that widespread solar PV uptake has limited potential to reduce NZ GHG emissions.

Nicholls and Patterson (2013) also proposed communities consider "rainmaker" projects – investing in large scale projects (in the SE Alaskan context typically hydro with long lifetimes) designed to meet energy needs decades into the future. These can provide employment during the construction phase and provide long term energy security. However these projects are noted to be very expensive, and can lock in technologies at the expense of future cost-reduction breakthroughs.

The partnership between CARES and PPN (Shelby et al., 2012) provides an example of university research into sustainable energy with an indigenous community. The PPN wanted to implement technologies to increase their self-sufficiency while meeting housing, energy and water needs. Lacking the in-house technical expertise or adequate funding to develop and implement the designs they sought, PPN contacted CARES to create the research partnership. Shelby et al. are mindful that some communities have "historical trauma associated with working with outsiders on projects that involved substantial use of engineering and science—renewable energy technologies, for example – that have not integrated their value system".

Some of the lessons learnt by the researchers included:

- the need for time invested into learning about cultural aspects;
- the need to allow significant amounts of time working directly with the community to build trust and understand community needs;

- the value of workshops for both researchers and the community to gain an understanding of concerns across the community;
- the need to allow a large number of community members to influence community decisions;
- that sustainability priorities are subjective and community specific;
- considering the community experts in their own needs changed the power dynamic of research; and
- co-designing with the community leads to designs that share the community's cultural values and that are more likely to have high adoption rates.

PPN community members stated an appreciation of the hard work put in and the genuine interest in community needs; the value of having a voice in planning processes; an awareness of cultural and historical barriers; and a raised interest in sustainable architecture.

How to perform engineering research within an indigenous community also needs to be carefully considered in the New Zealand context. Steer (2015) stated that Māori are increasingly seeking collaborations with universities and crown research institutes to research new technologies for a low-carbon economy.

Research in the social sciences (Bishop, 1999; Smith, 1999) has identified that academic research involving Māori communities has often historically been for the benefit of the researchers who have maintained power and control over the research process, which has led to mistrust towards academic research amongst Māori communities. As a response, a more careful and ethical approach to such research has been developed, labelled kaupapa Māori research. Some of the literature pertaining to kaupapa Māori research has been examined to help inform an appropriate approach to engineering research within the Parihaka community.

Important questions for researchers to ask themselves are:

- Who will the research benefit? and
- Will the venues and methods support Māori? (Smith, 1999).

Both university and professional researchers previously working with Māori communities have documented the importance to the research of the robustness of the relationship formed and maintained. This relationship is strengthened by kanohi ki kanohi (face to face) interactions, honest communication, long term involvement and commitment, and mutual tolerance and respect (Allen, et al., 2009; Bishop, 1999; Harmsworth, 2005; Mane, 2009; Stephenson & Moller, 2009).

Mane (2009) suggested that Māori – in common with other indigenous peoples – prefer research which will lead to positive change. Methods employed should be on the community's terms. Stephenson and Moller (2009) listed three essential elements to such an approach: consultation, collaboration and dissemination.

2. Methods

2.1. Community Engagement

The *Taiepa Tiketike* project was conceived by the Parihaka Papakāinga Trust, with an expectation that the research would be relevant and useful, which facilitated community engagement. The author's engagement with the community began with pōwhiri/mihi whakatau to the three marae of Parihaka during the 18th and 19th of December 2014. During the data collection phase of the project generally one to two weeks a month were spent on site by the author, where short term accommodation and office space were provided.

The monthly rā (Section 1.1) proved ideal forums to gradually become kanohi kitea (familiar faces), helping out where possible. Project updates were given on these days when time permitted, acknowledging that the days were often very full with many topics and visitors of importance to Parihaka. The amount of discussion on this research study during these open hui was left to the community, and varied from month to month.

Community guidance on how to establish a visually prominent wind tower structure (Section 2.4.1) was sought during the January 2015 rā. The advice given was to hold a karakia (blessing) ceremony upon commissioning (Fig. 2).

Figure 2: Karakia ceremony to comission the wind tower[2]

A local research assistant, Mr Tihikura Hohaia, was appointed to the research team in February 2015. He provided technical assistance on the ground and guided the entrance of researchers and research methods into resident's homes and marae.

[2] Photograph courtesy of Urs Signer

In late February 2015 an offer was made by Powerco (the local electricity distribution company) to sponsor and install electricity monitoring devices (Section 2.2.1) in ten papakāinga homes in conjunction with an Otago University study *100 Homes*. Although the community's stance on taking up this offer was sought immediately, a slow and cautious approach was taken due to the potentially intrusive nature of the monitoring, and the number and intentions of parties involved. The details of the offer were publically raised during multiple rā and were also discussed one on one with kaumātua. Once community acceptance was given, Mr Hohaia approached selected residents, arranged in-home meetings with residents, and along with myself discussed what was involved in participating. Mr Hohaia then collected signed consent forms from those who were willing to participate. Consent forms were also collected for researchers to access LPG and electricity billing information directly from the retailers.

Residents agreeing to electricity monitoring were provided with a website login so they could view their own historic and real time electricity use, and thereby engage with the data collection (and quantify the effects of energy behaviours).

One of the primary aims of the wider Taiepa Tiketike project was to increase knowledge capacity within the community around sustainable energy. A key method to deliver this was a series of six one-day workshops, predominantly arranged by Mr Hohaia and prepared and delivered by various members of the research team, drawing on some preliminary results where necessary. All three marae were used as venues twice. A number of these workshops incorporated focus group discussion sessions, chaired by Mr Hohaia, where Mr Quinn and the author sought community input into research methods and findings.

The final workshop consisted of Mr Quinn and the author orally presenting interim research findings to the community, to enable internal community discussion whilst awaiting the final results to become available. The initial intention had been to use ensuing community discussion to inform the ultimate conclusions and recommendations. However postponements of the workshop date meant that time was not available to incorporate feedback into findings.

Informal tutorial assistance was provided to several community members who undertook a qualification in renewable energy studies through the Southern Institute of Technology.

Overall the researchers were very fortunate to work on a topic viewed so favourably amongst many of the community. However, topic aside, a warm welcome was also extended on a personal level.

During the course of the project the author was invited to various community and whanau events such as

- Puanga celebrations (Māori New Year);
- Pāhua commemorations (marking the historic plunder of Parihaka);
- working bees in the Māra (community gardens);
- wānanga (learning sessions);
- tangi (funerals); and
- hāngi (earth oven) preparations.

2.2. Assessing Current Energy Demand

Suggesting energy solutions for the papakāinga requires some understanding of energy use. Energy for transport was investigated by Mohan (2016) and is thus excluded here. Due to resource constraints and the intrusion to residents, not all buildings at Parihaka were studied. The approach taken was to investigate in some detail buildings associated with all three marae and ten representative homes, the hope being that these homes could provide an indication of typical energy use patterns across all homes.

Mr Hohaia in conjunction with the research team selected which ten homes would be most indicative of current and future energy use, with occupants willing to work with the project. A range of building and family sizes was included, from retired couples to large families. One home was not situated within the papakāinga boundaries, but was thought to provide valuable information of a typical family home. Consent to be a participant and for use of the data was also collected by Mr Hohaia. For purposes of anonymity, the ten residential homes are labelled 1 through 10, and buildings associated with the three marae are labelled A through C.

In the first instance, walk through energy audits provided an initial insight into what energy was used for. Hernandez Pacheco (2016) along with Mr Leith Robertson (see acknowledgements) performed the energy audits of the homes, whilst Mr Hohaia and the author performed those of the marae (Appendix A).

LPG is used within the papakāinga for cooking, water heating, and space heating. Firewood is used for space heating, and water heating in one home. Electricity is also used for cooking, water heating, space heating and all other energy applications (excluding transport, which is predominantly dependent on petrol or diesel vehicles) (Table 1).

Table 1: Main energy sources currently used to meet demand in 13 selected buildings

	Grid electricity supply	Bottled LPG (excluding portable applications)	Firewood (excluding hangi fuel)
Number of representative homes using energy source	10	6	4
Number of marae using energy source	3	3	0

More detailed consumption data was then gathered for the study buildings over a 12 month period to capture seasonal variations. The BRANZ Household Energy End-use Project (Pollard, 1999) found that a trade-off between accuracy, data processing labour intensity, and cost of equipment installation was required for residential energy use data collection. Difficulties with data collection were also noted in measuring energy input to wood burning appliances (Camilleri et al., 2007) and portable LPG appliances (Stoecklein et al., 2000). Sanderson & Yeung (2002), Bailey et al. (1997), Hunter et al. (1999), and NEMS (2013) all provided valuable input into data collection techniques. Electricity data also needed to capture variation within the day. The measurement techniques employed are described in Sections 2.2.1 - 2.2.4.

The occupancy of the papakāinga varied over the course of the study, and the energy consumption of buildings outside of the 14 monitored is not known. Tragically, one of the study homes burnt down during the study period: the data from this home - and also data from the home not located at the papakāinga - is not used in energy load profiles for the current papakāinga, but is used for potential future demand. Homes located south of Mid Parihaka Rd (Fig. 1) were not included in energy load profiles (Section 1.1). An office building and a few unoccupied buildings which currently have intermittent use were also not included. This left only what appeared to be the fulltime equivalent of two small homes which contributed to the total papakāinga energy demand. These were modelled by reusing the data from two of the study homes of a similar size/occupancy.

The total current energy demand of the papakāinga was thus approximated by aggregating the energy use of buildings 1, 2, 4, 5, 6, 7, 8, 9, A, B, C and also buildings 1 and 2 a second time.

2.2.1. Electricity demand

An offer was made by Powerco to install electricity monitoring devices in the 10 representative homes, if the residents consented to the data becoming anonymously available to the University of Otago *100 Homes* research project. Mr Hohaia negotiated consent from each home, and with Dr Murray coordinated visits from the installers (a licenced electrician was contracted). Similar devices were subsequently installed in four buildings associated with the three marae (not part of the Otago study).

The electricity monitoring devices used were those of Gridspy Ltd[3]. Current transformers (CTs) measure the current in various circuits within the building. Instantaneous values are captured every second by a data collector (*grid-node*). This is typically situated within the building distribution board (Figs. 3 and 4); and drawing its power supply from there, is also able to measure voltage and hence power. Data is transmitted wirelessly to a *grid-hub* device, which utilises an internet connection to upload data to the cloud. Historic or real-time electricity consumption can be viewed with a web interface.

Logins to the web interface were provided to the researchers and to the associated resident. This allowed residents to monitor and modify their own electricity use appliances and behaviours, if desired.

Each *grid-node* could interface six current transformers. The installer chose which six circuits to monitor, ensuring that the incoming feed (whether one two or three phases) was captured. In some cases (buildings 6, A, B, C) additional *grid-nodes* and CTs were required (Appendix B).

[3] www.gridspy.com

Figure 3: Electricity monitoring (CTs and *grid-node*) installation in a household distribution panel

Figure 4: Electricity monitoring (*grid-node*) installation in a household distribution panel

During the monitoring period, the web interface was checked periodically to ensure data collection continued uninterrupted. Interruptions to data collection did occur, for a variety of reasons, which unfortunately led to gaps in the data records. Despite requests to ensure a constant power supply to the *grid-hubs*, in some cases they would be unplugged by occupants to utilise power sockets or to save electricity. Improvements were made by further education from Mr Hohaia, taping plugs into sockets, and making information signs for the marae. Occasional power cuts led to data loss, however the periods were typically short. Internet outages within the papakāinga were reasonably frequent, however the *grid-hub* can store and buffer data for a period and upload it later. There was a misunderstanding where it was thought data could be stored in this way for six months, which is not the case. This led to complacency when one *grid-hub* failed, which was thought instead to be an internet issue, leading to a loss of five months data in one home. Another resident had an issue with their internet service provider, which despite attempts remained unresolved and led to a loss of six weeks data.

After 12 months, the collected data was downloaded as time-stamped 10 minute means of power (W). The time-stamps were in civil time as shown on clocks, which varies between New Zealand Standard Time (NZST) and New Zealand Daylight Time (NZDT) depending on the time of year.

Gaps in the data record were filled from periods of similar electricity usage. To determine which periods had similar electricity usage, third party electricity consumption data was requested from the applicable retailer using an *Electricity Information Exchange Protocol* request to the NZ Electricity Authority [4]. *Taiepa Tiketike* was set up as an authorised agent with the Electricity Authority, and Mr Hohaia negotiated third party consent with residents and collected customer details. Although the most detailed data available was requested, this typically tended to be monthly readings. Although the buildings have smart meters capable of 15 minute readings, perhaps the poor 3G reception in the area prevented retailers from remotely collecting such fine-grained data.

[4] Refer to *Request for consumer consumption: Procedures*, retrieved from https://www.ea.govt.nz/dmsdocument/20062 July 2016

The data sets were then modified in the following manner:

- placed in order from 1 Jan – 31Dec;
- the time-stamps translated to New Zealand Standard Time (NZST); and
- values for 29 Feb 2016 deleted (2016 was a leap year).

Electricity monitoring of the transformer which supplies most of the papakāinga was understood to have been initiated by Powerco and underway concurrently over a 12 month period, to provide data on community loads. However this data was not collected. The graphical output of a one week period (5/2/2016 – 11/2/2016) of transformer logging was made available after the data analysis was complete (Appendix G).

2.2.2. LPG demand

Metering the flow of gas within pipes was initially considered, based on the methods detailed by Pollard (1999). Upon discussing this method with Mr Pollard (a researcher at BRANZ), he offered the loan of a number of meters and data loggers. However the expected high cost of the gas-fitting installation to ensure safety and compliance meant a different method was employed. A gantry was designed and built which could lift cylinders suspended by hanging scales[5], meaning that the LPG cylinders (which can weigh around 80kg when full) could be easily weighed (Fig. 5).

Figure 5: Mr Hohaia weighing LPG cylinders using gantry and scales

The change in weight between weighings gave an indication of the mass of LPG used over the interim period. An approximation of energy used was then found by multiplying by the specific calorific value of LPG. LPG in New Zealand is typically a mixture of 60% propane and 40% butane, (but varying as the cylinder empties). Elgas, the provider of the delivered cylinders, state a specific calorific value of 49 MJ/kg[6].

Mr Hohaia weighed the marae cylinders before and after the rā each month, and also before and after other major hui. He also weighed LPG cylinders of the 10 homes at least monthly. Most cylinders were located outside. One home utilised a 9 kg cylinder within the kitchen for cooking, and weighing of this cylinder was abandoned to avoid any intrusion into the home. Some homes used portable LPG heaters for spot heating, and some marae used portable LPG

[5] Wedderburn calibrated hanging scales model WS603, with capacity 150kg and resolution 50g
[6] https://www.elgas.co.nz/resources/elgas-blog/138-nz-lpg-conversion-values-kg-litres-mj-a-kwh, accessed June 2016

patio heaters very occasionally for heating large halls. These energy loads were not measured or incorporated into the study.

2.2.3. Firewood demand

Firewood at Parihaka is generally combusted in enclosed wood burners. The exception to this is driftwood collected from nearby beaches for outside hāngi fires. This was not measured due to challenges around the significant weight of the logs and the intrusion into the social dynamic of the process.

The useful heat energy available in a quantity of wood is described by the lower heat value (LHV), which depends on the weight and moisture content of the wood. To determine the energy content of firewood consumed in a given year would ideally require weighing all the wood used, and sampling moisture content by weighing samples before and after oven drying (Hartley & John, 1995). This was considered impractical, and so the following approximation was used.

Instead of measuring the weight, the bulk volume was measured, being the volume of stored wood pieces including air voids. To determine the quantity of wood used by a household over a winter, the bulk volume of the woodpile was measured before and after winter. Any additions to the woodpile during winter were measured and reported. Bulk volume was crudely measured with a tape measure and simple geometry. Bulk volume was converted to basic volume (volume excluding air voids) by assuming that 40% of the bulk volume is air voids. This is based on a value between 30% for roundwood logs and 50% for fist-sized chunks proposed by Sims (2002). In reality, the proportion of air voids will vary with wood shape and size, and whether wood is stacked or thrown.

A sample of 30 pieces of firewood was randomly selected from each home's woodpile. For each sample, the wood species (if known) was recorded, and the moisture content (wet basis) was measured using a handheld moisture content meter[7] (Fig. 6).

Figure 6: Mr Hohaia noting species and sampling moisture content of firewood stocks.

The weight of firewood used is the product of the basic volume and basic density. Different wood species have different basic densities. The proportional mix of wood species in the woodpile was assumed to be the same as the sample. The predominant species used at Parihaka are *Pinus* radiata (pine) and *Cupressus* macrocarpa (macrocarpa). The air-dried basic densities used for these species were 401 kg/m^3 and 485 kg/m^3 respectively (Eng et al., 2008),

[7] Sinsui digital 4 pin moisture meter, with range 5-40% and resolution 1%

485 kg/m^3 was used for any other species encountered.

Moisture content has a much greater effect on energy content than wood species (Sims, 2002). Senelwa & Sims (1999) experimentally derived the following relation for *Pinus radiata*, which has been applied for all the wood species encountered at Parihaka:

$$Higher\ heating\ value\ (MJ/kg) = -0.1335 \times moisture\ content\ (\%) + 20.15$$

To convert from HHV to LHV, the energy required to evaporate water is subtracted, which is 2.57 MJ/kg water + 1.39 MJ (Sims, 2002). The weight of water is calculated using the moisture content, and the moisture content is assumed to be the same as the mean moisture content of the 30 samples.

2.2.4. Hot water demand

The two main forms of water heating at Parihaka are thermostat-controlled electric immersion elements within insulated water storage cylinders, described as water cylinders henceforth, and continuous flow/instantaneous LPG water heaters consisting of a heat exchanger (without storage) heated directly by a gas flame, described as instant water heaters henceforth.

The amount of energy consumed by water cylinders for water heating (including standing losses) is captured by the electricity monitoring (Section 2.2.1, Appendix B). The amount of energy consumed by instant water heaters over a period of time is related to the change of weight in the supply LPG storage cylinder during that period (Section 2.2.2).

In two of the marae, one LPG cylinder/regulator supplies both cooking and water heating appliances. In this case weighing the cylinder cannot differentiate how much gas was used for each application. Measurements of hot water use were made to indicate the typical use of LPG in these situations. Recording the time of use water consumption was also intended to inform solar hot water design, and was thus carried out for all study buildings with instant water heaters; however the solar hot water evaluation method ultimately used (Section 2.5.4) did not require detailed time of use data.

The amount of energy required to provide water at a certain temperature depends on the mass of water heated and the initial temperature of the water. The mass of water heated over a certain time period was found by measuring the flow rate and integrating over time.

An ultrasonic flow meter (Fig. 7) with data-logger[8] (Fig. 8) was used to measure flow rates without disturbing the plumbing of buildings. Due to one flow meter being available, hot water consumption was unable to be monitored continuously in all study buildings over 12 months. Instead, the flowmeter was cycled between buildings. Hot water use was monitored in each marae over at least three separate hui. Hot water use was monitored in each study home which heated water using LPG for a continuous period of around 20 days - this being the typical period of time between major hui.

[8] Fuji Electric Company Portaflow C

Figure 7: Ultrasonic flow sensor attached to hot water supply pipe in Marae B

Figure 8: Ultrasonic flow meter data-logger

For each building, an appropriate water pipe was selected - typically either the cold pipe to or the hot pipe from the instant water heater, ensuring minimum distances from turbulent areas such as elbows or tees as per the manual. The ultrasonic flow meter was strapped to the side of the pipe, with silicon grease providing an airtight join between the sensors and the outside wall of the pipe. Volumetric flow rate is calculated using the internal cross-section area of the pipe and velocity of the water. Velocity is measured due to the difference in transit time between ultrasonic sound waves propagated upstream and downstream. To enable these calculations, the pipe outer diameter, wall thickness, and material sound velocity were entered into the settings. The pipe outer diameter was measured with calipers, and the wall thickness and material sound velocity were looked up in standard manufacturer's tables. The integrated data-logger has a 'totaliser' function which records total volume throughput. An initial calibration test was performed by timing the filling of a container from a hot tap, weighing the water added, calculating the volume, and comparing to the totaliser. Typically the two were in close agreement; however if there was a discrepancy of more than 5%, the calibration settings were adjusted.

The data logging capability of the ultrasonic flow meter was set to record the flow rate in l/min every 10 seconds. The totaliser function was not used in case it was susceptible to errors due to convection currents, dripping taps etc. The minimum water flow rate required to cause ignition of the gas burner was found from the appliance nameplate or from product information available online, and the data was adjusted to only consider flow rates above this value. The total volume of hot water used over a period of time was found by integrating the flow rate over time.

All of the instant water heaters controlled the output water temperature to a setpoint of 55° C. The incoming water temperature to the appliance was found by running a cold tap for a while and then measuring the temperature with a digital thermometer. This was done at the start and end of the period, and the average of the two values was assumed to apply for the entire period.

The heat required to raise the temperature of the water was calculated using

$$Q = mc\Delta T$$

where $Q =$ heat energy required (MJ)
$m =$ mass of water = volume (m^3) x density (1 000 kg/m^3)
$c =$ specific heat capacity of water (J/kg.K) ≈ 4184 (depending on temperature)
$\Delta T =$ change of temperature (K) = 55 – incoming water supply temperature (°C)

The energy input to the appliance is the heat required divided by the appliance efficiency. Part load efficiencies and also standing losses in pipe work and the appliance were ignored, and the appliance was assumed to run constantly at the nameplate efficiency – typically 0.8 for all of the appliances.

2.3. Modelling Possible Future Energy Demand

It is difficult to say with any certainty what the energy demand of the community will be in 20 years, with unknown changes in technologies and the papakāinga population and demographics. As a result many assumptions and simplifications were made about future demand:

- population growth of 5 – 10 homes per year (Gawn, 2016), leading to 100 – 200 new homes;
- space heating loads as suggested by Lambert (2015) for all new homes;
- all future domestic energy loads (other than space heating) based on energy use of the 10 study homes but incorporating energy efficiency measures proposed by Hernandez Pacheco (2016);
- marae energy use unchanged (although in reality it is likely that significantly more and larger hui will occur);
- future productive uses of energy (e.g. café, museum, workshop) not taken into account; and
- electric vehicle (EV) uptake and car sharing as suggested by Mohan (2016) . The potential for EV transport is considered in this study due to the effect on the electricity demand.

Future home energy load profiles were constructed by modifying the data from the existing ten homes with the findings of Hernandez Pacheco (2016) and Lambert (2015). Lambert recommended that new-built houses should incorporate a high level of insulation, double glazed windows, efficient ventilation, maximise north facing windows, and incorporate thermal mass. She suggested such homes would require an energy input of 1059 kWh/year for space heating. A heat pump load profile for future homes was constructed by scaling current heat pump data to provide this heat demand, and also the corresponding quantity of firewood needed was calculated. Hernandez Pacheco's findings were on a home by home basis. Modifying the data to incorporate energy savings is described in Section 2.5.3.

Four energy load profiles were produced for each home, being combinations of space heating (with heat pump or wood burner with wetback), and water heating (using solar water heater or electric water cylinder with a 2kW element on a timer). The purpose of modelling the timer on the electric heating load was to consider heating the cylinder in a continuous period centred on noon, rather than throughout a 24 hour period, in order to take advantage of the solar and/or diurnal wind resource. The energy for water heating included standing losses based on cylinder size (Section 2.5.6).

Three scenarios were proposed for papakāinga energy demand in 20 years:

1. no new homes (future energy demand is the same as current energy demand in Section 3.1);
2. 100 new homes (mid-growth scenario) made up of aggregating the current energy demand data from the 10 case-study homes ten-fold, and adding the charging

requirements of the equivalent of 47 Nissan Leaf and 23 Mitsubishi Outlander electric vehicles; and

3. 200 new homes (high-growth scenario) made up of aggregating current energy use data from the 10 case study homes 20 fold, and adding the charging requirements for the equivalent of 81 Nissan Leaf and 40 Mitsubishi Outlander EVs.

Assumptions used for the charging of EVs were as follows:

- vehicles are in use during the day, and charged at night;
- all charging occurs at the papakāinga;
- each vehicle travels to New Plymouth and back once per day, Monday to Friday;
- vehicles are charged slowly (1.5 kW charger) to minimise peak loads;
- charging of a Nissan Leaf type vehicle starts at 21:00 and completes at 07:00;
- charging of a Mitsubishi Outlander type vehicle starts at 01:00 and completes at 07:00; and
- the charging rate (1.5 kW) is constant for all battery states of charge.

2.4. Assessing the Renewable Energy Resources

2.4.1. Wind resource

The available wind resource of a location is very site specific, dependent on local climate, topography, and surface features. A typical procedure for assessing a local wind resource is shown below (Fig. 9).

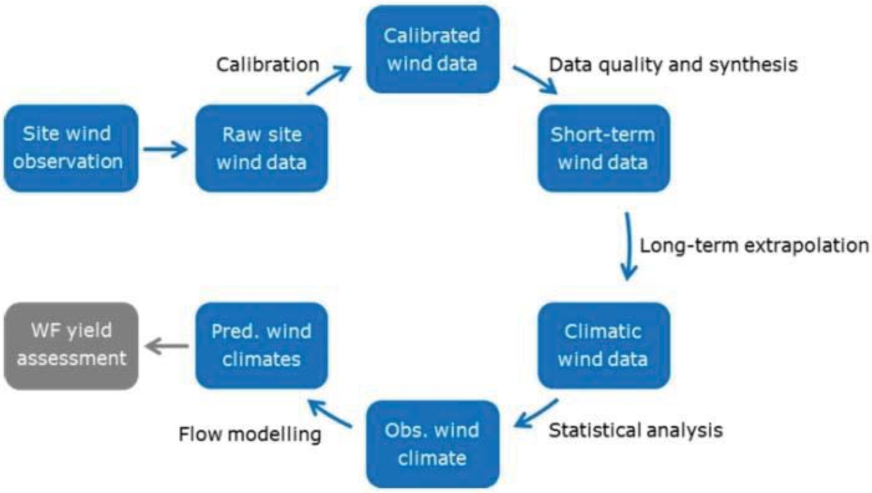


Figure 9: Typical wind resource assessment procedure[9]

A location on the papakāinga to observe the wind resource (Fig. 11) was chosen by Dr Murray using wind prospecting techniques and in discussion with the PPT around sensitive sites and vehicle access. The wind prospecting used historical wind speed/direction data available from NIWA[10], collected at Cape Egmont and Hawera AWS (Fig. 10).

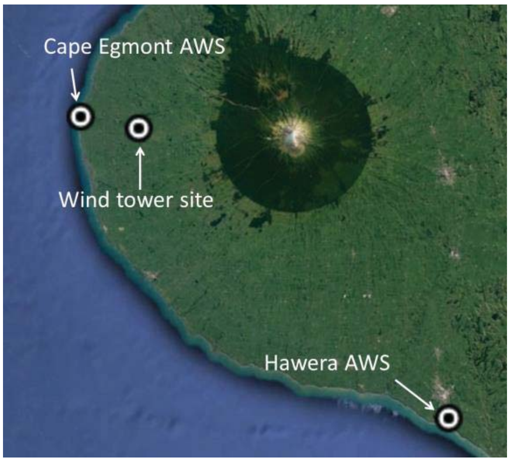


Figure 10: The location of the two meteorological data sets used to select a wind tower site[11]

Figure 11: The site chosen to install a wind tower on the papakāinga[12]

[9] Source: Mortensen (2016)
[10] https://cliflo.niwa.co.nz/
[11] Image: Google Earth
[12] Image: Google Earth

A meteorological mast or wind tower (Fig. 12) was erected in January 2015 at location 39° 17.209’S, 173° 50.498’E (Fig. 11).

Figure 12: The wind tower installed on the papakāinga

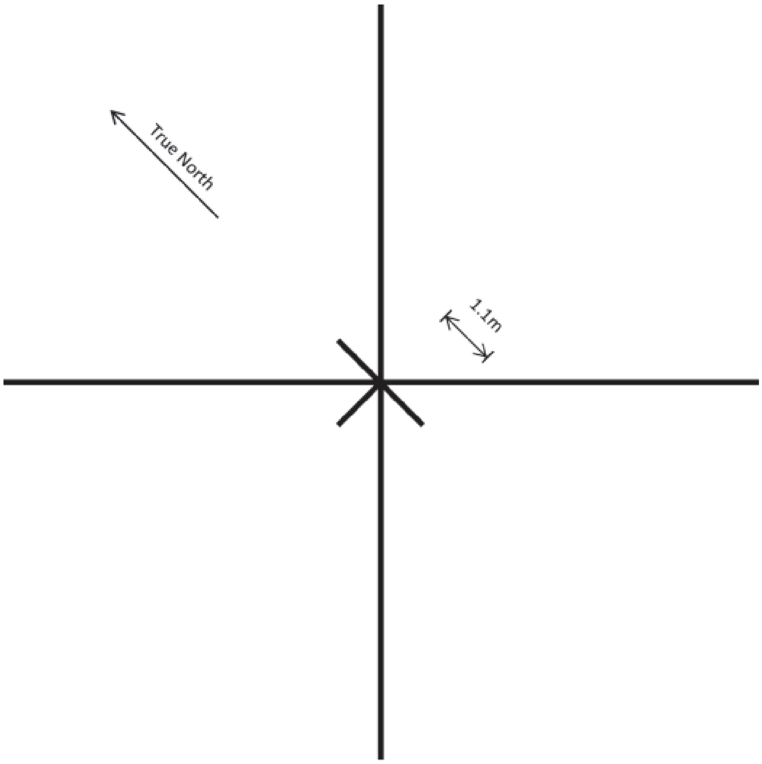
A tubular tilt up design was used with two sets of four guy wire stays, three screw-in anchors and one buried anchor. The location chosen limited the tower height to 15 m due to the footprint area required for the stays (Fig. 13).

The tower and anchor layout was chosen based on the (unlevel) topography of the site, 4WD vehicle parking positions (the tower was raised using a vehicle mounted electric winch), and expected predominant wind directions, This allowed the tower to be safely raised and lowered, and minimised wind shading of anemometers by the stays. Expected predominant wind directions were N, SW, and SE based on the wind data from Cape Egmont/Hawera and also local Parihaka knowledge.

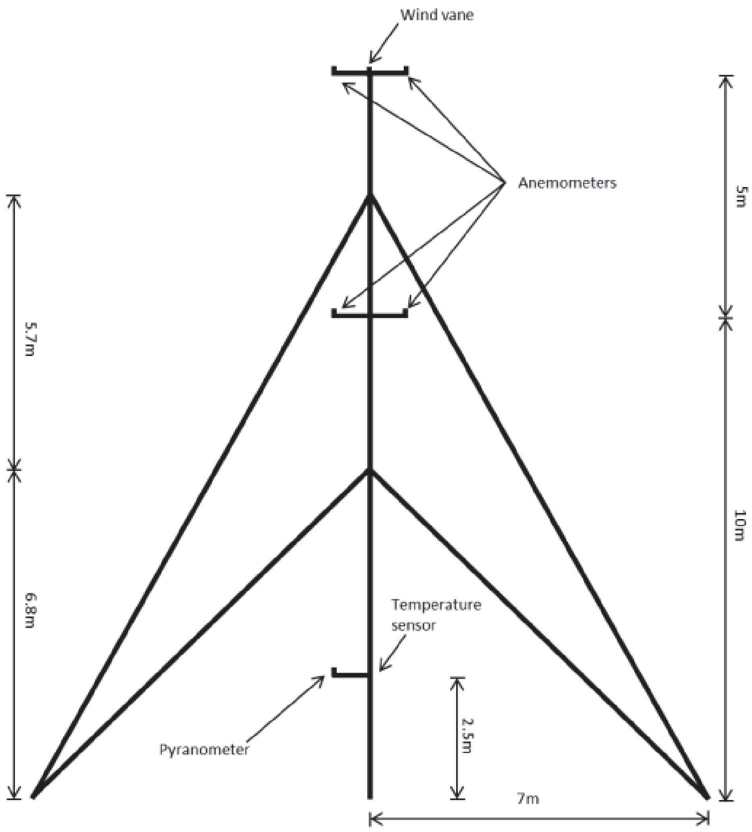
The following sensors were mounted on the tower prior to raising:

- one NRG 200P wind vane (wind direction origin in degrees east of north) at 15m. Deadband facing 90°T , the direction with the expected least wind;
- two NRG #40C cup anemometers (wind speed in m/s) at 15m (highest available). Mounted on 1.1 m booms (> 6 tower diameters) facing 180°T and 270°T (using a magnetic compass and accounting for local magnetic declination). Having two mounted on booms 90° apart provides both redundancy and the ability to use data from a non-shaded anemometer in all wind directions;
- two NRG #40C cup anemometers (wind speed in m/s) at 10m (standard meteorological height), mounted as above;
- one NRG 110S shielded thermocouple temperature sensor (ambient temperature in °C) at 2.3 m (south side); and
- one NRG Li-Cor LI-200SZ Pyranometer (global horizontal solar irradiance (GHI) in W/m^2) at 2.3 m (north side).

A Symphonie data logger was mounted in a weathertight enclosure at head height (powered by a small PV panel and battery). Sensor cables were spiral wound and taped around the tower to reduce wind interference. Sensor grounding and a grounded lightning rod were installed. An electric fence was placed around the footprint to keep any farm stock out.



Plan elevation



Side elevation

Figure 13: Plan and elevation of structure of installed wind tower

Scale factors and offsets of calibrated sensors were entered into data-logger settings.

The tower remained in service for two years. However only 12 months of the data set was used for this analysis due to time constraints. The data-logger recorded mean, maximum, minimum and standard deviation for each 10 minute period. Data was saved to an MMC data card. Each week Mr Hohaia changed the data card, saved the data, and emailed it to the research team who also saved and backed it up. He also kept the site clear of excess vegetation, maintained correct stay tension (which varies with seasonal temperature), monitored data-logger battery level and performed a general inspection weekly. Each week's data was inspected using Symphonie Data Retreiver software. Verification checks confirmed correct ongoing sensor and data-logger operation; redundant anemometers were compared, and range checks made.

The temperature data did not read correctly initially. After numerous attempts to remedy by adjusting calibration settings and replacing the signal conditioning module between the sensor and logger, the issue was resolved on 13/3/15 by changing channel on the logger (faulty channel assumed). The original data-logger failed at 14:00 NZST 11/6/15. Dr Murray and Mr Hohaia installed another (on loan) at 16:33 NZST 17/6/15, which in turn was replaced on 26/11/2015. Data is thus not available for the period 14:00 NZST 11/6/15 - 16:33 NZST 17/6/15. On 11/4/16 the tower was lowered for two hours to replace all galvanised saddle clamps on the stays, seeing as many were corroding. At this time the anemometer at 10 m on the west facing boom was replaced, as it had recently begun reading consistently slower than that on the south facing boom (potentially due to bearing wear).

As each height level of anemometry had two instruments, the data was only used from one set at any given time. Ideally the ratio between wind speeds measured by redundant anemometers would be 1. However the anemometers on south facing booms tended to record higher wind speeds for all wind directions other than northerly (they would be affected by tower shading in northerly winds) (Fig. 14).

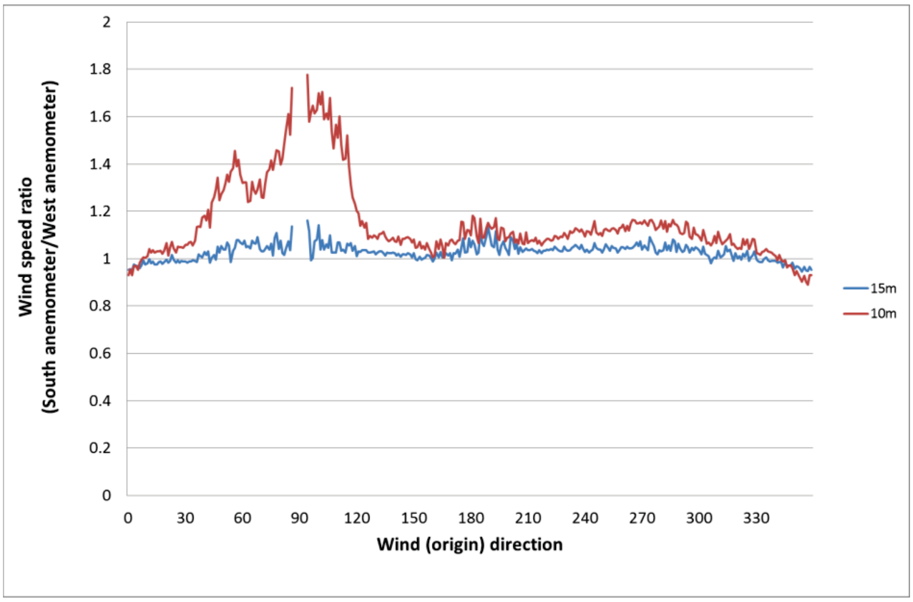


Figure 14: Wind speed ratios between anemometers mounted on booms at the same height facing different directions for the period 21/1/2015 - 20/1/2016

The large mismatch at 10 m for easterly winds may be due to differences in anemometer start thresholds in the typically very light nature of due easterlies, or local orographic effects. Based on this chart, the 15m dataset was preferred. Assuming that a higher reading anemometer here is more accurate (less shading etc. of wind flow), the data from south facing anemometers was used for all wind directions except for between 330°T and 35°T. The 12 month period of wind data used was 21/1/2015 – 20/1/2016 inclusive. The 12 month period of ambient temperature data used was 14/3/2015 – 13/3/2016 inclusive.

2.4.1.1. Temporal extrapolation of the wind resource

Various methods to perform the long-term extrapolation step of Fig. 9 are outlined by Carta, Velázquez and Cabrera (2013), based on the premise that wind data measured over a small number of years does not capture the average conditions present over the lifetime of a wind energy project. The following method was employed.

The 12 months of measured wind data at both 15 m and 10 m was compared with two nearby long-term reference data sets to consider the long term variations:

- a 35 year computer model hindcast of hourly wind speed and direction at 10 m above ground level at the Parihaka wind monitoring site, developed by Metocean Solutions;
- 10 years of 10 minute wind speed and direction averages from a monitoring site 7.6 km WNW of Parihaka (near the Kapoaiaia river mouth at Cape Egmont: 39° 16.407’S, 173° 45.433’ E), measured at 10 m above ground level (anemometer and vane) by Taranaki Regional Council (TRC).

A measure-correlate-predict (MCP) technique was used to hindcast (estimate the past) a long-term dataset from each of the above for use in wind modelling, as described:

- Timestamps of the measured data and reference data were matched during the concurrent period. Because the Metocean Solutions data used a different measurement interval, the correlations of both hourly means and hourly (filtered) spot values of the data measured at Parihaka were compared. Note wind direction averages are found by resolving into north and east components, averaging, then recombining.
- Any matched data pairs where either wind speed was less than 3 m/s or where the veer (difference in wind speed direction) was greater than 99° were discarded.
- A correlation index between the measured data and reference data was calculated (Jain, 2011) using

  $$\sum_{i=1}^{N}(M_i - \mu_M)(L_i - \mu_L)/(N.\sigma_M\sigma_L)$$

  Where N is the number of matched data pairs
  i is an index from 1 to N
  M is the data measured at Parihaka
  L is the long term reference data

μ is the mean of the data
σ is the standard deviation of the data;

- A correlation index of 0 suggests unrelated random series, with increasing values towards 1 signifying increasing correlation. Jain (2011) suggests that a correlation index > 0.65 of wind speeds indicates that the two time series share the same wind climate, with correlation indices > 0.9 considered excellent correlation.
- The matched data pairs were divided into 12 sectors, based on the wind direction origin of the measured data.
- Wind direction correlation factors were produced for each sector based on the average veer within that sector.
- Wind speed correlation factors were produced for each sector based on least squares linear regression (both with and without forced fit through 0,0).
- The long term data from the reference side was then transformed to construct a prediction of the wind at the Parihaka monitoring site during that period. Each wind direction value was transformed based on the appropriate wind direction correlation factor. Each wind speed value was transformed based on the wind speed correlation factor appropriate for the associated transformed wind direction value.

Jain (2011) pointed out that seeing as wind energy generation is a cubic function of wind speed, actual wind speeds that are higher than the regression fit have a greater effect than actual wind speeds lower than the regression fit. This implies that electricity production can be underestimated by up to 10% using the above method. For this reason, the above was repeated with a consideration made of the residuals (remaining errors from the least squares regression). For each direction sector, the standard deviation of the prediction errors within the concurrent time period was found. A simulated residual term was added to the wind speed correlations by using Microsoft Excel to generate a random number between 0 and 1 as a random probability, finding the inverse of the standard normal distribution curve associated with that probability, and multiplying it with the standard deviation of the associated sector's prediction errors.

The factors considered when deciding which prediction set to ultimately use in further analysis were:

- the correlation index within the concurrent period prior to data transformation/prediction;
- the correlation index within the concurrent period after data transformation/prediction of the reference data;
- the standard deviation of the prediction errors within the concurrent period ; and
- a comparison of the properties of a Weibull distribution fit of the measured data and the concurrent predicted data.

The Weibull distribution fit was performed by importing the data into Climate Analyst 3[13] software, which is also used to import the local observed wind characteristics into WAsP software (Section 2.4.1.2).

The Weibull probability density function is

$$P(v) = \frac{k}{A}(\frac{v}{A})^{k-1}e^{-\frac{v}{A}^{k}} \text{ for v > 0}$$

where v = wind speed (m/s)
A = Weibull scale factor
K = Weibull shape factor

Table 3 shows the variation between the various data sets/ prediction methods. Seeing as the data measured at 15 m exhibited better correlation than that measured at 10 m in all cases, and the Metocean correlation with hourly averages exhibited better correlation than that with hourly spot values, the 10 m data set and the hourly spot values were not considered further.

The prediction based on the TRC data using a sector-wise linear regression with a forced fit through (0,0) was chosen. There is a good match in all columns of Table 3, an excellent correlation of 0.91, and any discrepancy is on the conservative side (i.e. resulting in a lower energy prediction).

The transformations used to convert the TRC data to produce a Parihaka hindcast are shown in Table 2. The wind direction offset between the two data sets seems rather excessive and it may be possible that the TRC vane is aligned to magnetic north rather than true north, adding an extra 21° veer between the readings. If this is the case the data transformation will correct for this.

Table 2: Transforming long-term reference wind data to a long-term hindcast of the wind resource at the monitoring site

Sector	Direction of measured wind origin the sector applies for	Coefficients applied to transform TRC wind speeds into Parihaka hindcast	Offset (°) applied to transform TRC wind direction into Parihaka hindcast
1	345° - 15°	1.126	23.9
2	15° - 45°	1.248	13.1
3	45° - 75°	1.055	14.5
4	75° - 105°	0.743	31.7
5	105° - 135°	0.961	28.4
6	135° - 165°	0.862	23.2
7	165° - 195°	0.862	27.0
8	195° - 225°	0.844	28.9
9	225° - 255°	0.782	31.3
10	255° - 285°	0.791	40.0
11	285° - 315°	0.958	30.0
12	315° - 345°	1.067	29.6

[13] www.wasp.dk

Table 3: Comparison of correlations between measured wind data and various hindcast predictions from long term reference data for the period 21/1/2015 - 20/1/2016

	Wind speed corr index pre prediction	Wind speed corr index post prediction	Standard deviation of prediction errors	Weibull scale factor A	% error of A	Weibull shape factor k	% error of k	Annual mean wind speed (m/s)	% error of wind speed	Power density (W/m^2)	% error of power density
Measured data at 15m				6.1		1.81		5.4		204	
Transformed Metocean data, linear regression	0.81	0.85	1.61	6.1	0	2.17	20	5.4	0	174	15
Transformed Metocean data, linear regression through (0,0)	0.81	0.85	1.64	5.9	3.3	1.93	6.6	5.2	3.7	174	15
Transformed Metocean data, linear regression, residuals added	0.81	0.74	2.16	6.3	3.3	2.06	14	5.6	3.7	199	2.5
Transformed Metocean data, linear regression through (0,0), residuals added	0.81	0.75	2.24	6.2	1.6	1.91	5.5	5.5	1.9	205	0.5
Transformed TRC data, linear regression	0.78	0.91	1.33	6.2	1.6	1.97	8.8	5.5	1.9	195	4.4
Transformed TRC data, linear regression through (0,0)	0.78	0.91	1.33	6	1.6	1.81	0	5.3	1.9	198	2.9
Transformed TRC data, linear regression, residuals added	0.78	0.82	1.80	6.3	3.3	1.97	8.8	5.6	3.7	211	3.4
Transformed TRC data, linear regression through (0,0), residuals added	0.78	0.83	1.84	6.2	1.6	181	0	5.5	1.9	217	6.4

2.4.1.2. *Spatial extrapolation of the wind resource*

The site chosen for the wind tower was not necessarily the best location for constructing a wind turbine generator in the immediate surroundings, which depends in part on wind speed distribution within these surroundings. Wind modelling of the expected wind resource made use of Wind Atlas Analysis and Application Program (WAsP) 11 computer software[14]. Mortensen (2012) explained the use of WAsP (Wind Atlas Analysis and Application Program) computer software in wind resource assessment, where WAsP provides the flow modelling step in Fig. 9. This program takes as inputs:

- the predicted or measured time series of wind speed and direction, described as the observed wind climate;
- descriptions of surrounding terrain orography and surface roughness; and
- descriptions of nearby obstacles to wind flow.

The observed wind climate is "cleaned" of local terrain and obstacle effects to produce a generalised wind climate, and spatial extrapolation is made by accounting for the terrain and obstacles surrounding potential wind turbine sites.

The observed wind climate was produced by importing the MCP hindcast described in Section 2.4.1.1 into Climate Analyst.

Orography, or terrain elevation variations, is imported as a digital vector topographical map. Mortensen and Petersen (1997) cautioned that wind speed errors in WAsP predictions are highly sensitive to the resolution of the topographical input data. In this case WAsP Map Editor 11 was used to nest a detailed topographical map inside another of less detail but greater area. The wider map represents 20 km x 20 km centred on Parihaka, produced from data from the NASA Shuttle Radar Topography Mission. This has contours of 5 m. The data it is based on is a 90m x 90m grid, and a considerable amount of smoothing of the contours was required. During this smoothing process, a background image of the 20 m contour NZTopo50-BJ28 map produced by LINZ (Land Information New Zealand) was underlaid to ensure correct general routing of the contours.

The large scale topography surrounding Parihaka is dominated by a gradual but increasing rise from the Cape Egmont coastline up towards the flanks of Mt Taranaki - this is captured well by the NASA data. However much finer detail is missed, such as the small lahars (volcanic hillocks) which dominate the landscape immediately surrounding Parihaka. To incorporate finer detail the nested map detailed approximately 1 km x 1 km around the wind monitoring area. Calibre Consulting provided 0.5 m contours in digital format generated from both LIDAR (Light Detection and Ranging) aerial survey and manual survey of Parihaka. Map Editor was used to transform the map projection from Taranaki 2000 To UTM (zone 59H). Again, significant contour smoothing was required; in particular the LIDAR data was of high resolution and had captured individual large trees and vegetation, which were removed (to be added back into the WAsP model as obstacles or surface roughness). Spot heights of significant hills

[14] www.wasp.dk

were added, and contours were thinned to 2 m and "stitched" into the corresponding 5 m contours of the wider area.

Surface roughness information was generated for the entire map area by drawing polygons around areas of contiguous roughness in Google Earth (Fig. 15). Increasing detail was provided as proximity to Parihaka increased.

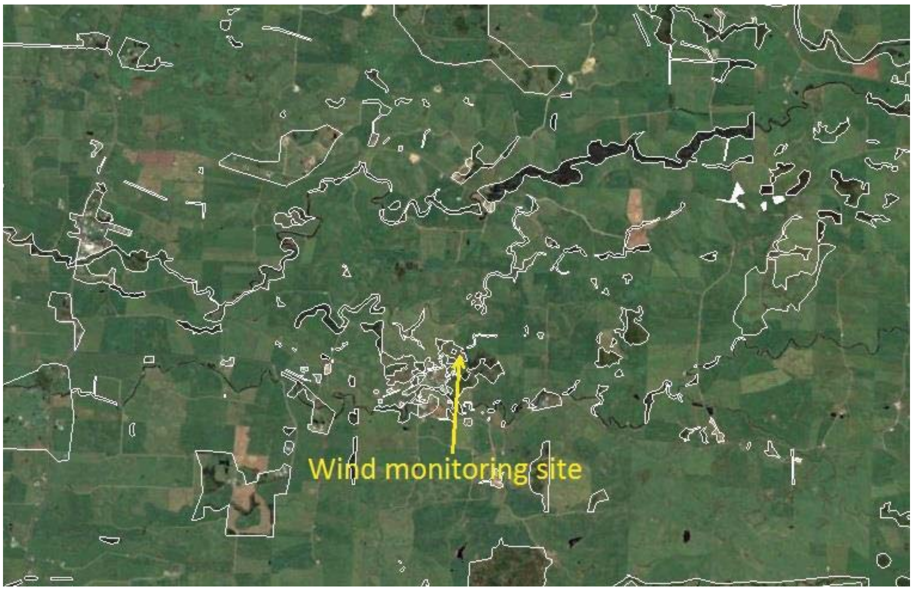


Figure 15: Example of areas of contigous surface roughness surrounding Parihaka

These polygons were imported into Map Editor, and surface roughness values attached, using values such as those shown in Table 4 (based on suggestions found in the European Wind atlas (Troen & Petersen, 1989)):

Table 4: Surface roughness factors applied for wind modelling

Feature	Surface roughness values used (m)
Water (i.e. Tasman Sea)	0.00
Bush/dense vegetation	1.00
Farmland (distant from site, open e.g. near coast)	0.05
Farmland (distant from site, many shelterbelts and remnant bush e.g. near national park)	0.20
Farmland (surrounding site; much detail of vegetation, buildings etc provided separately and hence representative of pasture only)	0.02
Riparian plantings	0.20
Scrub/gorse	0.30
Townships, papakāinga, collections of farm buildings	0.50
Shelterbelts	0.30

Obstacles to wind flow are specified within WAsP as rectangular boxes. The bearings and distances to two corners of the rectangle from a given known co-ordinate are entered; along with the depth, height and porosity (to wind flow). Features were included as obstacles rather than roughness (not both) if either the wind tower or potential wind turbine sites were thought to lie within a distance of 50 obstacle heights and have an elevation lower than three obstacle heights. These typically tended to be stands of large trees planted for wind shelter.

The obstacle description above was found by marking wind tower or potential wind turbine sites by GPS, and using these sites as a vantage point to both sight bearings to obstacle corners using a compass and to sight elevation angles to obstacle tops using an inclinometer. The distance to corners was measured using Google Earth, and obstacle heights calculated using trigonometry. The difference between the elevation of the obstacle top relative to the vantage and the contour on which the obstacle was situated determined the obstacle height.

The chosen porosity of identified obstacles was based on suggestions by Troen and Petersen (1989):

- solid structures - 0%;
- very dense vegetation - 35%;
- open vegetation - 50%.

It is possible that large trees (around 30 m tall) within 200 m of the wind monitoring site may have had some shelter effect on the data collected. If WAsP was to overestimate this shelter effect, the generalised wind climate would be overestimated. Based on research by Taylor and Salmon (1993), the WAsP help file suggests that the shelter model used may overestimate the effect of shelter provided by 3D objects (such as trees) by up to a factor of two. To ensure a conservative generalised wind climate, porosity values for these close obstacles were the midpoint between those originally chosen and 100% (i.e. the shelter effect is halved).

WAsP can provide a prediction of the expected wind resource either at a specific potential wind turbine location, or as a resource grid showing the varying resource over the landscape at a particular height above ground. To choose which height above ground to model, the wind shear (the change in wind speed with height) was calculated using the two heights of wind speed measurement. Shear was approximated using the power law profile (Jain, 2011), assuming that

$$\frac{v_2}{v_1} = (\frac{h_2}{h_1})^{\gamma}$$

where $v_2 =$ mean wind speed at the upper measured level = 5.5 m/s
$v_1 =$ mean wind speed at the lower measured level = 5.2 m/s
$h_2 =$ upper measurement height above ground level = 15 m
$h_1 =$ lower measurement height above ground level = 10 m
$\gamma =$ wind shear

The wind shear is thus 0.176. Wind increases dramatically with height up to around 10 – 20 m, and continues increasing at a lesser rate thereafter (Fig. 16). To choose an optimum wind turbine hub height would require a detailed comparison of tower and installation costs versus energy yields, which has not been done. Instead a tentative hub height of 30 m is chosen as a typical available tower height which falls within the zone of less change with height.

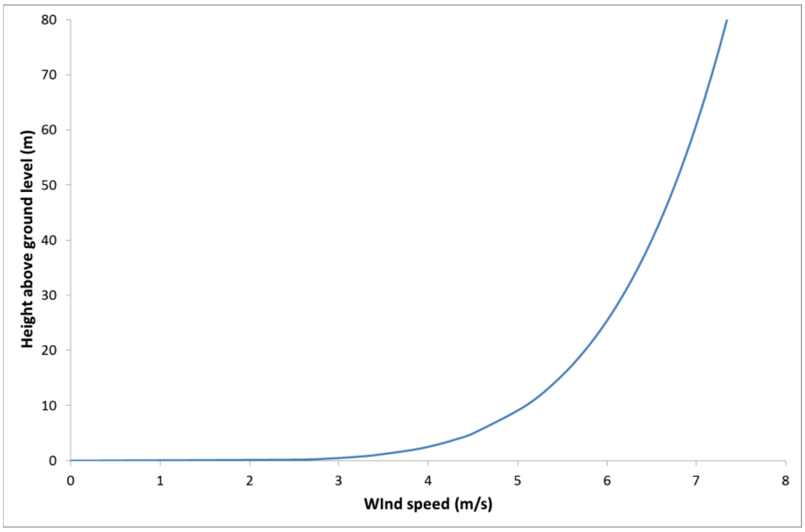


Figure 16: Wind shear profile at the monitored location, using the power law approximation

A 10 m x 10 m resource grid over a 1.6 km x 1.6 km area was generated using WaSP at a height of 30 m above ground level.

2.4.2. Solar resource

The NRG Li-Cor LI-200SZ pyranometer installed on the wind tower (Section 2.4.1) measured global horizontal solar irradiance (GHI) in W/m^2. Data stored by the Symphonie data-logger were the mean, maximum, minimum, and standard deviation for each 10 minute period. The data used was the 10 minute means for the period 21/1/2015 – 20/1/2016 inclusive.

To take into account the interannual variation in solar radiation, hourly means of the measured data were correlated with concurrent Metservice data from the New Plymouth airport (38kms north east of Parihaka). The correlation index was 0.95 which suggests a very strong correlation. The measured Parihaka data was then scaled by a factor of 0.989, being the ratio between the mean GHI at the New Plymouth airport for the period 1992 – 2015 and the mean GHI at the New Plymouth airport for the concurrent period, to produce a long-term corrected dataset.

The surfaces available for collecting solar radiation on the roofs of buildings was found by measuring the roof pitch (using a builder's bevel, spirit level, and protractor) and length, width and orientation (using Google Earth satellite imagery). Transforming the irradiance on a horizontal surface to that on an unshaded inclined plane at Parihaka was calculated using both RETScreen[15] 4 software (for solar water heater calculations), and HOMER software (for solar photovoltaic electricity calculations).

[15] http://www.nrcan.gc.ca/energy/software-tools/7465

2.4.3. Hydro resource

Three waterways within or near the papakāinga (Fig. 17) were assessed for run-of-river micro-hydro potential.

Figure 17: Rivers and streams assessed for micro-hydro potential within the Parihaka locality[16]

The available power to a micro-hydro scheme depends on the head and flow of the waterway.

$$P = \rho Q g h$$

where P = Power (W)
ρ = density of water ≈ 1000 kg/m^3
Q = volumetric flow rate (m^3/s)
h = head (m)

The head (or drop in elevation) of the accessible portion of each waterway was measured using a dumpy level. However the available head to a hydro scheme is reduced by headrace channel (and/or low head scheme delivery pipe/flume) slope to keep water moving at a minimum velocity, dynamic friction losses in penstock piping, and the need to keep equipment (turbines, powerhouse etc) out of the flooding zone. The Waitotoroa, in particular was observed to be "flashy" with a high flooding zone. A very significant flooding event occurred on the 20th June 2015, which deposited debris on the road bridge. A good indication of the flooding zone was found by surveying the bridge height above the river bed, and also by examining debris in vegetation in river banks.

The flow of a waterway varies with time based on rainfall, inflows, upstream extractions etc. The flow (also known as discharge) of each waterway was measured over a range in flow variation during a 12 month period.

The open channel flow of a waterway at a given location (m^3/s) is a product of the mean velocity of water (m/s) and the cross-section area of the water (m^2). The Awaiti and Otahi-iti waterways both pass through concrete culverts, which were used as convenient points of known cross section area. Discharge measurements of these two waterways were made by Mr Hohaia approximately weekly, in the following manner:

- The level of the water (m) within the culvert was measured with a ruler (either from the bottom of the culvert, and low flows; or from the top of the culvert and subtracting from the culvert diameter). The area of a segment was then used to calculate the cross-section area of the water in the culvert.

[16] Image: NZTopo50-BJ28 map, 20m contours, LINZ

- The velocity of the water was measured using a hand-held electromagnetic velocity meter[17], taking the average reading over a 40 second period (Fig. 18). The sensor was placed at arm's reach inside the culvert exit. The sensor was positioned at 60% of water depth below the surface, at the midpoint of laminar flow.

Figure 18: Mr Hohaia measuring water velocity and area within the Otahi-iti culvert pipe

Early in 2016 it was noticed that earthworks above the culvert had damaged it, causing a significant amount of water to exit the wall of the culvert and then flow beneath it. From March 2016, discharge measurements were made at the entrance side of the culvert, and previous data were therefore not used in calculations.

Discharge measurements of the larger Waitotoroa river used the Velocity Area method described by National Environmental Monitoring Standards (NEMS, 2013), as follows.

- The site chosen was upstream of the confluence with the Awa-iti, with smaller boulders than elsewhere, and a reasonable uniform profile and laminar flow. An old brick chimney had fallen into the river nearby and may have influenced readings at high flow.

- A staff gauge (Fig. 19) was installed at the measurement site to enable visual readings of the river stage (level). The staff gauge was surveyed against nearby known objects, so that it could be reinstated if washed away.

- The area at the point of measurement was found by dividing the width into 20 segments with a tape measure, and measuring the water depth with a ruler at the boundary of each segment (Fig. 20). The area of each segment was approximated by multiplying its width by the average of the two boundary depth measurements.

Figure 19: Staff gauge installed in the Waitotoroa river

[17] Valeport model 801 flat type, with range -5 m/s to 5 m/s, accuracy +/- 0.5% of reading plus 5 mm/s, minimum water depth 5 cm

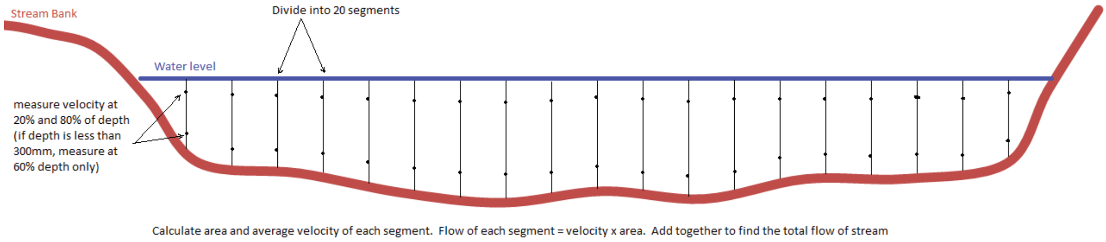


Figure 20: Velocity Area method of measuring waterway discharge

Figure 21: Electromagnetic sensor measuring water velocity in a stream

- At each segment boundary, the velocity was measured using the electromagnetic velocity meter (Fig. 21), taking the average reading over a 40 second period (the meter was set up to perform this). Measurements were taken at 60% of depth below surface (if depth < 0.3), or else were the average of readings at 20% and 80% of depth below surface (depth > 0.3). The velocity of each segment is the average of the two boundary values.
- The discharge (velocity x area) of each segment was calculated, and the 20 values summed to calculate the total area.
- The stage was recorded before and after the gauging, and the average taken.

Wading the river in this way was not done if the water level was above 0.5 m on the staff gauge, for safety reasons. In this case a timed float method was employed, where the transit time of a floating object is measured over a known distance. A straight section of river run of relatively uniform profile near the staff gauge was chosen, and wooden pegs driven into the banks to mark start/end points of a 17.4 m stretch. A dumpy level was used to survey the cross section profile at the start, middle and end of this stretch, using the staff gauge as a datum. The average cross-section area for a given water level could then be calculated by reading the staff gauge (readings taken before and after discharge gaugings).

Oranges were used as the floats; due to being visible, of uniform shape and size, and floating low in the current. An orange was placed mid current well upstream, then timed through the marked stretch. This was repeated at least six times (rejecting any results where the orange left the main current), and the average taken.

The mean velocity of the river is approximated by 0.45 x distance travelled/mean transit time, where 0.45 is a correction factor (for a relatively shallow rocky waterway) to account for the fact that mean river velocity is less than the high velocity at the surface, centre of flow (Harvey, 1993).

Because these are time consuming processes, weekly discharge measurements were not made. Rather, 11 discharge measurements were made over a range of flows, and correlation found with river stage (level). Mr Hohaia visually inspected and recorded stage (level) more or less weekly. The correlation was approximated by a 2nd order polynomial regression fit (using Microsoft Excel) to the measured data points (Fig. 22). This correlation was then used to calculate regular flow data.

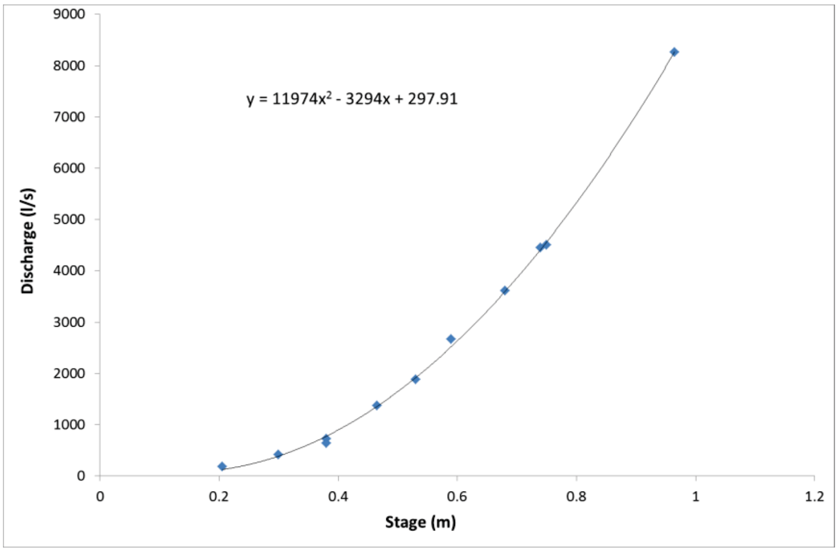


Figure 22: Stage/Discharge Rating of the Waitotoroa river

Although water flow data continued to be collected until December 2016, the periods of data used for calculation were:

- 13/5/2015 – 20/5/2016 11 discharge measurements, 88 stage readings (Waitotoroa);
- 21/8/2015 – 5/9/2016, 33 discharge measurements (Awaiti); and
- 5/3/2016 – 5/9/2016, 18 discharge measurements (Otahi-iti).

To take into account inter-annual variation, and also the sometimes dramatic variation within a week (indeed a day), the collected data was compared to concurrent flows of two nearby rivers (Fig. 23):

- the Punehu river, monitored by NIWA, mean daily flows, Jan 2001 – May 2016; and
- the Kapoaiaia river (monitored by Taranaki Regional Council), 5 or 15 minute spot flows, Jan 2001 – May 2016.

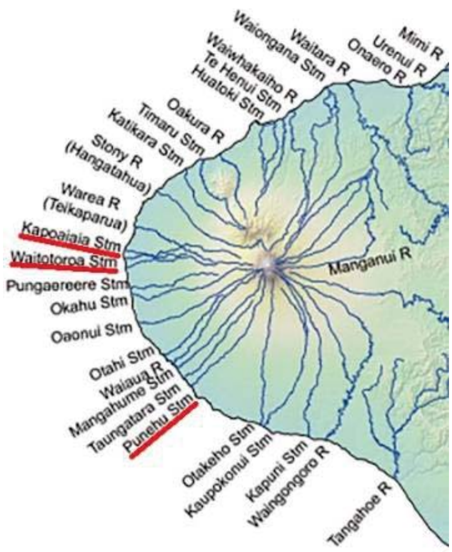


Figure 23: Rivers with similar origins used for long term hindcasts[18]

After matching timestamps or averaged data, various correlations using least squares linear regression were compared. Because the design of a micro hydro scheme is constrained by low flows, high flow values were in many cases discarded for generating

[18] Reproduced from https://reihana23.wordpress.com/cultures/, accessed December 2016

the correlation, in order to improve accuracy at low flows. The best correlations (particularly at low flows) between each waterway and long term data were (Figs. 24 to 26):

- Waitotoroa: Kapoaiaia river, for Waitotoroa flow < 1000 l/s, correlation index 0.96;
- Otahi-iti: Kapoaiaia river, for Kapoaiaia flow < 4000 l/s, correlation index 0.82; and
- Awa-iti: Kapoaiaia river, correlation index 0.82.

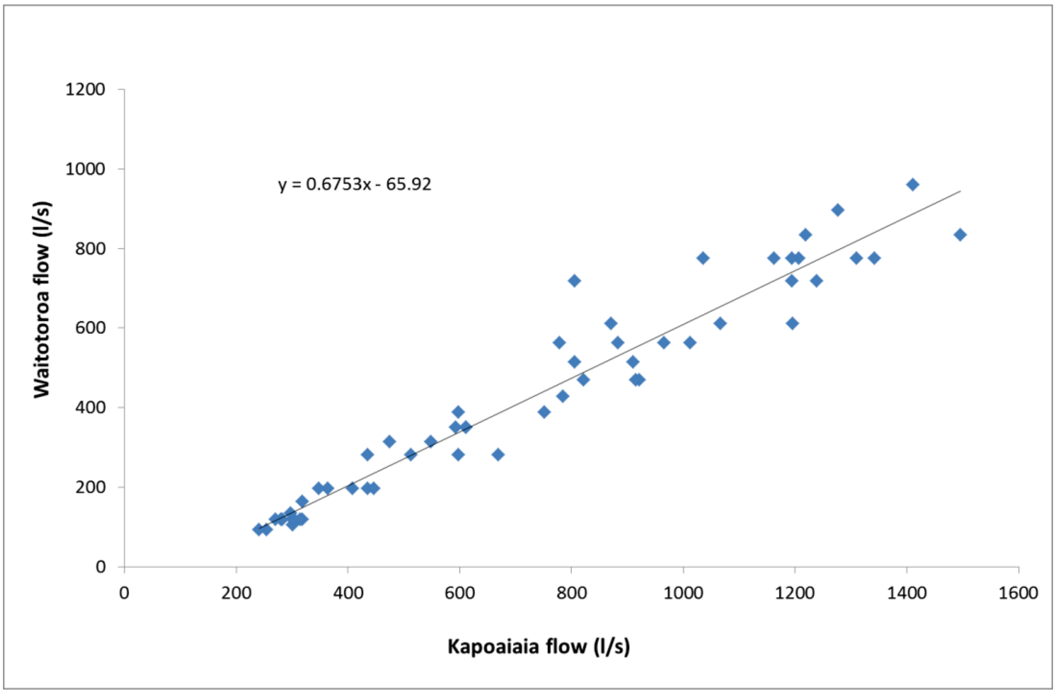


Figure 24: Relation between Waitotoroa flow and Kapoaiaia flow, for period May 2015 – May 2016

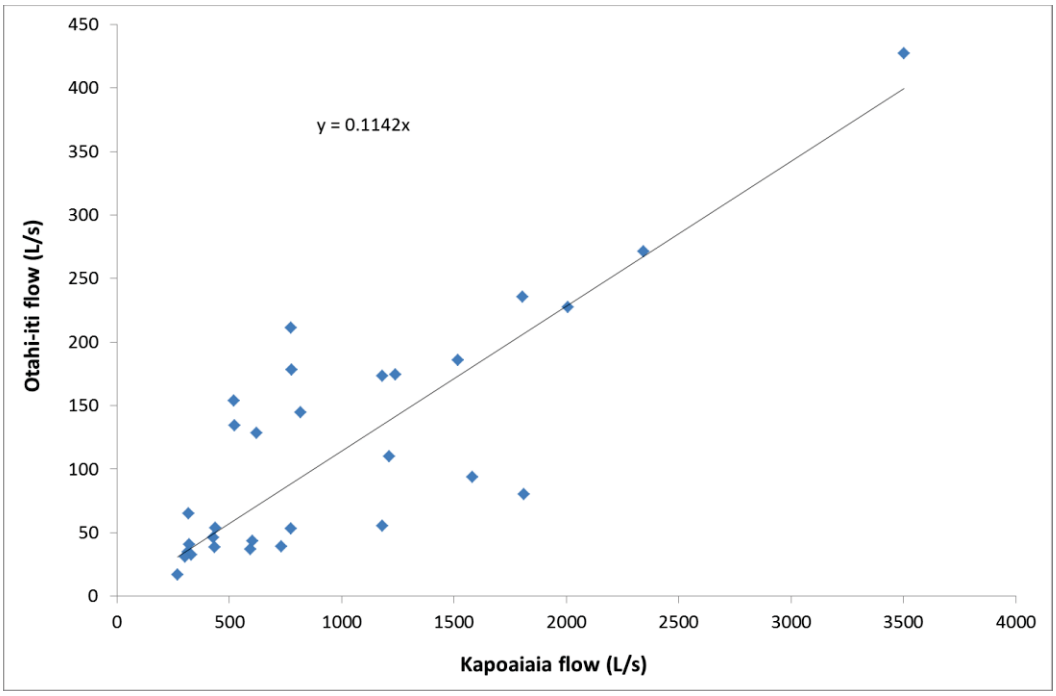


Figure 25: Relation between Otahi-iti flow and Kapoaiaia flow, for period March 2016– September 2016

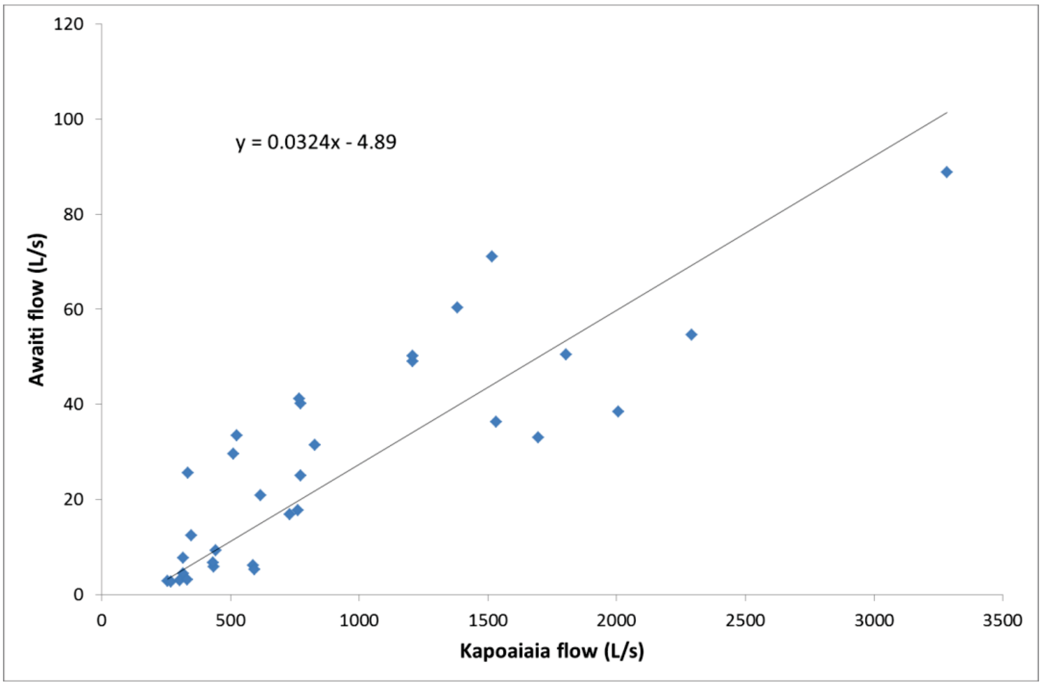


Figure 26: Relation between Awaiti flow and Kapoaiaia flow, for period August 2015 – September 2016

Long term hindcasts of the hydro resource were made by transforming the Kapoaiaia flow data as follows:

Waitotoroa flow (l/s)	= 0.6753 x Kapoaiaia flow (l/s) - 66
Otahi-iti flow (l/s)	= 0.1142 x Kapoaiaia flow (l/s)
Awaiti flow (l/s)	= 0.0324 x Kapoaiaia flow (l/s) - 5

Note that intercepts of the linear fit for the Awaiti and Otahi-iti were forced to ensure predictions were not significantly overestimated at low flows. Note also that these two waterways are smaller than the other two, with less catchment area. As such, they have a poorer correlation with the Kapoaiaia river (which originates on Mt Taranaki).

Flow duration curves of each waterway were then generated by reordering the hindcast values by magnitude.

To find the best location (in terms of energy available and cost effectiveness) for a micro-hydro scheme at Parihaka, the power output and indicative cost of many different configurations of intake location, channel, penstock, design flow, turbine type and size, and discharge location were estimated. Assumptions used were:

- damming rivers was not considered due to the environmental effects;
- due to the low gradient, a channel or low pressure pipe would be used to divert water to a forebay tank out of the flooding zone;
- the selection of turbine type was based on the selection chart in Appendix C (Fig. C1);
- many costs were not included, e.g. powerhouse shed or inverter. The major costs estimated were (see Appendix D for details):
    - channel materials and excavation;

- penstock or flume;
- turbine; and
- cable from powerhouse to grid connection;

- the turbine would run at a fixed design output due to the complexity of varying output with river flow (for flows less than the design flow, no output was assumed;
- residual flow (not diverted to hydro scheme) is 75% of minimum flows (actual allowable take would be restricted by resource consent conditions);
- overall efficiency of the hydro scheme is 0.5 (Harvey, 1993);
- minimum water velocity is 0.3 m/s to avoid silting (Harvey, 1993); and
- the effect of elbows at the end of the penstock was not considered.

To determine potential channel/penstock layouts, a dumpy level and GPS were used to mark waypoints/contours of equal elevation from potential intake locations.

Waitotoroa layouts considered

The terrain surrounding the Waitotoroa river within the papakāinga would make a water diversion scheme very challenging. Due to the high steep banks and vegetation, diverting water to the true right of the river was not considered. Challenges on the true left include a section of very steep vegetated bank (which would necessitate either a suspended aqueduct within the flood zone, or very extensive earthworks), a footbridge, and a house situated close to potential discharge points (and which may be affected by noise issues). Figs. 27 and 28 show the infrastructure layouts considered. The expected power and indicative cost of various intake and discharge points were calculated. Both turgo turbines with penstock and low head propeller turbines with a flume/supply pipe were included, based on the head and flow available (Fig. C1).

Figure 27: Water diversion routes considered for micro-hydro schemes on the Waitotoroa river (intake upstream of a steep bank)[19]

[19] Image: Google Earth

Figure 28: Water diversion routes considered for micro-hydro schemes on the Waitotoroa river (intake downstream of a steep bank) [20]

Otahi-iti layouts considered

Although the Otahi-iti does not pass through the papakāinga, a portion of it passes through a closely associated block of land. Within this portion, the culvert which was used for discharge measurements is an ideal intake location. Diverting water on either the true left or true right was considered. For much of the lengths of potential channels, the river bank has a slope of around 40° (estimated using an inclinometer). This means that an open channel would likely have stability issues, requiring either a retaining wall on the uphill side, or the use of an enclosed pipe. Fig. 29 shows the position of potential diversion channels: various discharge points were considered. Only turgo turbines with penstock were considered, based on the head and flow (Fig. C1).

Figure 29: Water diversion routes considered for micro-hydro schemes on the Otahi-iti river[21]

[20] Image: Google Earth
[21] Image: Google Earth

Awaiti layout

The only configuration considered for the Awaiti (Fig. 30) would use a low head propeller turbine (Fig. C1) as there is a natural slot in the waterway near the confluence with the Waitotoroa river which would lend itself well to discharge through a vertical draft tube. The culvert used for discharge measurement would be used as the intake position (note this culvert is due to be replaced), as upstream of the culvert the fall of the waterway is very flat, and subject to flooding.

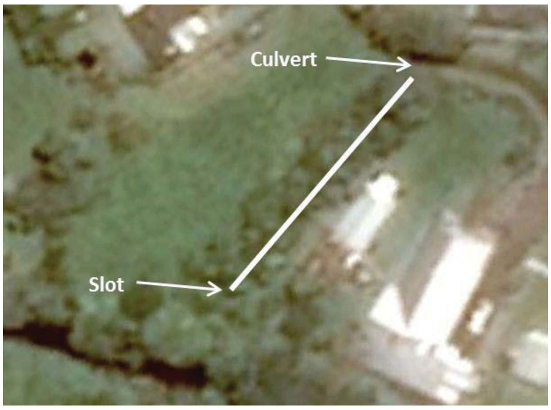


Figure 30: Water diversion route considered for a micro-hydro scheme on the Awa-iti stream[22]

Comparing micro-hydro sites

For a number of various configurations and design flow, both expected annual production (kWh) and cost effectiveness in terms of initial installed capital cost and available power output ($/W.cf) were calculated, where cf is capacity factor. In this case, the capacity factor is the proportion of time that the turbine is running at design flow (found from the flow duration curve).

$$Annual\ production\ (kWH) = \frac{Power\ output\ (W)}{1000\ \times 365 \times 24 \times proportion\ of\ time\ design\ flow\ available}$$

$$Power\ output\ (W) = \eta_{overall}\rho Q g h_{effective}$$

where

$$h_{effective} = h_{measured} - channel\ drop\ (to\ keep\ water\ moving\ at\ minimum\ velocity) - flume\ drop\ (for\ propellor\ turbine) - flood\ level - head\ loss\ due\ to\ penstock\ friction\ (for\ turgo\ turbine)$$

$$channel\ drop = channel\ length\ \times\ channel\ slope$$

$$channel\ slope = \left(n \times \frac{v}{R^{0.667}}\right)^2$$

v = water velocity (m/s): various values from 0.3 – 1.5 iterated
n = roughness coefficient of channel, as per Table 5
$\mathrm{R} = \text{hydraulic mean radius (m)} = \frac{A}{P}$
$A = \text{channel cross section area } (\mathrm{m}^2) = Q \times \frac{F}{v}$
F = freeboard allowance of channel = 1.3
P = wetted perimeter (m), as per Fig. 31

[22] Image: Google Earth

Table 5: Roughness coefficents of micro-hydro headrace channels

Channel surface	Roughness coefficient n
Earth channels, depth of water (H) < 1m	$\frac{0.04}{\sqrt{H}}$
Precast concrete	0.01
Poured concrete	0.018
Uncorrugated plastic pipe (aged)	0.01

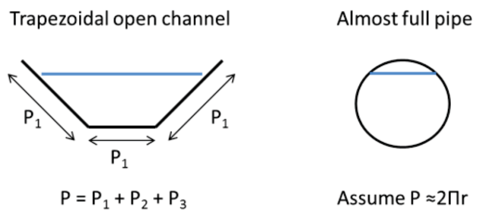


Figure 31: Wetted perimeter of channels

Flume drop is calculated in the same way as channel drop

$$\text{Head loss due to penstock friction (m)} = \frac{0.08 f L Q^2}{d^5}$$

where f = friction factor (from Moody chart, Fig. 32)

d = internal diameter of penstock (m)

L = length of penstock

In each applicable case a penstock diameter was chosen (for costing purposes) to keep static head losses (due to pipe friction) between 5 – 15% of the available head.

Cabling between the turbine and the inverter (assumed to be located near the 100 kVA transformer, Fig. 89) is chosen (for costing purposes) to keep voltage drop less than 5%, assuming copper cable and a voltage of 350 V, which is a typical operating voltage of locally manufactured Powerspout micro-hydro generators (Lawley, 2014).

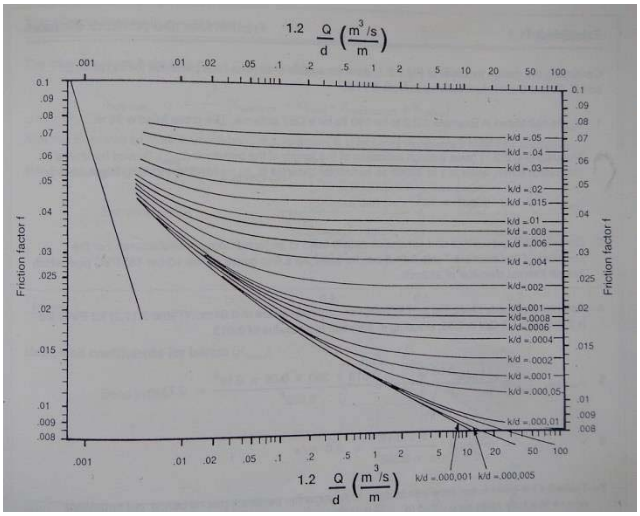


Figure 32: Moody chart for determining penstock internal friction factor[23]

[23] Reproduced from Harvey (1993)

2.4.4. Biomass resource

Potential local biomass resources include various waste streams (sewage, green waste, farm animal by-products) and crops grown on papakāinga or surrounding land. Producing biogas energy from organic wastes was not included in the study and may be a prime area for further study at Parihaka (for example the potential for anaerobic digestion of organic wastes). A survey of land area available for growing biomass crops was not performed. This is because there are many potential competing uses for Parihaka land - such as food production or housing - and determining which areas may be available for energy purposes will require significant community discussion. Instead, the approach taken was to calculate the area of land required for various scenarios. This information can now be used to inform decision making on land use at Parihaka.

Previous experimental work was referred to in order to provide an indication of how much energy could be grown per hectare per year at Parihaka. This will differ for different crops, which in turn will have their performance affected for better or worse by the local climate, soil type, drainage etc. For this study the focus was limited to short rotation coppicing (harvesting trees a few years after planting, allowing them to regrow from the stumps, periodically harvesting every few years) of *Eucalyptus* trees for the following reasons:

- fast growing, hence can produce high levels of stored energy per hectare per year, and shorter lead time to first harvest;
- coppicing ability saves on the cost and effort of regular replanting (however mechanical harvesting can be challenging); and
- a reasonable level of data is available. Massey University has a body of practical research into yields in a neighbouring region (Manawatū) of New Zealand, which may have somewhat similar climatic conditions.

Sims et al. (1999) investigated coppicing *Eucalyptus* yield at Palmerston North, New Zealand. Small plots of various *Eucalyptus* species were planted at a stocking density of 2200 stems/ha, and harvested every three years for five rotations. Mean annual incremental yields measured ranged between 12 – 24 oven dry tonnes per hectare per year (odt/ha/yr).

However the authors state that “commercial scale crop yields are likely to be considerably lower”. Sims (2002) provided a commercial case study example in Sweden where *Salix* coppice yields were 40% of what had been expected.

For this study the midpoint of the trial results, 23 odt/ha/yr (equivalent to 28.75 t/ha/yr at 20% moisture content i.e. air dried) was scaled by a factor of 0.4 to produce a working value of 9.2 odt/ha/yr or 11.5t/ha/yr at 20% moisture content.

Senelwa & Sims (1999) state the LHV energy density of Eucalytus wood is

$$-0.1391 \times moisture\ content\ (\%) + 19.481$$

and so a LHV of 14.79MJ/kg is used, giving an expected energy yield of 171 GJ/ha/yr.

This is not to say that there are not many other potential energy crops suitable for biomass production. Community interest in native species (such as *Kunzea* ericoides (kānuka) and *Leptospermum* scoparium (mānuka)) was also noted – however data is not available for yields, and these species are much slower growing than *Eucalyptus* species.

No consideration of the local ecological effect of an energy crop was made.

2.5. Predicting the Performance of Various Renewable Energy Conversion Technologies

2.5.1. Performance indicators

For each potential renewable energy system which could be installed at the papakāinga, there would be many resulting technical, economic, social/cultural, and environmental outcomes. For this study the expected outcomes were simplified into the three following estimated quantitative descriptions:

- the expected net present cost (NPC) to the papakāinga over 20 years (based on approximate rather than detailed prices);
- the expected percentage reduction of energy imports to the papakāinga; and
- the expected percentage reduction of carbon dioxide equivalent emissions

Net present cost (NPC)

This provides an indication of opportunity cost of renewable energy projects against other papakāinga development projects, and to identify which renewable energy projects are more cost-effective than others at providing the desired outcomes. The NPC is the sum of all expected major costs, capital and operational, discounted to the current period. Costs are assumed to occur at the end of the year in which they occur. A nominal discount rate of 8% and an inflation rate of 2% were used, resulting in a real discount rate of 5.88%. The most applicable rate to apply for a papakāinga is not known, however a value of 5.88% is similar to the 6% recommended by the New Zealand Treasury for "water and energy infrastructure"[24].

Reduction of energy imports

During one of the focus groups held at Parihaka (Section 2.1), input was sought from the community as to what the research drivers were. Some of the key drivers identified were:

- uptake of innovative ideas and technology;
- reducing reliance on outside partners, increasing self-sufficiency;
- practicing peace by reducing conflict based on finite resources;
- procuring food from supermarkets may be easier and cheaper, but Parihaka prefers to grow food at the papakāinga, so in a similar approach utilising local sustainable resources for energy is preferred even if not the cheapest or most convenient option;
- there is no "sense of connection" to energy supplied from outside the papakāinga; and
- becoming consumers of energy supplied from outside has led to a loss of independence.

Based on the community input, one significant cultural and social factor which was identified is the independence of Parihaka. A dependence on energy sourced from outside is equated with a loss of sovereignty or independence. A community with full energy independence would

24 http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/currentdiscountrates, accessed October 2016

produce and use all of its own energy fuels. However the more achievable/feasible goal of *partial* energy independence is harder to quantify.

There are different ways to conceptualise energy independence. For example, the Ministry of Business, Innovation and Employment (2014) defines national “Energy Self-Sufficiency” as the “ratio of indigenous production of energy to total primary energy supply”, where indigenous production utilises local (in this case national) resources, and total primary energy supply is the total amount of energy supplied for use locally.

This may be a useful measure of energy independence for a papakāinga/reservation, however difficulty is encountered when different energy fuels and conversion efficiencies are compared. For example, consider a home which imports all of its energy from the electricity grid, 15% of which is used for a heat pump with COP = 2 for space heating. The energy self-sufficiency is 0%. Now consider replacing the heat pump with a wood-burner, η = 0.5, fuelled with locally grown wood, heating the home to the same level. The proportion of indigenous production to total primary energy supply is now

$$\frac{Energy\ content\ in\ wood}{Total\ energy\ use} = \frac{15 \times \frac{2}{0.5}}{100 + 15 \times \frac{2}{0.5} - 15} = 0.41\ or\ 41\%$$

The energy self-sufficiency measure has leapt to 41% in large part by significantly increasing the total energy supply, which seems to overstate the change.

Alternatively, Eurostat (2016) defines “Energy Dependence” as the ratio of net imports of energy to gross energy consumption, where net imports are total imports of energy minus total exports of energy. While this may also be a useful measure for a papakāinga, the treatment of energy exports causes difficulty. A home (electricity only) with a grid connected solar PV array which exports as much energy to the grid as it imports from the grid over a year would then have an energy dependence of 0% (and hence implied energy independence of 100%). However in one sense this home is still wholly dependent on the grid, for functions such as meeting significant and important winter evening loads, or for providing stable voltage and frequency.

Due to the difficulties in quantifying energy independence in these ways, a different approach was taken. Considering that energy independence is the inverse of energy dependence, and energy dependence is related to meeting energy needs by importing energy, then percentage reduction of energy imported (abbreviated to REI) is used here as a measure of progress towards independence.

Firewood is treated as a special case. Currently firewood is sourced locally through foraging. However recognising that significant population growth may deplete the resource, and that growing firewood increases independence, any firewood not specifically planted is treated as though imported within this measure.

$$REI\ (\%) = 100 \times (1 - \frac{Annual\ energy\ imported, proposed\ case}{Annual\ energy\ imported, base\ case})$$

where

$"proposed\ case"$ is the scenario under consideration
$"base\ case"$ is the current "as measured" situation

$$Annual\ energy\ imported\ (MJ) = annual\ LPG\ consumption\ (kg) \times specific\ energy\ of\ LPG + annual\ electricity\ consumption\ (kWh) \times 3.6 + annual\ wood\ consumption\ NOT\ sourced\ from\ local\ plantation\ (kg) \times specific\ energy\ of\ wood\ used$$

$$specific\ energy\ of\ NZ\ LPG = 49\ MJ/kg$$

$Specific\ energy\ of\ wood\ used$ varies with moisture content and species. The base case uses the LHV value calculated as in Section 2.2.3. The proposed case assumes that firewood is sourced from a local plantation and does not contribute to imported energy.

This measure has a couple of other advantages. The amount of energy supplied in forms other than electricity, LPG and firewood (for example, solar thermal water heating or ambient temperature for air source heat pumps) does not need to be explicitly calculated. This measure also allows a comparison of the merits of saving energy through efficiency or conservation versus generation.

Reduction of greenhouse gas (GHG) emissions

During the focus group discussions, much more emphasis was placed on local independence than global climate contributions. However a measure of the expected emissions of various proposals is also included, as an environmental factor. In order to take into account the range of greenhouse gases emitted, the carbon dioxide equivalent (CO_2-e) values were used as taken from the Summary of Emissions Factors for the Guidance for Voluntary Corporate Greenhouse Gas Reporting[25] , Ministry for the Environment, 2015 (Table 6).

Table 6: Carbon dioxide equivalent emissions factors applied for existing energy sources

Emission source	Unit	Emission factor total CO_2-e (kg CO_2-e /unit)
LPG	kg	3.03
Wood (closed carbon cycle) in residential fireplaces	kg	0.0795
Electricity purchased from NZ grid	kWh	0.138

Only emissions due to fuel consumption were considered, and not embodied energy in plant and equipment. The emissions of systems with significant battery storage are not provided in the results, as the validity of ignoring embodied energy for this case (where batteries are replaced at the end of their useful life) is not known (battery recycling capacity is also unknown).

It is also worth noting that using a single emissions factor for grid electricity may be an oversimplification, as different mixes of national generation sources may be online at different

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25 http://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/voluntary-ghg-reporting-summary-tables-emissions-factors-2015.pdf

times. Generating electricity locally is likely to have best potential for reducing emissions during national peak demand times (evenings).

All firewood (whether classed as imported or grown) was assumed to have been harvested sustainably (with crops replanted) and hence with a closed carbon cycle.

2.5.2. Renewable energy conversion technologies and system architectures considered

Many renewable energy technologies have been developed which may be useful for Parihaka. To limit the scope of study to a manageable level, only a selection were considered, based on author judgement.

Generating biogas may provide a useful role in providing a papakāinga with heat and/or electricity, but is not covered here due to the technical challenges in storage and distribution. District heating was not considered due to the dispersed building layout. Cooking as an application is not specifically considered, as the data collection did not isolate energy for cooking in all cases. Combustion of biomass is considered for heat generation only, rather than combined heat and power (CHP) generation. This is because heat is easier to produce than electricity from biomass, and because land area for biomass production is likely to be limited. If establishing biomass production for heating proves successful and significant land area is available, then producing community electricity with an alternator and internal combustion engine fuelled by producer gas from a biomass gasifier could be considered as an area of further research.

Due to the community desire for an increase in energy independence, only technologies utilising local resources were considered. Importing renewable energy (such as solid fuels from forestry by-products e.g. pellets/briquettes, or recognition that grid electricity is from 80% renewable sources) was not considered.

The approach taken to investigate an “off-grid” community was to consider stand-alone residences rather than a stand-alone micro-grid. This was to allow for the planned population growth – stand-alone homes could be added as required. Community scale energy storage systems are not covered, however to consider maximum community independence further research into this may be warranted. Storing energy as hydrogen fuel may be an option in the future, however was assumed not yet readily commercially available. A hybrid off-grid system incorporating wind, solar and battery (or flow battery) storage may be feasible although likely expensive for the existing papakāinga. However expanding it to cater for rapid population growth would be very difficult, and the high growth scenarios proposed would likely require either dispatchable generation (e.g. bioenergy generators) or a significant reduction in energy storage costs. Using diesel generators to facilitate off-grid systems is not considered, due to becoming dependent on a fossil fuel supply chain. Surveying of an existing hilltop water reservoir for use in a small pumped hydro storage scheme was initiated but a full study was not completed. The cost of a community shed for storing harvested firewood or firewood harvesting/processing plant was not included.

Table 7 lists the technologies that were considered, whether on a building by building basis or utilising community distribution.

Table 7: The renewable energy technologies which were included in this study

	Individual buildings	Community distribution
Heat	- Biomass combustion, for space and/or water heating - Air source heat pump using electricity from renewable sources for space or water heating - Solar water heating (residences only)	- Not considered
Electricity	- Grid connected solar photovoltaics - Stand-alone systems: solar photovoltaics with energy storage	- Grid connected wind turbine generator - Grid connected solar photovoltaics - Grid connected micro-hydro
Energy storage	- Lead acid batteries - Hot water cylinders	- Not considered

Each building had a number of energy load profiles constructed to consider the effect of different combinations of technologies (Sections 2.5.3 to 2.5.8). Note that in all cases other than the measured base case, the load profiles were also modified to reflect recommended energy efficiency measures (Hernandez Pacheco, 2016). Residents' attitudes to various renewable energy technologies were surveyed (Quinn, 2016). Using wood for heating for a building was not considered if residents responded that they felt negatively about this.

Both grid-connected solar PV and combinations of the technologies listed in Table 8 were considered for existing individual residences.

Note that if residents were not open to using wood for space heating, then an "off-grid" or stand-alone home was not considered, as solar PV would be a poor choice for space heating in NZ, and survey results by Hernandez Pacheco (2016) indicated no existing home has sufficient passive solar heating to meet all winter heating loads. Stand-alone homes with wood heating were considered for all future homes. Although initially battery storage for individual homes while grid connected was considered, an update to HOMER software meant that optimising by "fuel minimisation" (and hence reduction of grid imports) was no longer available.

The very low load factor of marae energy use (due to the peak use during intermittent hui) suggests that powering marae from renewable energy resources would be challenging, given the diffuse nature of many RE resources. Stored and relatively concentrated energy resources such as biomass are most likely to be of use. Thermal storage within - or load control of - chillers may maximise RE penetration but were not modelled. The following technologies were considered for the three marae:

- Grid connected solar PV;
- Wood fired boilers for water heating.

	Heat pump, grid connection	Wood burner, grid connection	Wood burner, no grid
LPG water heating	If currently heating water with LPG	If currently heating water with LPG and wood heating acceptable	No
Solar water heater, LPG boost	If currently heating water with LPG	If currently heating water with LPG and wood heating acceptable	No
Wetback (or boiler) and LPG water heating	N/A	If currently heating water with LPG and wood heating acceptable	No
Solar water heater with wetback (or boiler) and LPG boost	N/A	If currently heating water with LPG and wood heating acceptable	If wood heating acceptable
Electric water cylinder	If currently using electric water cylinder but not wood heating	If currently heating water with LPG and wood heating acceptable	No
Electric water cylinder with excess PV diverter	If currently using electric water cylinder but not wood heating	If wood heating acceptable	No
Wetback (or boiler) and electric water cylinder with excess PV diverter	If currently using electric water cylinder but not wood heating	If currently using electric water cylinder and wood heating acceptable	No
Solar water heater with electric boost	If currently using electric water cylinder but not wood heating	No	No
Solar water heater with wetback (or boiler) and electric boost	If currently using electric water cylinder but not wood heating	If currently using electric water cylinder and wood heating acceptable	No
Heat pump water heater	If not currently heating with wood	If wood heating acceptable	No

Table 8: Energy source and appliance configurations considered for individual buildings

Given the many possible space and water heating configuration combinations for individual buildings, there are many possible aggregations of loads when considering community electricity demand. Three combinations of individual buildings were considered for aggregation:

1. each building uses the configuration with the lowest expected NPC;
2. each building uses the configuration with the most reduction of energy imports without increasing NPC;
3. each building uses the configuration with the maximum input of renewable thermal energy (solar water heater and biomass combustion if acceptable).

There is a limit to how much distributed electricity generation can be connected to the local electricity grid, without adversely affecting the quality (voltage, frequency, protection) of supply in the area. This could potentially be increased by allowing generation sources to be controlled, however for uncontrolled generation a maximum capacity must be defined by Powerco based on studying local load patterns. Upon requesting this information, Powerco were unable to supply a definitive answer without further study, however suggested that generation capacity at low voltage behind the main transformer would be primarily limited by transformer capacity. The maximum amount of total electricity generation capacity considered for grid connected systems was limited to 100kW, based on the 100kVA transformer. Note that larger systems may be able to connect to the medium voltage network if Powerco research identifies this, or if Powerco was provided with curtailment control.

Connecting generation sources to the medium voltage network is not considered, as the electricity produced would then presumably attract a (lower) wholesale rate rather than be self-consumed. One way to distribute locally generated electricity amongst the community would be to make use of the existing low voltage grid network. However, a mechanism is then required to allocate the benefits of locally generated electricity amongst the users.

One way to allocate the benefits of on-site grid-connected community generation might be to install a bi-directional kWh meter between the main distribution transformer and the various existing building ICPs fed by this transformer. These buildings could then be billed by a retailer as a group ICP at the new meter. An intermediate entity could then pay the group retail bill and also bill individual buildings based on the existing (or new if required) meters.

One challenge with this approach is that papakāinga properties north of the Waitotoroa river are supplied by a different transformer to those to the south. When considering this approach for the current population, load profiles from the two sides of the river are aggregated separately:

- north of river : 1 (used to model an unmonitored home), 2 (used to model an unmonitored home), 5, 6, 7, 8, 9, A, B, C;
- south of river: 1, 2, 4.

A different approach would be if a retailer offered peer to peer trading was available on the local network. In this case all buildings could be aggregated as one load.

2.5.3. Modelling energy efficiency gains

Energy load profiles were modified by incorporating the expected energy savings due to the energy efficiency gains proposed by Hernadez Pacheco (2016). Note that all that these changes were included when any electricity or heat generation was proposed, and excluded for "as measured" base case scenarios.

Modification to load profiles was made on a case by case basis. Some proposals were not included (reducing hot water element size, insulation in cathedral ceilings). In many cases Hernandez Pacheco provided an estimated saving in kWh/year for a given electrical circuit. These were modelled by scaling the power values. Note that this is an approximation – in reality many of the measures reduce overall energy by reducing run-time not power draw (e.g. refrigerator duty cycle). For this reason any calculations involving peak loads (e.g. inverter sizing) used the original unmodified data.

2.5.4. Modelling solar water heating

The expected performance of solar water heaters on individual buildings was predicted using the f chart method for service hot water only (Duffie & Beckman, 2013). This method assumes typical hot water use occurs every day; day to day variations in load can significantly affect the prediction. For this reason, solar water heaters were evaluated for residences only, and not for marae which have significant day to day variation. Solar water heating on marae would be better modelled using TRNSYS (not performed), but the large variability in loads would suggest that solar water heating is not an ideal match for marae.

The f chart method predicts the fraction of annual water heating load which is met by a solar water heating system.

$$F = \frac{\sum fiLi}{\sum Li}$$

where F = fraction of annual water heating load met by system
i = month
f_i = fraction of monthly water heating load met by system (see below)
L_i = monthly energy load required to heat water (J), including standing losses

$$f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3$$

$$X = F_R U_L \times \frac{F_R{}'}{F_R} \times \left(T_{ref} - \overline{T}_a\right) \times \Delta t \times \frac{A_c}{L} \times \left(\frac{11.6 - 1.18T_W + 3.86T_m - 2.32\overline{T_a}}{100 - \overline{T_a}}\right) \times \left(\frac{cylinder\ storage\ capacity}{75}\right)^{-0.25}$$

$$Y = F_R(\tau\alpha)_n \times \frac{F_R{}'}{F_R} \times \frac{(\overline{\tau\alpha})}{(\tau\alpha)_n} \times \overline{H_t} \times N \times \frac{A_c}{L}$$

where cylinder storage capacity is in l per m^2 of collector area – typically 75 l/m^2

$F_R U_L$ and $F_R(\tau\alpha)_n$ describe the performance/efficiency of a given solar collector

$\frac{(\tau\alpha)}{(\tau\alpha)_n}$ relates to the transmission and absorption of solar radiation by the various parts of a given solar collector. Klein (1979) suggests a value of 0.96 for collectors facing the equator at a tilt angle of latitude + 15°: this value is used here for all cases over all months

T_{ref} = 100°C, reference temperature

$\overline{T}_a$ = mean ambient temperature (°C), found by taking monthly means of the ambient temperature measured at the wind tower

Δt = number of seconds in the month

A_c = solar collector area (m^2)

L = monthly water heating load (J), described below

N = number of days in the month

T_W = minimum acceptable water delivery temperature, 60°C as per NZ regulations for stored domestic hot water

T_m = mains water temperature (°C), found from the cold water supply temperatures measured as described in Section 2.2.4

$\frac{F_R'}{F_R}$ is a heat exchanger performance penalty for active systems (collector needs to operate at higher temperature than tank),

$$\frac{F_R'}{F_R} = \left(1 + \left(\frac{A_c F_R U_L}{(\dot{m}C_p)_c}\right)\left(\frac{(\dot{m}C_p)_c}{\varepsilon(\dot{m}C_p)_{min}} - 1\right)\right)^{-1}$$

and $\dot{m}$ = mass flow rate through collector due to pump

C_p = fluid heat capacity = 3850 J/kg ◦C on the collector side, assuming glycol is used

c = collector

min = smaller of c (collector) and t (tank)

$\varepsilon(\dot{m}C_p)_{min}$ = heat exchanger effectiveness, assume = 0.8

and assuming $(\dot{m}C_p)_c = (\dot{m}C_p)_t$

Two types of collector were evaluated, flat plate and evacuated tube. Sample values for $F_R U_L$, $F_R(\tau\alpha)_n$ and A_c were found using the RETSCREEN database (Table 9)

Table 9: Solar water heater performance parameters used

	Flat plate	Evacuated tube
RETSCREEN library model used	Edwards Titan Plus	Thermomax TMO600
$F_R U_L$	4.91	1.65
$F_R(\tau\alpha)_n$	0.73	0.59
A_c	1.81	2.15

In the case of residences with LPG instant water heaters, the monthly heating load was found as follows.

- Multiple weighings of cylinder weights had typically been made each month (Section 2.2.2). The average rate of LPG consumption per day was calculated for each month.

- This was multiplied by the number of days in the month to find expected LPG consumption for the month (kg).
- Monthly energy draw-off of hot water (J) = monthly LPG consumption (kg) x specific heat capacity of LPG (49 x 10^6 J/kg) x efficiency of LPG water heating appliance (0.8).
- The average daily kWh was then calculated, which along with cylinder condition and volume was used to decide an appropriate level of cylinder standing losses.
- The monthly water heating demand for solar water heating system is the sum of the monthly energy draw off and expected monthly standing losses.

Isaacs et al. (2005) measured standing losses in electric water cylinders in NZ homes (Table 10: Findings from HEEP: Standing losses in electric water cylinders), as part of the nationwide Household Energy End-use Project.

Table 10: Findings from HEEP: Standing losses in electric water cylinders in NZ

Volume (L)	Grade	Standing losses (kWh/day)	Standard deviation of experimental results	Sample size
135	A or B	2.1	0.1	51
135	C or D	2.8	0.2	56
135	Wrapped	1.8	0.1	9
180	A or B	2.2	0.1	76
180	C or D	2.7	0.2	28
180	Wrapped	2.1	0.3	10
270	A or B	3	0.4	8

Cylinders installed as part of a solar water heating system are assumed to have an installation performance equivalent to the wrapped cylinders in this table (assuming similar ambient temperature surrounding the cylinder year-round). Standing losses for cylinders larger than 270l are estimated as follows.

Standing losses (kWh/day) = heat current (W_{th}) of heat loss through cylinder wall x 1000 x 24 h/day

$$H = kA\frac{T_H - T_C}{L}$$

where H = heat current (W)
k = thermal conductivity of cylinder wall & insulation (W/mK)
A = total area of cylinder wall (m^2)
T_H = temperature of stored water (K)
T_C = ambient temperature surrounding cylinder
L = thickness of cylinder wall & insulation (m)

Assuming different sized cylinders have similar k, A, T_H, T_C, and L, then

$$\Delta H \propto \Delta A \propto \Delta V^{\frac{2}{3}}$$

So proportional change in standing losses = (proportional change in volume)$^{2/3}$

The standing losses used in the analyses are shown in Table 11.

Table 11: Water cylinder standing losses used in the analysis of hot water demand at Parihaka

Cylinder volume (L)	Standing losses (kWh/day)
135	1.8
180	2.1
270	3
300	3.2
400	3.9
500	4.5
800	6.2
1000	7.2

For buildings with electric cylinders, a current transformer was dedicated to the element circuit (Section 2.2.1). The standing losses are included in the measurement data, and so finding monthly totals is all that is required.

For each building, various iterations were made of number of solar collectors and the corresponding nearest sized cylinder to 75 l/m^2 collector area, for both the flat plate and evacuated tube collectors. The configuration with the highest annual fraction without causing the highest monthly fraction to exceed 1.05 was chosen. This is because oversizing the system is both uneconomic and causes reliability issues due to stagnation[26].

The solar fraction was used to modify the energy demand data (whether electric load profiles or annual LPG usage) with the expected energy savings.

2.5.5. Modelling heat pump water heating performance

Heating water using air-source heat pump water heaters (HPWHs) is an energy efficient way of heating water with electricity, and also a form of indirect solar water heating. This was compared against other options such as solar thermal or diverting excess PV generation to an immersion element within an electric water cylinder (for residential buildings only).

A common measure of heat pump water heater performance is the coefficient of performance (COP), the ratio of the electrical input energy used to the energy content of the hot water supplied. Pollard (2010) pointed out that in reality HPWH COP decreases with lower daily water draw offs (due to the effect of standing losses), and lower ambient temperatures. The following modelled results (Fig. 33) from a study of installed HPWHs in New Zealand conditions (Pollard, 2010) were used to choose a COP for each building:

[26] http://www.heliodyne.com/wp-content/uploads/2016/02/Drawbacks-to-oversizing-a-SHW-system.pdf, accessed January 2017.

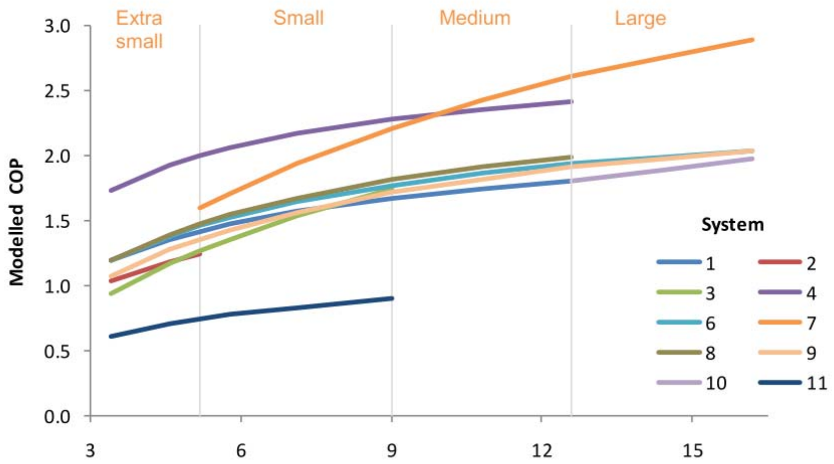

Figure 33: COP of various existing heat pump water heaters in NZ, modelled by BRANZ[27]

For each residence with LPG water heating, the monthly water heating demand and average daily draw-off energy over the year were calculated as per Section 2.5.4. The average daily draw off over the year was applied to the middle of the curves in Fig. 33, and a COP chosen. Assuming constant day to day water usage over each month,

$$Mean\ daily\ electrical\ energy\ input\ to\ the\ HPWH = \frac{Mean\ daily\ draw\ off}{COP}$$

The power draw of the heat pump water heater was assumed to be 0.8kW, and the daily run time during each month was the electrical energy input (kWh) divided by 0.8kW.

For each resident with electric water heating, the following assumption was made

$$COP_{existing\ water\ heater} = 1 - \frac{expected\ standing\ losses}{mean\ daily\ electrical\ input\ (measured) over\ the\ year}$$

where daily standing losses were estimated as per Section 2.5.4.

The measured electricity load profile was modified by scaling the water heating portion by a factor of $\frac{COP_{existing\ water\ cylinder}}{COP_{HPWH}}$.

2.5.6. Modelling heat storage in water cylinders

The thermal mass associated with storing hot water in a cylinder means there is some temporal buffering available between heating water and using it, providing a temporary form of energy storage. However energy will be lost over time due to heat loss through the insulation. The heat lost as the water cools from one temperature to another (in the absence of energy input) is described by

$$Q = \rho V c \Delta T$$

[27] Reproduced from (Pollard, 2010)

where Q = heat (J) associated with temperature change ΔT (K)
ρ = density of water (kg/m$^{3)}$ ≈ 1000
V = volume of water storage cylinder (m^3)
c = specific heat capacity of water (J/kg.K) ≈ 4184 at 60°C

The time taken for this change in temperature is dictated by the heat current (Section 2.5.4), which is a function of cylinder size, insulation, water temperature and ambient temperature. Ignoring the varying water temperature (and assuming steady ambient temperature throughout the year), the standing losses are assumed to be at all times those described in Table 11.

A cylinder can thus be sized to provide enough energy storage to retain an acceptable water temperature after a maximum period of no heating. The following assumptions were applied:

- minimum delivery temperature required is 37°C (Isaacs et al., 2005);
- the cylinder is heated to a minimum temperature of 60°C (further storage could be utilised by heating to higher temperature, but at the price of higher standing losses);
- the standing losses in Table 11 apply for the whole temperature range; and
- to provide diurnal energy storage, the cylinder needs to maintain minimum temperature for 17 hours (afternoon to morning).

This method was used to size cylinders (and hence indicate associated standing losses) for use with wetbacks and also with cylinders which are used to store excess PV generation.

2.5.7. Modelling wood fired boilers for water heating in marae

LPG consumption data from each marae was modified to reflect heating water for hui using wood fired boilers. Due to the intermittent nature of marae use, the boilers would not run constantly, but would rather be started up early in the morning of hui. Incorporated insulated water storage would allow enough water for the day to remain warm after being heated. The current LPG instant water heaters could be retained as boost/back up option.

It was quite obvious from inspecting the electricity consumption data of each marae which days the marae was in use for hui. The various hui over the 12 months were listed, along with the number of days duration of each hui. The total energy required to heat water for each hui event was assumed to be $E_{load} + E_{standing\ losses}$

where

E_{load} = energy required to heat the hot water draw off, with a minimum of $E_{load} \geq E_{heat\ up}$
$E_{heat\ up}$ = energy to heat the water in the storage tank from ambient = $mc\Delta T$
m = 1025 kg water storage capacity (based on hui water used as per Section 2.2.4 and commercially available storage size[28])
ΔT = 60 – ambient temperature (°C), where ambient temperature is measured as per Section 2.4.1

[28] https://www.marshallheaters.co.nz/products.html, accessed May 2016

E_{load} was found from the gas cylinder weight change over the course of the hui (Section 2.2.2).
$E_{standing\ losses}$ (MJ) = 7.2 kWh/day (from Table 11) x 3.6 x (number of days -1)

Assuming a boiler efficiency of 0.6,

$$Annual\ energy\ content\ of\ wood\ required = \frac{\sum energy\ required\ for\ all\ hui}{0.6}$$

2.5.8. Modelling other heat generation and use

For each building/scenario, the amount of energy supplied for space heating was found as described in Section 2.2. The amount of energy which would need to be supplied using wood burners or air source heat pumps was found assuming that:

$\eta_{existing\ wood\ burner}$ = 0.6 (0.5 for house 10 as the appliance had degraded);
$\eta_{new\ wood\ burner}$ = 0.7;
$COP_{heat\ pump}$ = 2.05 (Burrough et al., 2015); and
$\eta_{electric\ heater}$ = 1.

Quinn (2016) surveyed residents on their attitudes to various renewable energy technologies. Using wood for heating was not considered if residents responded negatively. The measured electricity load profiles were adjusted to reflect both heat pump and wood burner use.

To consider the effect of using a heat exchanger in the wood burner (referred to as a wetback in New Zealand and hereafter) to supply some water heating, the following assumptions were made.

- An equal quantity of wood would be burned each night over the heating season.
- The heating season for each residence was found from Hernandez Pancheco's (2016) survey, which asked which months space heating was used (typically May-September).
- The efficiency of the wetback was equal to the overall efficiency of the wood-burner. In other words, for a given piece of firewood burned, the same amount of energy would be lost (e.g. up flue) whether the wetback was present or not. Energy supplied to water heating is thus diverted from space heating.
- Existing and proposed rating of wood-burners is 15 kW_{th}.
- Available wetback sizes are 2, 4 and 6 kW_{th} (6 kW_{th} applies to a water jacket heat exchanger).
- The same amount of wood is burned each night over the heating period, and the same amount of hot water is used each day over each month.

The energy provided by different size wetbacks was found using the ratio of wetback capacity to overall wood-burner capacity. In each case, the space heating provided was kept constant and hence extra wood is supplied to meet the total demand. For house 6 (with large heating loads), a wood fired boiler able to meet all water and space heating loads was considered.

The biomass fraction (the fraction of water heating demand which is met by wetback or wood fired boiler) was calculated on both an annual and monthly basis. The wetback capacity was chosen to maximise annual biomass fraction while limiting the maximum monthly fraction to less than 1.05 (to prevent cylinder boiling). This was repeated for load profiles with solar water systems.

The biomass fraction was used to modify the energy consumption data (whether electric load profiles or annual LPG usage) with the expected energy savings.

2.5.9. Modelling electricity generation and use

The HOMER (Hybrid Optimization of Multiple Electric Renewables) computer model was used to:

- identify feasible solutions to meeting energy needs ;
- provide an estimate of expected NPC over 20 years for different scenarios; and
- provide an estimate of kWh of electricity purchased from the grid over this period (Fig. 34).

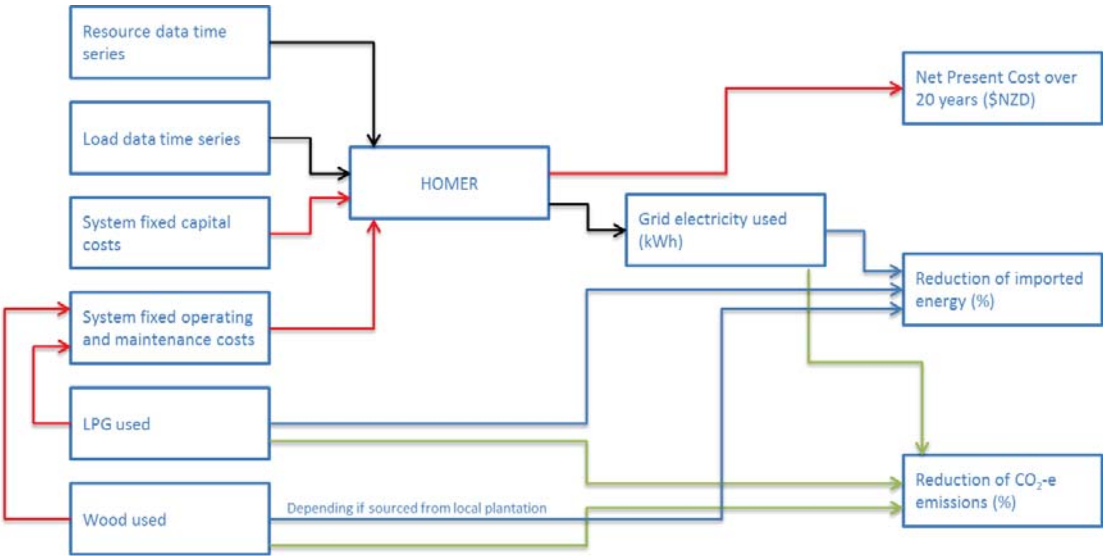

Figure 34: Diagram showing how HOMER was used to calculate the performance of each modelled solution

Individual building applications were treated first. Each cell in Table 8 required a separate HOMER model. For each building, the results of all HOMER models were exported to Microsoft Excel, and both the percentage reduction of energy imports and percentage reduction of carbon dioxide equivalent emissions calculated. Technically feasible solutions were ranked by NPC, and any solutions with an increase in NPC but no increase in reduction of energy imports was deleted. Least cost curves of the NPC of reducing energy imports were then generated.

Individual building load profiles, capital costs, O&M costs, LPG and wood consumption were aggregated to run HOMER models of community electricity supplies. Due to the current lack of one cohesive low voltage network (Section 2.5.2), separate aggregations were made each side of the Waitotoroa river. Community electricity generators were assumed to be connected behind the 100kVA transformer on the north side of the river, and hence only the north side is modelled in HOMER. For community supplies, the NPC to the papakāinga also included:

- the costs of establishing and replanting a firewood plantation; and
- the aggregated NPC of energy south of the river.

When it comes to future growth scenarios, growth would presumably happen in stages over the 20 year period. Rather than model a demand increasing with time against costs changing with time, the approach taken was to model future growth scenarios as if the future demand was currently present, with current prices and constraints applied. If a renewable energy system applicable to these future loads can be first envisaged and to some degree detailed, and then compared to a system applicable to current demand, then an expected programme of expansion of the system over time can be proposed.

The current grid-connect capacity constraint of 100kW was retained for future scenarios, even though the grid asset may be significantly different in 20 years (for example the transformer would need upgrading to cope with the uptake in electric vehicles proposed in the growth scenarios). This constraint is applied to test the effect of a limited generation capacity allowance – without it, similar results to the zero growth scenario are expected to scale up proportionally with population growth.

Three aggregations (Section 2.5.2) were used for each of the three growth scenarios (Section 2.3), and again least cost curves were generated. All new homes were assumed to be able to access community generated electricity.

3. Results and Discussion

3.1.Current Energy Demand

The quantity of LPG, firewood and electricity consumed in 13 papakāinga buildings over 12 months has been assessed, and an estimation of existing annual papakāinga electricity and heat demand has been derived from this (Table 12 and Fig. 35).

Table 12: Annual energy demand in study buildings

	Annual electricity demand (MWh)	Peak 10 min average (kW)	Annual LPG demand (kg)	Annual firewood demand (t)
House 1	2.85	4.4	100	0
House 2	5.87	9.1	0	0
House 3	5.21	7.9		0
House 4	5.44	6.5	190	0
House 5	5.43	5.8		0
House 6	14.29	8.2	0	1.7
House 7	2.59	6.2	80	2.2
House 8	2.88	4.3	120	0
House 9	3.73	7.5	200	2.4
House 10	5.83	7.4	0	1.3
Marae A	9.25	23.8	170	
Marae B	5.38	8.9	540	
Marae C	4.45	11.4	370	
Estimated Papakāinga	70.9 (255 GJ)	33 (behind N transformer)	1 900 (91 GJ)	6.2 (88 GJ)

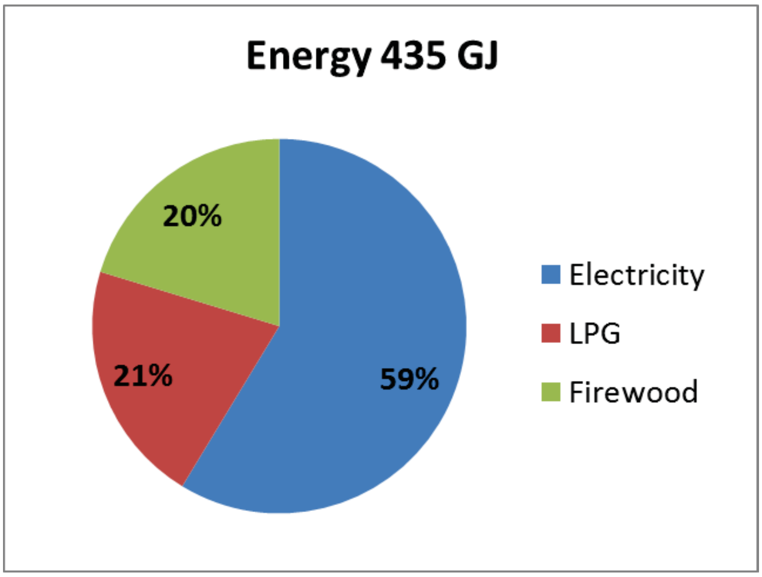

Figure 35: Estimated annual energy demand of the papakāinga (excluding transport) by fuel type

Data recovery rates from the electricity monitoring of 13 buildings had a mean of 91%, and missing records were filled as described in Section 2.2.1. The 12 months use of LPG was well captured where 45 kg cylinders are used. However, measuring LPG consumption from 9kg cylinders proved problematic. Meaningful results could not be extracted from the cylinder weighings at house 9, due to the frequent changing and rearranging of cylinders. The LPG consumption for house 9 gas is instead based on anecdotal information from the occupant that a 9kg capacity cylinder lasts for 3 weeks in summer and 2 weeks in winter. LPG was used for space heating in house 3 and for cooking in house 5, but was not measured in these instances.

Errors in modelling community electricity demand based on aggregating sample individual buildings are likely to be at least 10% (Appendix G), and electricity demand may well increase as intermittently used buildings are used more frequently or secure a grid connection.

The method employed for measuring firewood consumption was fairly crude and there will be significant uncertainty in these results. Of help was that most residents already appeared to have a reasonable idea of how much firewood they used annually.

The times of the highest 12 community peak 10 minute average loads during the measurement period (Table 13) typically correspond to lunch times during winter/spring hui and also winter/spring evenings.

Table 13: Times of largest community peak loads

Date/time NZST	Peak 10 minute average (kW), N transformer
4/06/2016 12:50	33
4/06/2016 13:20	32
18/07/2016 11:30	32
10/06/2016 17:50	32
18/07/2016 11:20	31
18/07/2016 12:10	30
18/10/2015 10:00	29
18/08/2015 7:30	29
14/08/2015 12:00	28
18/05/2016 11:20	28
4/10/2015 17:10	28
2/09/2015 18:50	28

The main end-uses of household energy (10 homes averaged, excluding transport) are presented in Figs. 36 - 38.

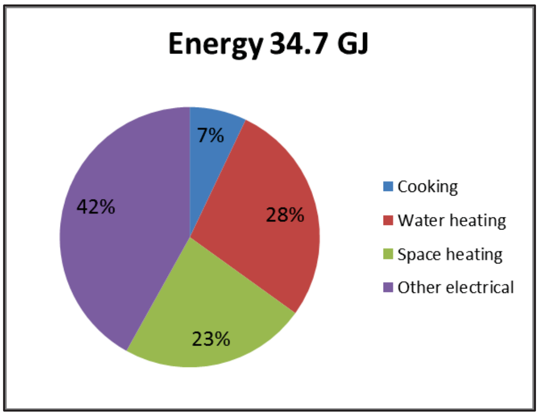

Figure 36: Mean annual household energy demand (exluding transport)

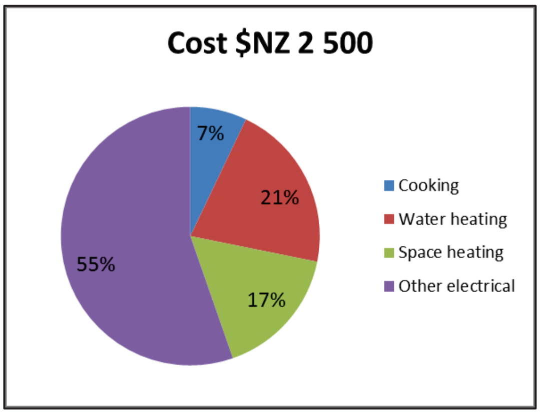

Figure 37: Mean annual household energy cost (excluding transport)

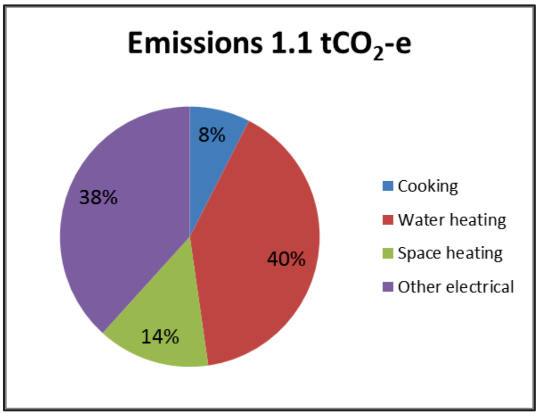

Figure 38: Mean annual household energy use related GHG emissions (excluding transport)

Although cooking has high instantaneous power demands, it does not represent a large proportion of energy use. Approximately half of household energy demand is for space heating and water heating.

The Household Energy End-use Project studying energy use in New Zealand homes 1999-2005 (Isaacs et al., 2010) recorded a mean annual energy demand of 40.4 GJ in New Zealand homes and 36.4 GJ in Māori homes. The mean annual energy demand of 34.7 GJ in this study (Fig. 35) is similar to the HEEP results for Māori homes.

A brief comparison is given with household energy use including transport (Figs. 39 to 41). Although transport energy use has not been measured, Mohan (2016) provided survey results detailing the average annual vehicle distance travelled self-reported by residents of 22 500 km per year. The following indicative comparison assumed

- 22 500 km per household per year;
- average fuel economy of 7 l/100km;
- a fuel price of NZD 2.00/l; and
- average GHG emissions of 0.231 kg CO_2/km for small passenger vehicles[29].

[29] http://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/voluntary-ghg-reporting-summary-tables-emissions-factors-2015.pdf

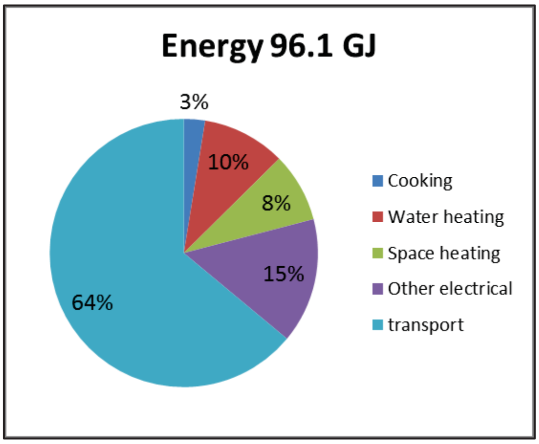

Figure 39: Mean annual household energy demand (including transport)

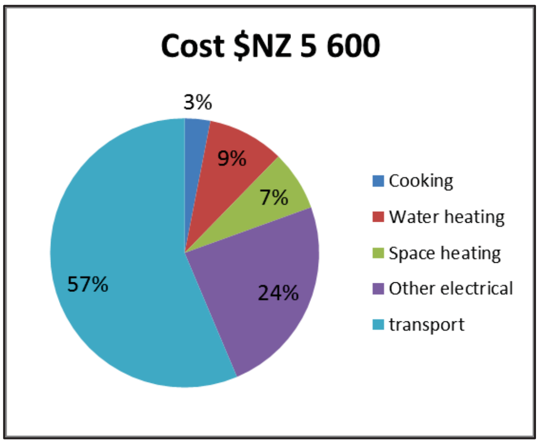

Figure 40: Mean annual household energy cost (including transport)

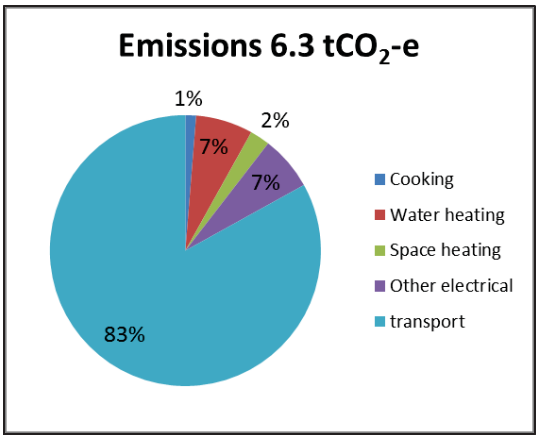

Figure 41: Mean annual household energy related GHG emissions (including transport)

This indicates that the largest household end use of energy in terms of energy cost and particularly GHG emissions is from private transport, highlighting the relative importance of the study by Mohan (2016).

The main end-uses of marae energy (3 marae averaged) are presented in Figs. 42 to 44.

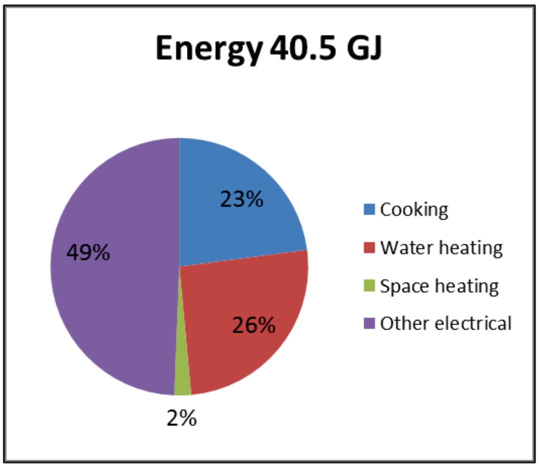

Figure 42: Mean annual marae energy demand

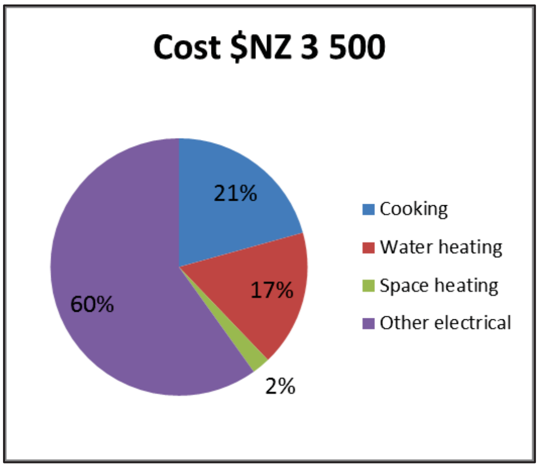

Figure 43: Mean annual marae energy cost

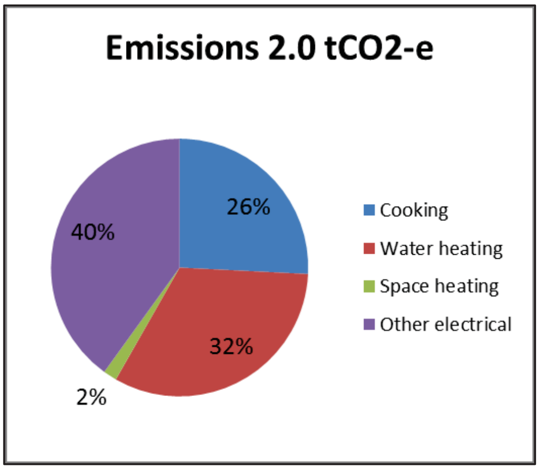

Figure 44: Mean annual marae energy related GHG emissions

Although cooking and water heating are large energy users during hui, a significant proportion of energy demand is in the form of other electrical loads which run between hui, such as freezers and refrigerators. Current annual energy quantity is not dissimilar to a household, although the frequency of hui may well increase with population growth. Although space heating is provided using basic resistive electric heaters, this does not currently represent a significant portion of annual energy demand.

Although not presented here, individual buildings have significantly diverse load profiles. However when aggregated, the load profile is a classic community profile for this climate (Fig. 45), with a large evening peak, lesser morning peak, and low power use in the small hours of the morning. The profile shape is likely dominated by household energy use, with significantly different profiles on days of large hui.

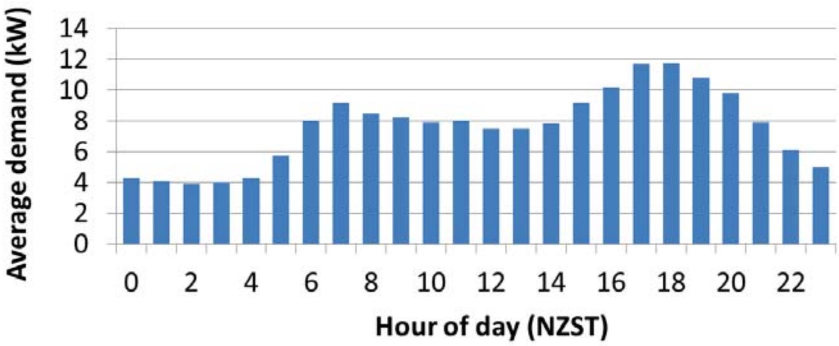

Figure 45: Mean daily electricity load profile of current papakāinga (as modelled)

Monthly community electricity demand shows significantly more energy use in the lower temperatures and shorter daylight hours of winter than in summer (Fig. 46). This difference will be further pronounced in LPG and firewood demand.

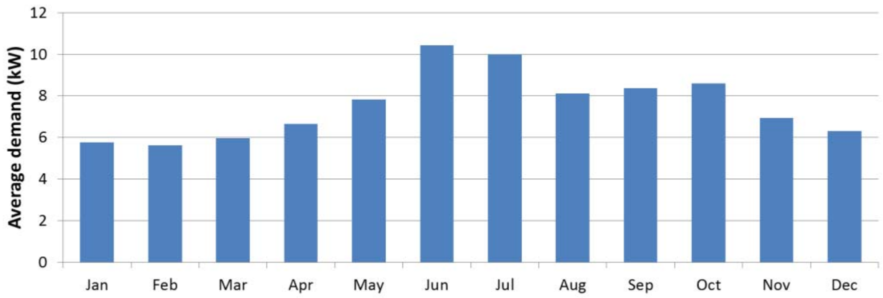

Figure 46: Mean monthly electricity demand of current papakāinga (as modelled)

Hot water use during the short periods of measurement is presented in Table 14. There are significant differences between means and maximums in even these short monitoring periods. This means that assumptions employed in the methods about typical hot water use occurring each day in households may not be entirely valid. Based on the measurement of hot water use during hui, it appears that proposed marae water heating systems should be capable of providing at least 1000 l of hot water in any given day.

Table 14: Measured daily hot water use in study buildings which use LPG to heat water

Building	Period	Mean daily hot water use (l/day)	Maximum daily hot water use (l/day)
House 1	20/2/16 - 13/3/16	85	152
House 4	21/5/16 - 16/6/16	111	252
House 7	20/1/16 - 14/2/16	40	99
House 8	20/9/15 - 16/10/15	60	109
House 9	22/11/16 - 16/12/16	130	297
Marae A	3 separate hui	273	281
Marae B	3 separate hui	502	605
Marae C	3 separate hui	486	961

The estimated net present cost of energy for the papakāinga (excluding transport) over 20 years is $368,000. This is used as the base case for comparing alternative options. This may be a conservative approach as the probable fuel cost escalations over and above general inflation are not considered, and some energy uses have not been included.

3.2. Future Energy Demand

The expected future papakāinga energy demand under a mid-growth scenario (100 new low energy homes, 47 EVs and 23 PHEVs, Section 2.3) has been proposed for various appliance configurations (Table 15), along with the expected time distribution of the corresponding electricity use (Figs. 47 and 48).

Table 15: Papakāinga annual energy demand (modelled for mid growth scenario)

Existing homes configuration	New homes configuration	Annual electricity demand (MWh)	Peak 10 minute average (kW)	Annual LPG demand (kg)	Annual firewood demand (tonnes)
Most economic (Table 21)	Heat pumps, electric water cylinders	835	348	1,802	6
Solar water heaters if economic	Heat pumps, solar water heaters	660	343	3,982	6
Most economic (Table 21) wood boilers in marae	Wood-burners and wetbacks, electric water cylinders	725	236	788	69
Wood burners and wetbacks (if acceptable), solar water heaters, wood boilers in marae	Wood-burners and wetbacks, solar water heaters	582	192	1,395	65

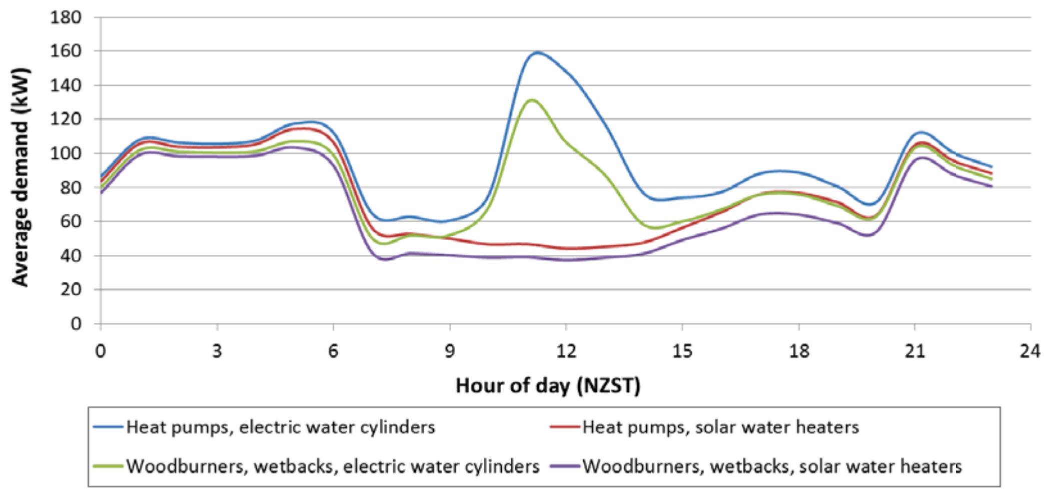

Figure 47: Average daily electricity load profiles (modelled for mid-growth scenario)

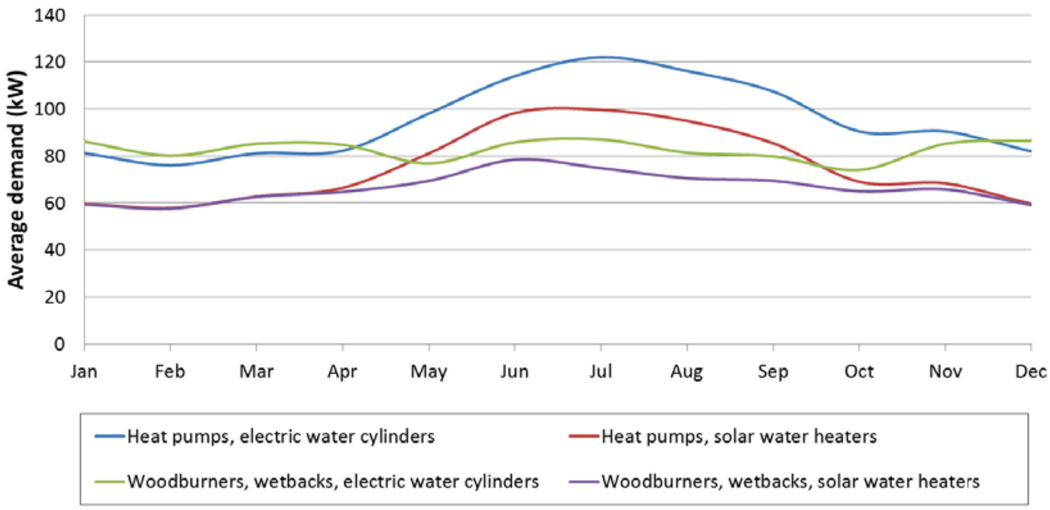

Figure 48: Mean monthly electricity demand (modelled for mid-growth scenario)

The expected future papakāinga energy demand under a high-growth scenario (200 new low energy homes, 81 EVs and 40 PHEVs, Section 2.3) has been proposed for various appliance configurations (Table 16), along with the expected time distribution of the corresponding electricity use (Figs. 49 and 50)

Table 16: Papakāinga annual energy demand (modelled for high growth scenario)

Existing homes configuration	New homes configuration	Annual electricity demand (MWh)	Peak 10 minute average (kW)	Annual LPG demand (kg)	Annual firewood demand (tonnes)
Most economic (Table 21)	Heat pumps, electric water cylinders	1,550	659	1,802	6
Solar water heaters if economic	Heat pumps, solar water heaters	1,203	647	3,982	6
Most economic (Table 21), wood boilers in marae	Wood-burners and wetbacks, electric water cylinders	1,331	459	788	128
Wood burners and wetbacks (if acceptable), solar water heaters, wood boilers in marae	Wood-burners and wetbacks, solar water heaters	1,051	352	2,601	117

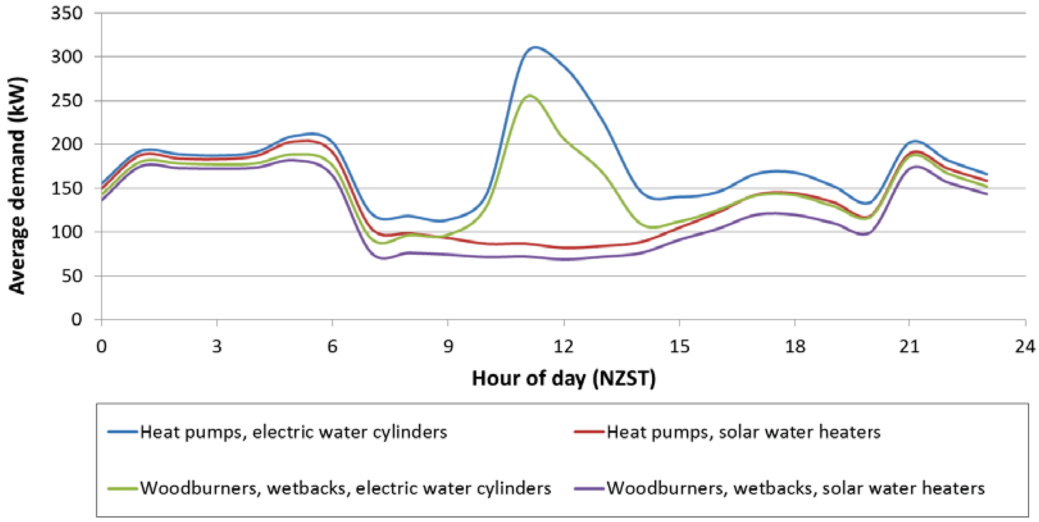

Figure 49: Average daily electricity load profiles (modelled for high-growth scenario)

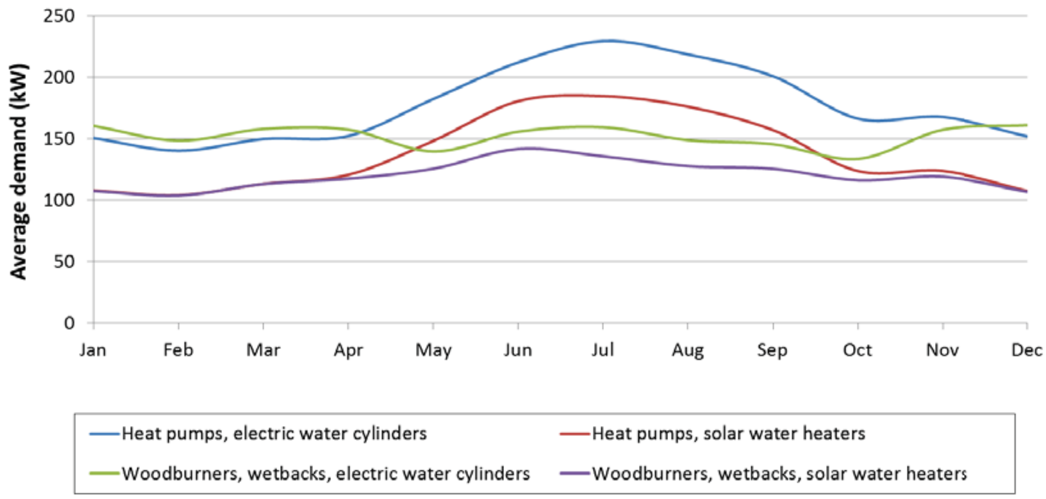

Figure 50: Mean monthly electricity demand (modelled for high-growth scenario)

The potential widespread uptake of electric vehicles would significantly change the daily load profile from the current profile, with high overnight charging loads.

The profiles with electric water cylinders are modelled the effect of using a timer to shift the water heating into the middle of the day, coincident with solar energy availability. However would cause a very high peak load (with all cylinder elements on at once) and a high load factor. A smoother profile could be obtained by using 1kW elements instead of 2kW elements.

The use of wood-burners with wetbacks is expected to significantly reduce winter electricity use.

3.3. Renewable Energy Resources

The data from the wind tower had a recovery rate of 98%. Missing records were filled by taking data from adjacent days.

3.3.1. Wind resource

The wind speed and direction has been measured at Parihaka over a 12 month period (Figs. 51 to 52).

Predominant wind directions during the monitoring period were northerly, south easterly and south westerly.

The monthly distribution of the measured wind resource (Fig. 53) is a good match with the energy demand (Fig. 46), being a steady resource through the year with slightly higher average wind speeds over the winter months when energy demand is also higher.

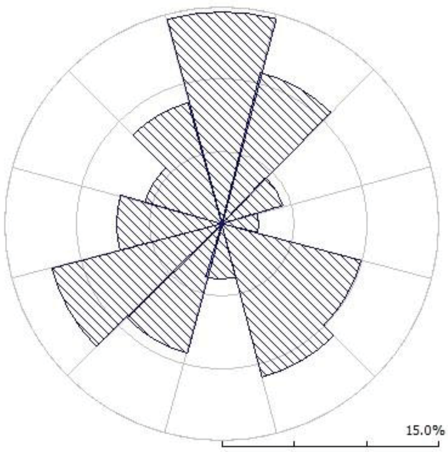

Figure 51: Wind direction frequency rose of measured data over 12 months

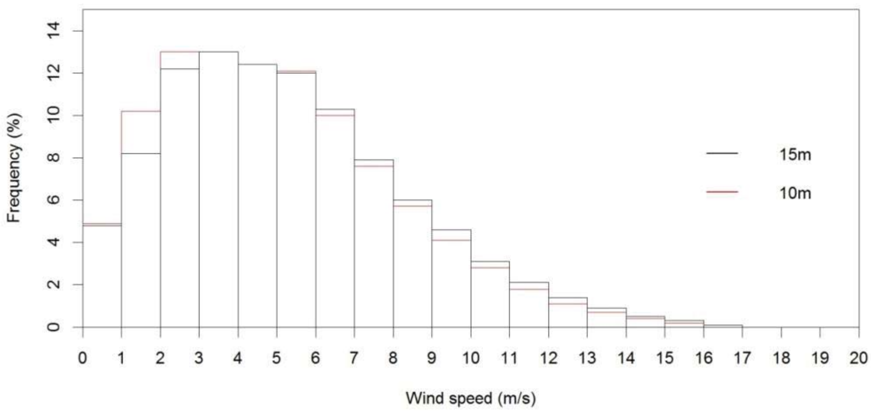

Figure 52: Wind speed frequency distribution of measured data at 10m and 15m above ground over 12 months

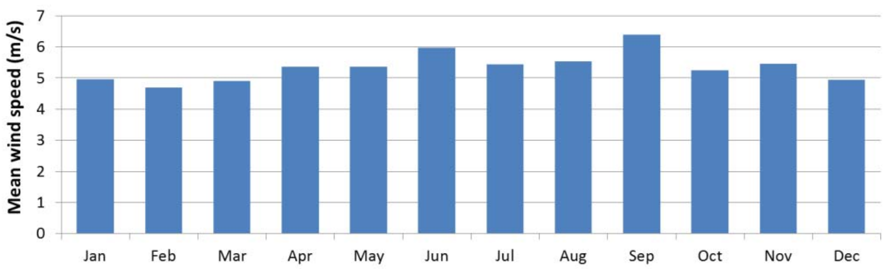

Figure 53: Monthly mean wind speeds, measured data at 15m above ground over 12 months

A clear diurnal pattern of higher wind speeds during daylight hours, peaking mid-afternoon is evident (Fig. 54). This is likely due to local orographic effects due to being located between and near to both the ocean (with a relatively steady surface temperature) and Mount Taranaki (with a relatively fluctuating surface temperature based on solar heating). Unfortunately this diurnal pattern is not a complementary match to the solar resource, peaking at a similar time of day.

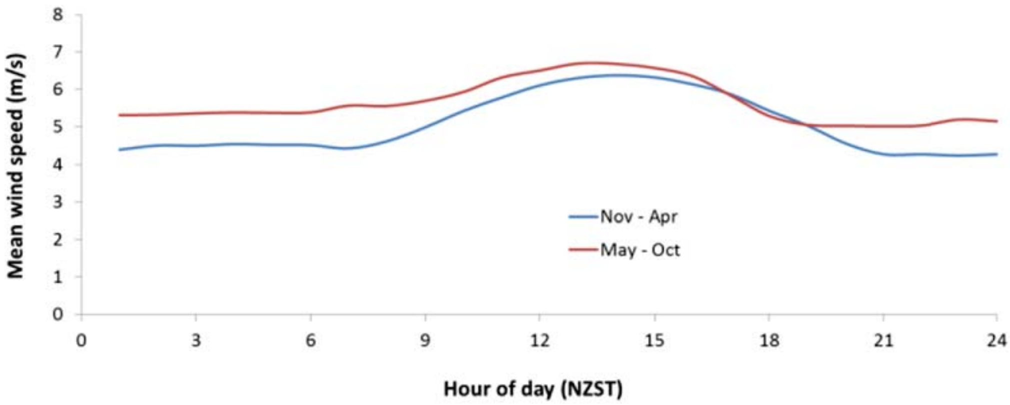

Figure 54: Average diurnal wind speed variation, measured data at 15m over 12 months

Ideally the wind direction and speed frequency distributions of the Measure-Correlate-Predict (MCP) hindcast corrected data during the concurrent period (Figs. 55 and 56) should present very similar to the measured data.

There are some small differences in the wind rose, however the predominant wind directions remain the same. A slight decrease in wind speed and power density (Table 17) suggest a conservative MCP prediction, the Weibull distribution fit is very similar, and so the MCP hindcast is used with some confidence.

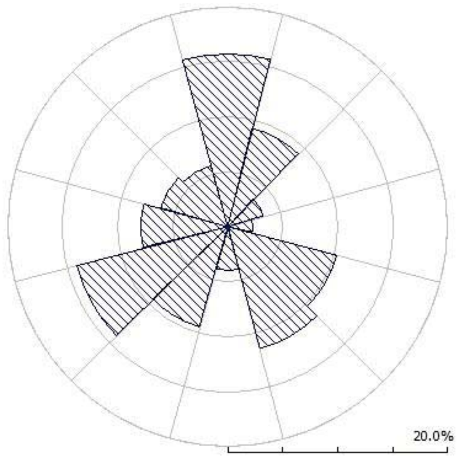

Figure 55: Wind direction frequency rose, MCP hindcast over concurrent 12 month period

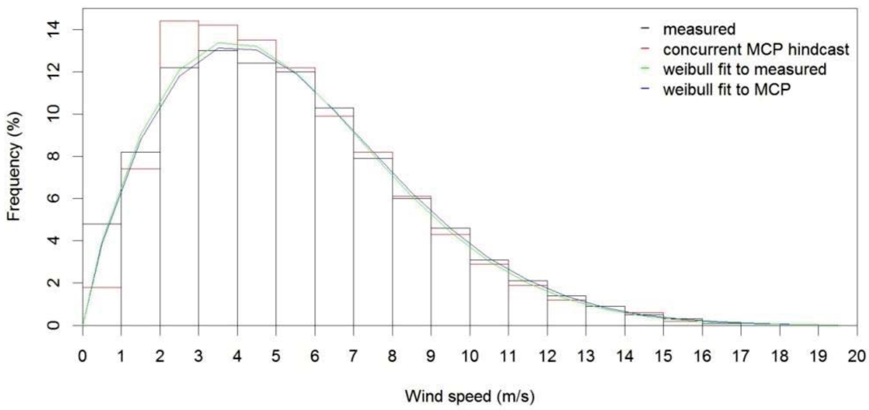

Figure 56: Wind speed frequency distribution, MCP hindcast over concurrent 12 month period

The main differences between the predicted long term resource (Figs. 57 and 58) and the short term resource are higher frequencies of westerlies and north-easterlies, and higher average wind speeds over the long term. This aligns well with local anecdotal information and the high prevalence of westerlies experience over spring 2016 (which will feature in the longer two year dataset).

The expected long term wind resource at Parihaka has been characterised (Table 17).

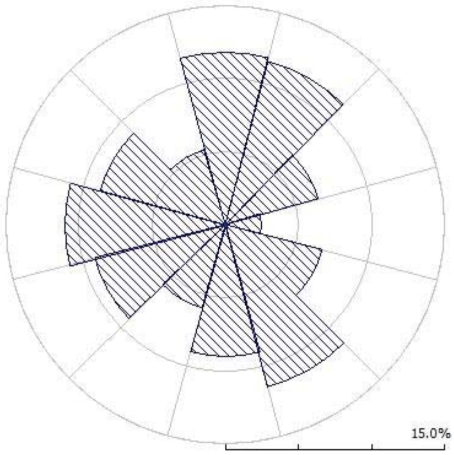

Figure 57: Wind direction frequency rose, MCP hindcast over ten year period

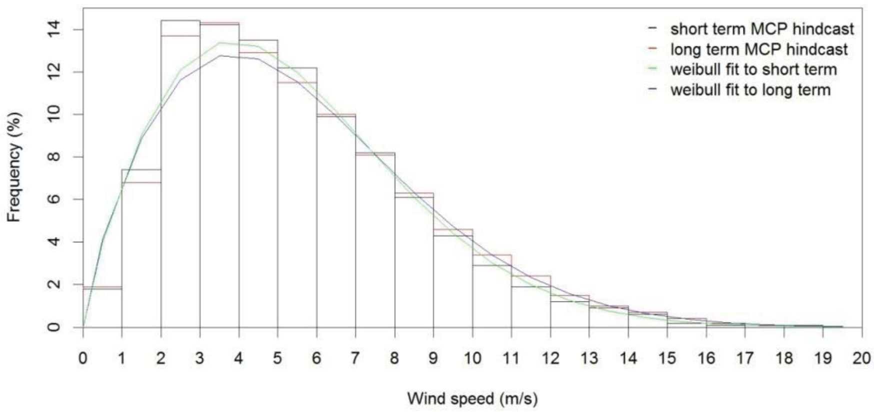

Figure 58: Wind speed frequency distribution, MCP hindcast over ten year period

Table 17: Comparison of Parihaka wind resource characterisations

Dataset	Weibull A parameter	Weibull k parameter	Mean wind speed (m/s)	Power density (W/m^2)
Measured at 10m	5.8	1.81	5.2	179
Measured at 15m	6.1	1.81	5.4	204
MCP at 15m, concurrent period	6.0	1.81	5.3	198
MCP at 15m, 10 year period	6.2	1.76	5.5	228

A spatial prediction of mean wind speeds at 30m above ground level in the vicinity of the papakāinga was produced using WAsP modelling (Fig. 59). Four potential sites were identified as areas of higher wind speeds. Large sheltering trees near to sites A B and C were incorporated in the model as obstacles. The modelling was repeated with those obstacles removed, to simulate the effect on wind speed of felling those trees (Fig. 60).

The site chosen for wind energy modelling in HOMER is site D, due to the reasons listed in Table 18 .

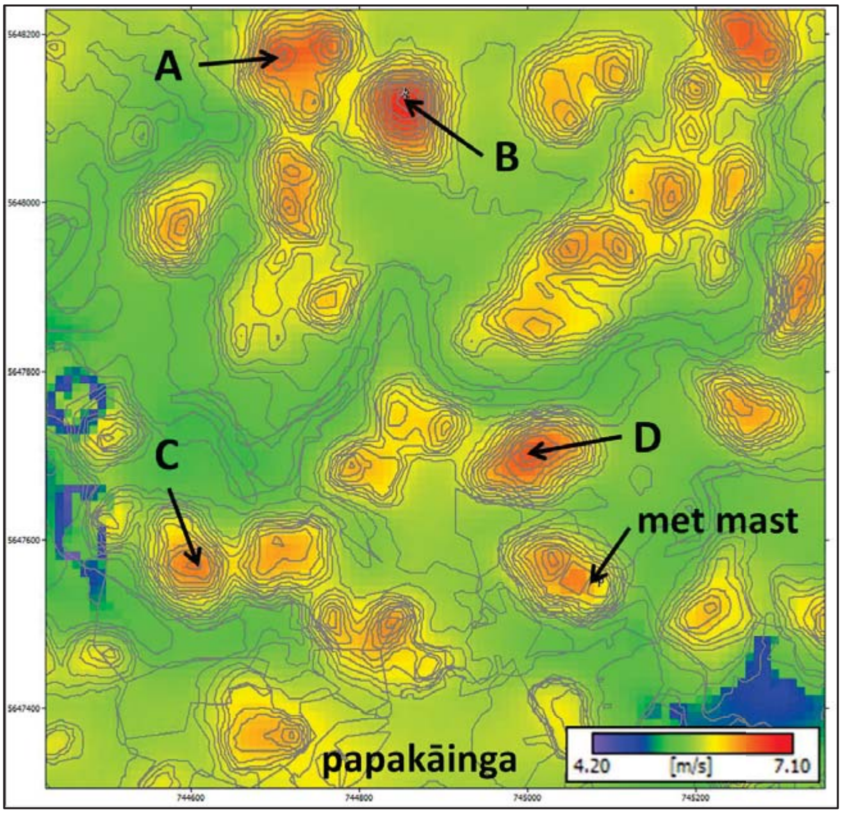

Figure 59: Predicted mean wind speeds in the papakāinga vicinity at 30m above ground level, with potential wind turbine sites identified

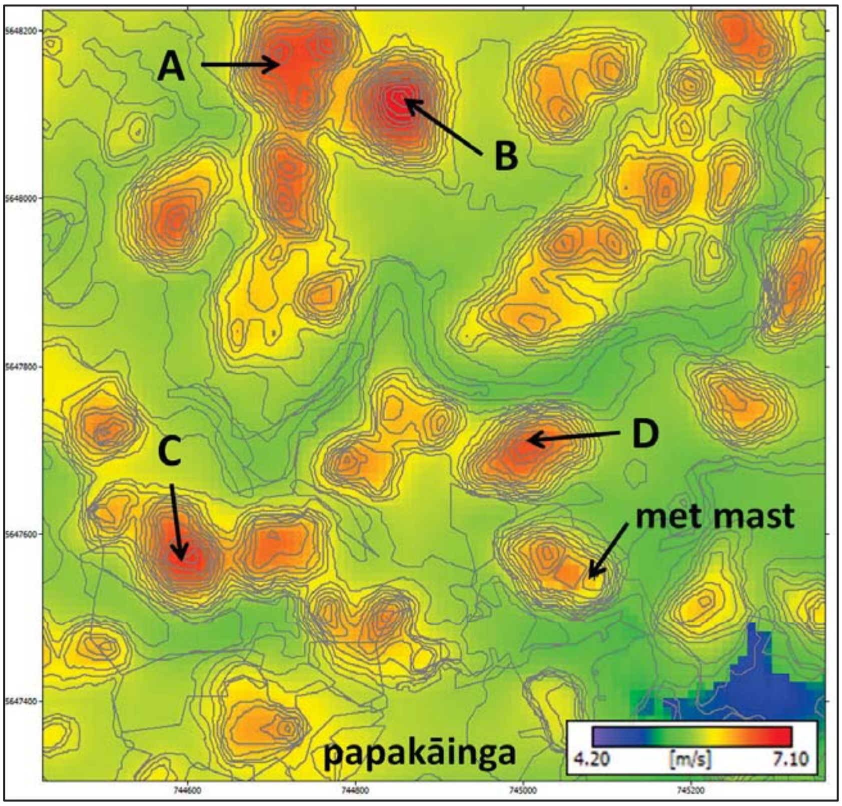

Figure 60: Predicted mean wind speeds in the papakāinga vicinity at 30m above ground level, if sheltering trees near potential wind turbine sites were removed

Table 18: Comparison of potential wind turbine sites in the papakāinga vicinity

Potential wind turbine site	A	B	C	D
Location	39° 16.875'S, 173° 50.224'E	39° 16.900'S, 173° 50.325'E	39° 17.208'S, 173° 50.155'E	39° 17.125'S, 173° 50.439'E
Predicted mean wind speed at 30m (m/s)	6.57	6.85	6.43	6.59
Predicted mean wind speed at 30m (m/s) if trees removed	6.7	7.05	6.77	6.61
Distance to grid transformer (m)	900	850	390	415
Advantages	Existing farm track access.	Highest wind resource.	Closest to transformer.	No sheltering trees nearby
Disadvantages	Sheltering trees on neighbouring property. Visible to neighbours. Longer transmission including waterway crossing.	Steep/difficult access and small footprint area. Sheltering trees on neighbouring property. Visible to neighbours. Longer transmission including waterway crossing.	Sheltering trees on neighbouring property. Possible historic site. Higher risk of noise.	Higher risk of noise.

The WAsP model suggests an annual mean wind speed of 6.97 m/s and a power density of 454 W/m^2 at 50 m above ground level at site D. This corresponds to a class 3 to 4 wind speed, or a "fair to good" wind resource (Jain, 2011).

Figure 61: Impression of a 50kWp turbine at site D from the marae ātea of Toroānui

3.3.2. Solar resource

The annual solar resource is 1409 kWh/m^2 or 5072 MJ/m^2, an average daily resource of 3.86 kWh/m^2. The large variation between the summer and winter resource (Fig. 62) is a function of latitude. This is a poor match with the energy demand (Fig. 46), which is higher in winter than summer and higher in the evening than midday

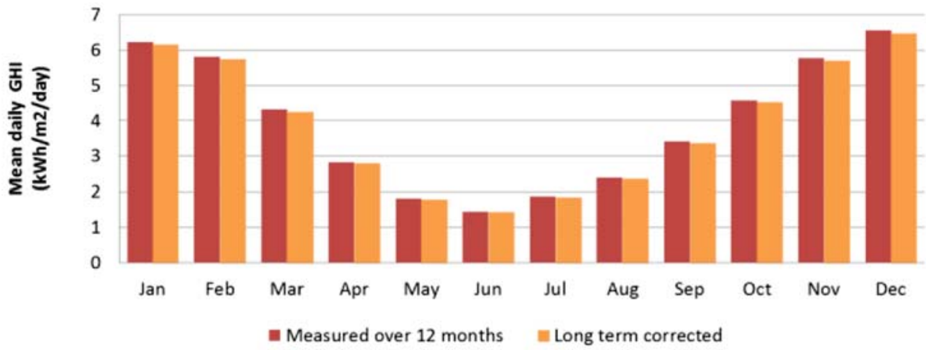

Figure 62: Monthly mean daily global horizontal irradiance at Parihaka

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3.3.3. Hydro resource

The variation of waterway flows over the year, found by correlating measured values with long-term data from the nearby Kapoaiaia river (Fig. 63), is an ideal match for the energy demand (Fig. 46).

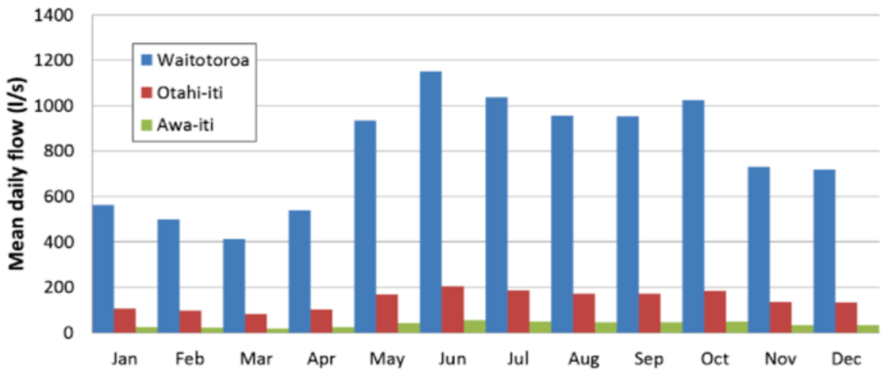

Figure 63: Expected monthly mean daily flows of Parihaka waterways

The Waitotoroa river has a potential head of 5.7 m in proximity to the papakāinga (Figs. 64 and 65), its flow is expected to range from a minimum of 58 l/s to in excess of 1500 l/s 10% of the time (Fig. 66).

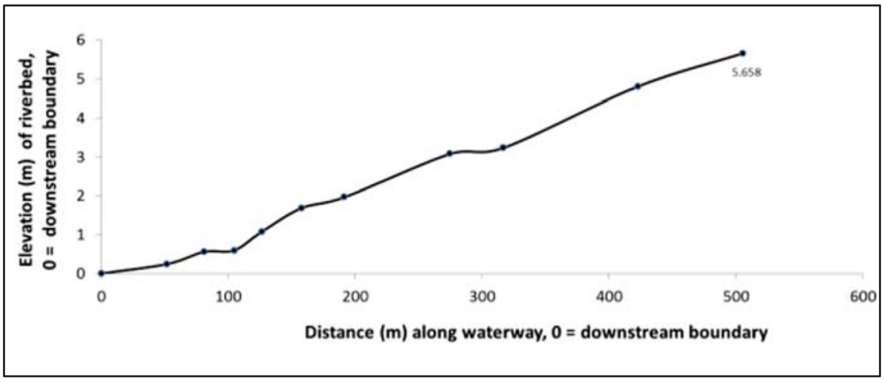

Figure 64: Surveyed head of the Waitotoroa river

Figure 65: Elevation of surveyed points along the Waitotoroa river, with uppermost point as reference datum[30]

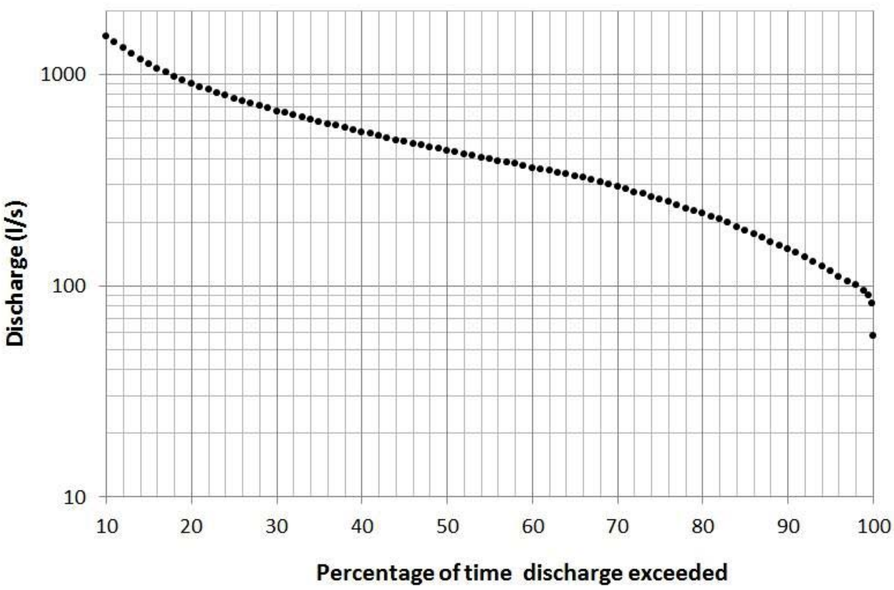

Figure 66: Predicted flow duration curve of the Waitotoroa river

[30] Image: Google Earth

For residual flow calculations, the very lowest data point in Fig. 66 was ignored, leaving a required residual flow (75% of minimum) in the Waitotoroa river of 60 l/s.

The Otahi-iti river has a potential head of 14.3 m in proximity to the papakāinga (Figs. 67 and 68), however the the potential head of 13 m was used, as the topography is unsuitable for extending a diversion channel further than shown in Fig. 29. The flow of the Otahi-iti is expected to range from a minimum of 30 l/s to in excess of 270 l/s 10% of the time (Fig. 69).

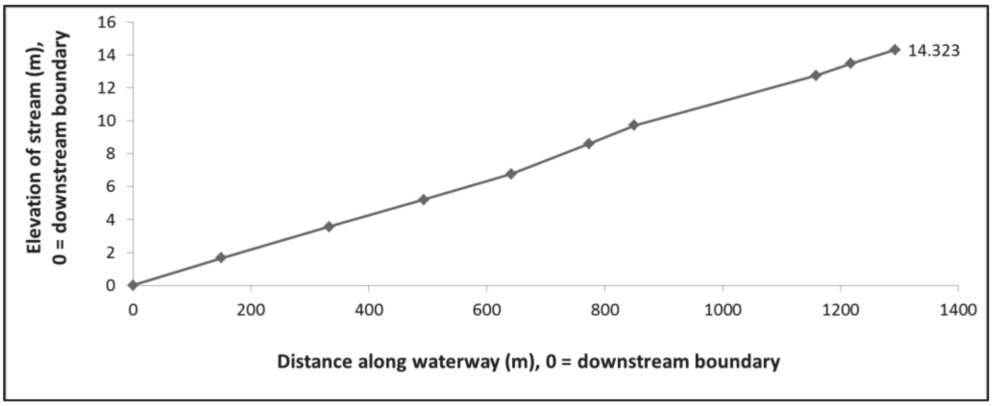

Figure 67: Surveyed head of the Otahi-iti river

Figure 68: Elevation of surveyed points along the Otahi-iti river, with uppermost point as reference datum (numbers in parantheses are interpolated)[31]

The required residual flow (75% of minimum) in the Otahi-iti river is 23 l/s.

[31] Image: Google Earth

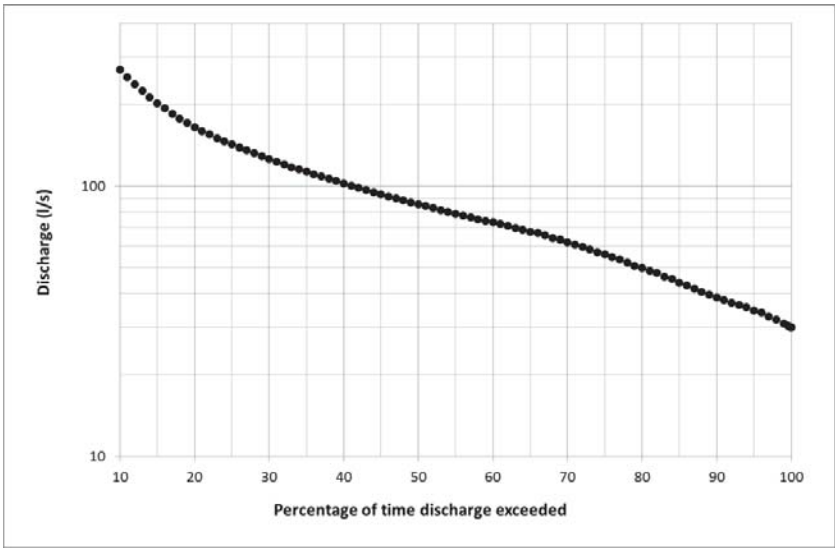

Figure 69: Predicted flow duration curve of the Otahi-iti river

The Awa-iti stream has a potential head of 3.1 m in the section surveyed (Fig. 70), its flow is expected to range from a minimum of 3 l/s to in excess of 60 l/s 10% of the time (Fig. 66).

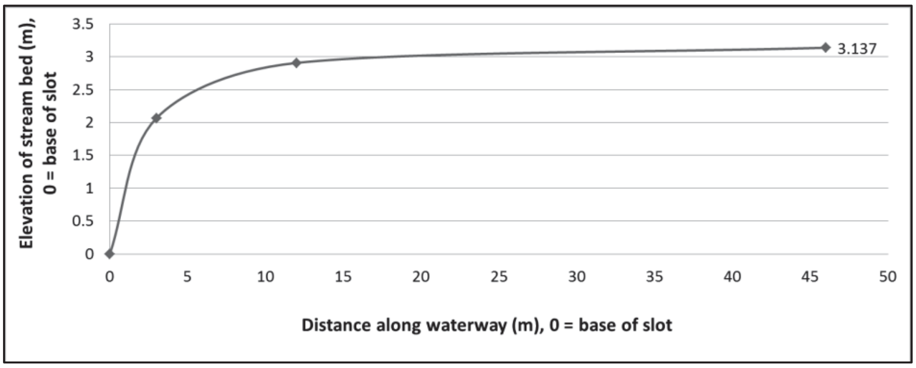

Figure 70: Surveyed head of the Awaiti waterway

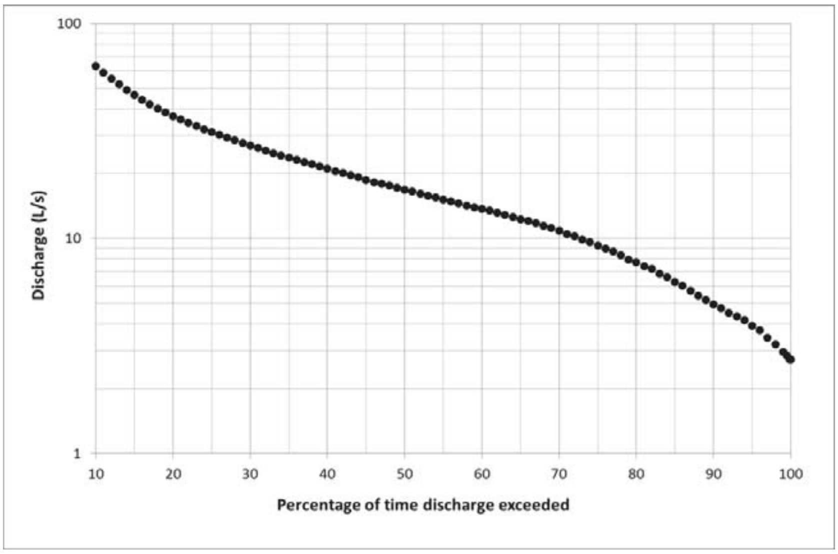

Figure 71: Predicted flow duration curve of the Awaiti waterway

Residual flow was assumed to not apply in this modified waterway, as a small waterfall likely prevents migration of aquatic life. Note that the minimum flow required to generate meaningful electricity using a Powerspout turbine is 30 l/s (Lawley, 2014), which according to this FDC is available only 25% of the time.

Fig. 72 compares the many micro-hydro scheme layouts considered in terms of both cost effectiveness and annual energy production, as described in Section 2.4.3. Note that although the cost-effectiveness of a micro-hydro installation may be expressed in $\$/W_{installed\ capacity}$, the installed capacity power rating in the y-axis units of this chart have been multiplied by the expected plant capacity factor (cf) to account for any performance de-rating lack of year-round flow. See Section 2.4.3 for further details.

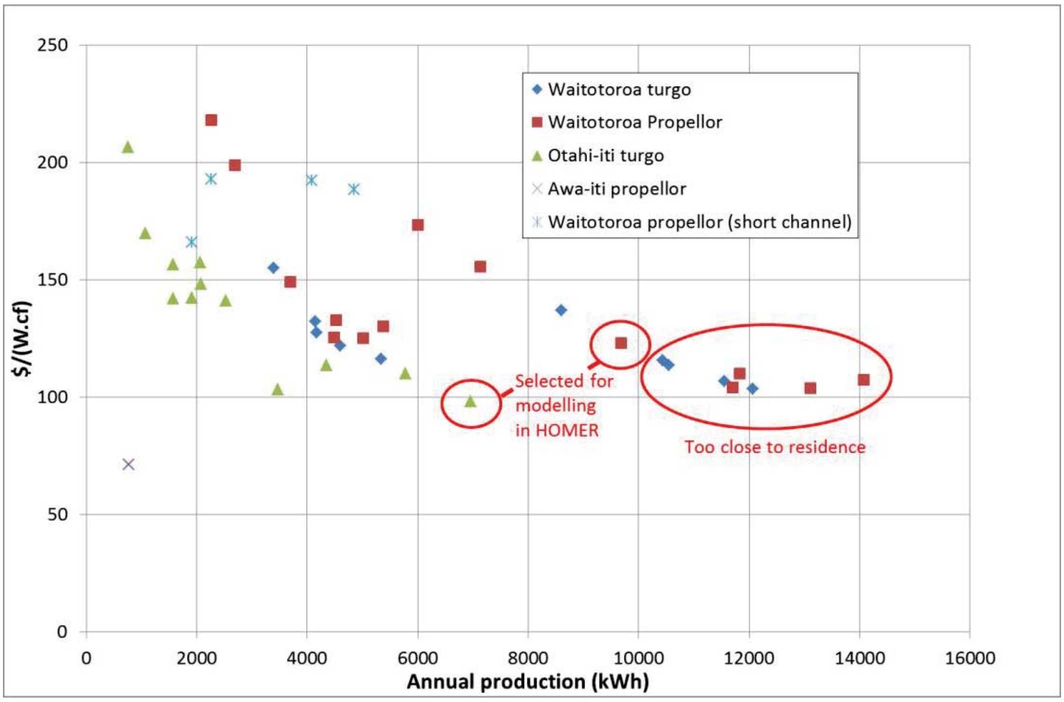

Figure 72: Comparison of various potential micro-hydro scheme layouts

A number of layouts result in turbines located within 30 m of homes – this is not recommended by the Powerspout manufacturer (Lawley, 2014) due to noise concerns, and so these layouts were not considered further, nor were layouts impacted by space constraints due to a driveway and mature trees. The layout on the Awaiti was not considered further for a community scheme due to its low annual production, as there is insufficient flow for meaningful electricity generation for much of the year. This location may be useful for winter battery charging for an off-grid home, however hydro-power to supply individual buildings has not been covered.

Of the remaining layouts, two are used in the subsequent modelling described in Appendix E: that yielding the most annual electricity production (Fig. 73), and that with the least cost production of electricity (Fig. 74).

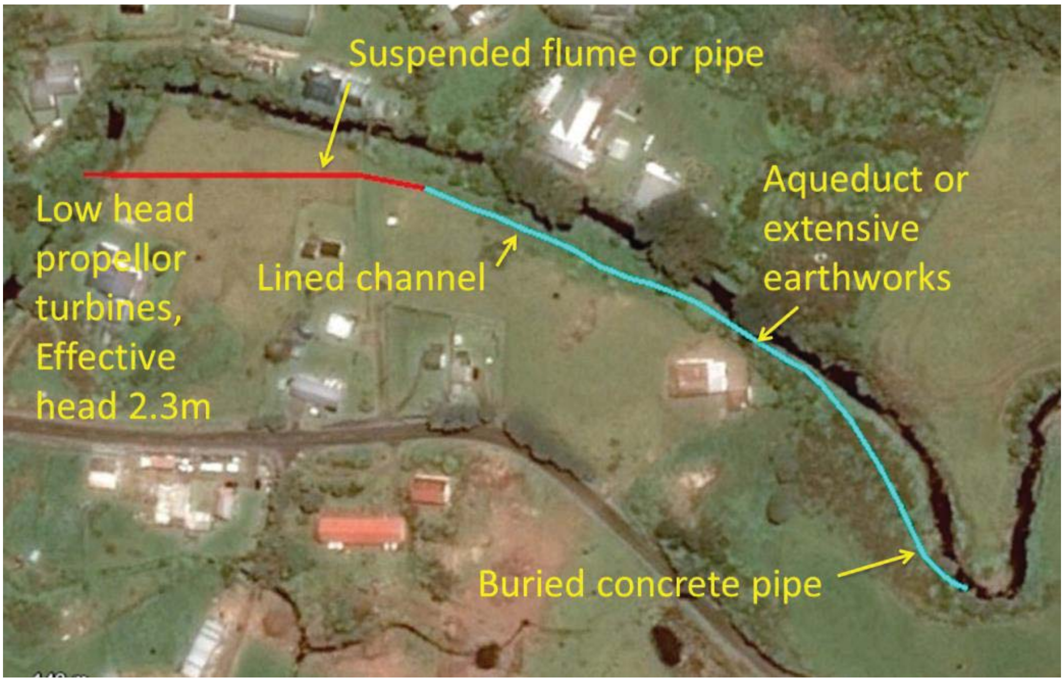

Figure 73: Micro-hydro scheme layout expected to produce the most electricity annually, assuming that turbines cannot be located further downstream due to space and noise constraints[32]

However, the layout shown in Fig. 73 may not be feasible to construct (Section 2.4.3). The expected power and energy output of this micro-hydro scheme were based on the following.

Elevation difference between intake and discharge (m)	4.58
Potential change in river level during flood (m)	-2.2
Length of channel(m) x drop in channel per m	$-105 \times 3.2 \times 10^{-4}$
Length of initial pipe(m) x drop in pipe per m	$-165 \times 9.2 \times 10^{-5}$
Length of flume/pipe(m) x drop in flume/pipe per m	$-123 \times 4.4 \times 10^{-4}$
Net (useable) head (m)	**2.28**

Design flow rate = 115 l/s
Capacity factor = 86% (ensuring uninterrupted operation May – October)
Power output = 1.28 kW

The indicative capital cost of $156,400 (further detail in Appendix D) used for the modelling (Appendix E) was based on:

- 165 m precast concrete pipe, 750 mm diameter;
- 125 m galvanised steel pipe, 750 mm diameter (which would need to be supported 1.5 m above ground at discharge);
- 180 m of insulated copper cable; and
- the equivalent of 3 Powerspout low-head propeller turbines.

[32] Image: Google Earth

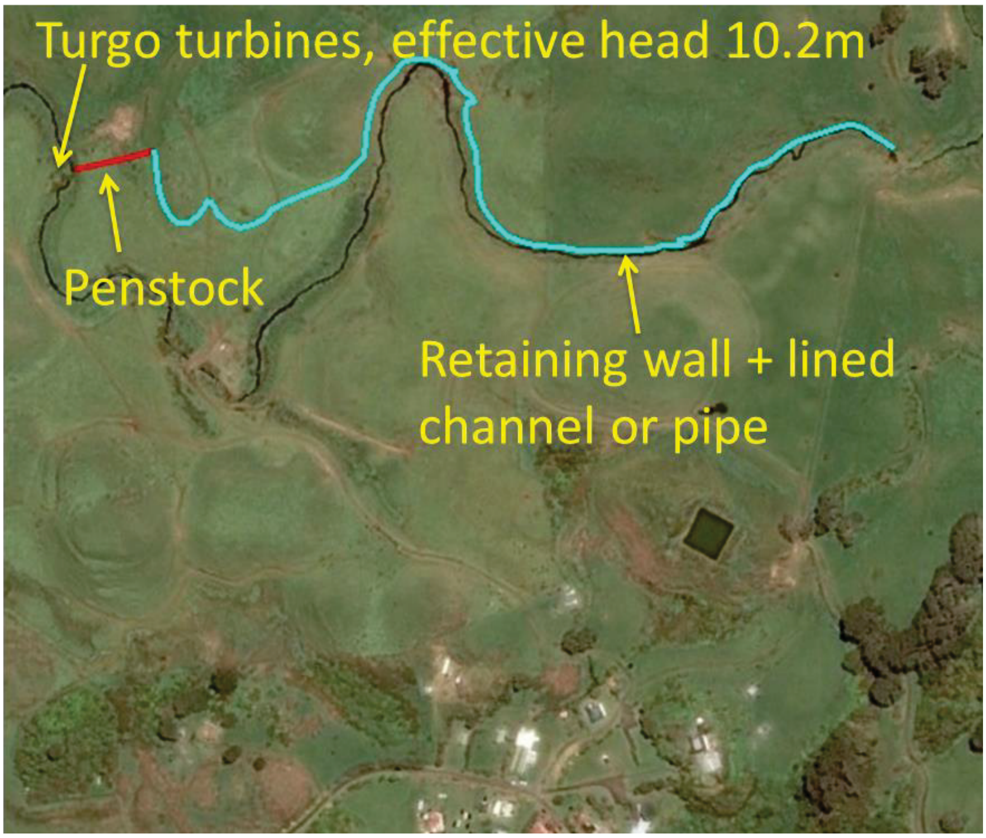

Figure 74: : Micro-hydro scheme layout expected to produce electricity at least cost[33]

The expected power and energy output of the micro-hydro scheme layout expected to produce least-cost hydroelectricity (Fig. 74) were based on the following.

Elevation difference between intake and discharge (m)	13
Potential change in river level during flood (m)	-0.6
Length of channel pipe(m) x drop in channel per m	$-873 \times 1.3 \times 10^{-3}$
Penstock friction losses	-9%
Net (useable) head (m)	**10.25**

Design flow rate = 18 l/s
Capacity factor = 86% (ensuring uninterrupted operation May – October)
Power output = 0.90 kW

The indicative capital cost of $89,900 (further detail in Appendix D) used for the modelling (Appendix E) was based on:

- 873 m polypropylene low pressure pipe, 300 mm diameter;
- 68 m MDPE penstock, 125 mm diameter;
- 730 m of insulated copper cable; and
- the equivalent of 2 Powerspout turgo turbines.

[33] Image: Google Earth

3.3.4. Biomass resource

As previously mentioned, the land available and thus local woody biomass resource potential is not specified. Instead, the expected land requirements (Section 2.4.4) pertaining to various appliance use scenarios (Section 2.5.2) is presented (Table 19) to facilitate discussion of appropriate land use at Parihaka.

Scenario	Annual wood required (t)	Land required (ha)
Current situation	7.2	0.63
Current buildings use most economic configuration	5.9	0.51
Current buildings use biomass if retrofit is economic	6.2	0.54
Current buildings use biomass if acceptable	12.6	1.10
Current buildings use biomass if retrofit is economic, marae wood boilers	9.6	0.83
Current buildings incorporate energy efficiency, new homes have heat pumps	6.2	0.54
Current buildings incorporate energy efficiency, 100 new homes have wetbacks or boilers	69	5.97
Current buildings incorporate energy efficiency, 100 new homes have solar water and wetbacks or boilers	65	5.65
Current buildings incorporate energy efficiency, 200 new homes have wetbacks or boilers	128	11.11
Current buildings incorporate energy efficiency, 200 new homes have solar water and wetbacks or boilers	117	10.21

Table 19: Expected land area required for biomass production under various appliance scenarios

Suitable land for biomass production within the 20 hectare papakāinga is likely to be limited. The significant population growth (200 new homes) would likely need an expansion of papakāinga land regardless, and there is a neighbouring farm associated with the papakāinga.

3.4. Predicted Performance of Renewable Energy Conversion Technologies

3.4.1. Existing buildings

Results are presented first for technologies which are applied to individual buildings, rather than community distribution.

Water heating by biomass combustion is only considered for homes open to using biomass, and would be achieved with a heat exchanger (wetback) on a space heating appliance: the exception is house 6, which could be served by a wood fired boiler providing hot water for consumption and space heating.

High proportions of annual water heating demand can be supplied using a combination of solar water heaters (effective in summer months) and wood heating (effective in winter months) (Table 20), and it is conceivable that occupants may be able to modify their use patterns such that all water heating could be supplied this way. If the biomass is produced locally in a sustainable manner, then this is an independent way to heat water.

Table 20: Annual fractions of residential water heating demand able to be met by solar and/or biomass

Building	Solar fraction	Wetback/ boiler fraction	Solar & wetback/ boiler fraction	Collector area (m^2)	Cylinder volume (l)
House 1	0.76	N/A	N/A	2.2	180
House 2	0.75	N/A	N/A	3.6	270
House 3	0.67	0.25	0.9	1.8	180
House 4	0.64	0.37	0.72	5.4	400
House 6	0.75	0.59	0.96	21.5	800
House 7	0.71	0.23	0.78	2.2	300
House 8	0.7	N/A	N/A	2.2	180
House 9	0.65	0.41	0.85	4.3	300
House 10	0.65	0.26	0.86	4.3	300

The results of modelling various renewable energy conversion technologies for individual buildings, using the measured and modified load profiles and resource data, are presented in Appendix F.

In some cases an economic (cost), social (reduced dependence) and environmental (reduced emissions) benefit is expected. Where there is no direct economic benefit expected, the desired trade-off between cost and the social and environmental benefits can be selected from the charts of Appendix F. As the desired trade-off (if any) for the community is unknown, three specific points on each curve are detailed further (Table 21):

1. the solution with the lowest expected NPC;
2. the solution which is expected to reduce energy imports as much as possible without raising the NPC;
3. the solution which is expected to reduce energy imports as much as possible.

Table 21: Summary of the most cost-effective technologies to reduce energy imports of individual buildings

	Lowest NPC	Maximum REI without increasing NPC	Maximum REI
House 1	Energy efficiency[34]	Energy efficiency	Energy efficiency, HPWH, PV
House 2	Energy efficiency	Energy efficiency	Energy efficiency , PV, diverter to water cylinder
House 3	Energy efficiency, wood-burner	Energy efficiency, wood-burner, wetback, PV, diverter to water cylinder	Energy efficiency, wood-burner, wetback, SWH, PV, batteries
House 4	Energy efficiency	Energy efficiency	Energy efficiency , wood-burner, wetback, PV, diverter to water cylinder
House 5	Energy efficiency	Energy efficiency, PV	Energy efficiency, PV
House 6	Energy efficiency , HPWH or SWH	Energy efficiency , HPWH, PV or SWH, PV	Energy efficiency, biomass boiler, SWH, PV
House 7	Energy efficiency	Energy efficiency	Energy efficiency, wood-burner, wetback, PV, diverter
House 8	Energy efficiency	Energy efficiency	Energy efficiency, PV, diverter to water cylinder
House 9	No change	No	Wetback, SWH, PV, batteries
House 10	Energy efficiency, wetback, SWH	Wetback ,PV, diverter to water cylinder	Wetback, SWH, PV, batteries
Marae A	No change	No change	Biomass boiler, PV
Marae B	Energy conservation	Energy conservation	Energy conservation biomass boiler, PV
Marae C	No change	No change	Biomass boiler, PV

In general it can be seen that the least cost option typically includes energy efficiency. In fact this would likely be the case for all buildings (a study of energy efficiency gains has not yet been performed for some buildings, such as the marae). When considering which sustainable energy technologies to invest in for individual buildings, energy efficiency measures should be the first consideration. Hernandez Pacheco (2016) has presented some opportunities, and no doubt further gains are possible, especially if significant capital investments are considered for the papakāinga.

[34] Energy efficiency includes those measures identified by Hernandez Pacheco (2016), and also any applicable heat pump retrofits.

Also of note is that the (electricity and heat) generation technologies do not often reduce the NPC from the base case (Appendix F). In general the trend is for increasing local renewable generation to have an increasing long run cost.

Reducing energy imports and reducing greenhouse gas emissions (fuel only) are linked and the results tend to be similar whether considering independence or emissions. The main difference is that reducing LPG use (e.g. solar water heaters and wetbacks) has a greater impact on emissions then reducing grid electricity use.

3.4.2. Community outcomes – zero-growth scenario

Results of various aggregations of the individual results from Appendix F are shown (Table 22 and Fig. 75), to show the cost to the community as a whole.

Table 22: Papakāinga electricity, LPG and firewood demand for various aggregations of individual building technologies

Scenarios aggregated	Annual electricity demand (MWh)	Annual LPG demand (kg)	Annual firewood demand (t)
No change	71	1 860	6.2
Lowest NPC for each building	46	1 800	5.9
Most thermal generation without raising NPC	44	1 800	6.2
Most thermal generation (SWH, wetbacks, boilers)	42	190	12.6
Lowest NPC plus SWH each residence	43	1 280	6.2

The solution which would provide the largest reduction in papakāinga energy imports ("most independent") without community distribution of electricity would reduce energy imports by 64%, but at a 50% increase in energy costs (Fig. 75). Factors limiting further reductions in imports include roof size limitations, loads too large to meet with batteries (within reasonable voltages and currents), and heating with biomass considered unsuitable for some residents.

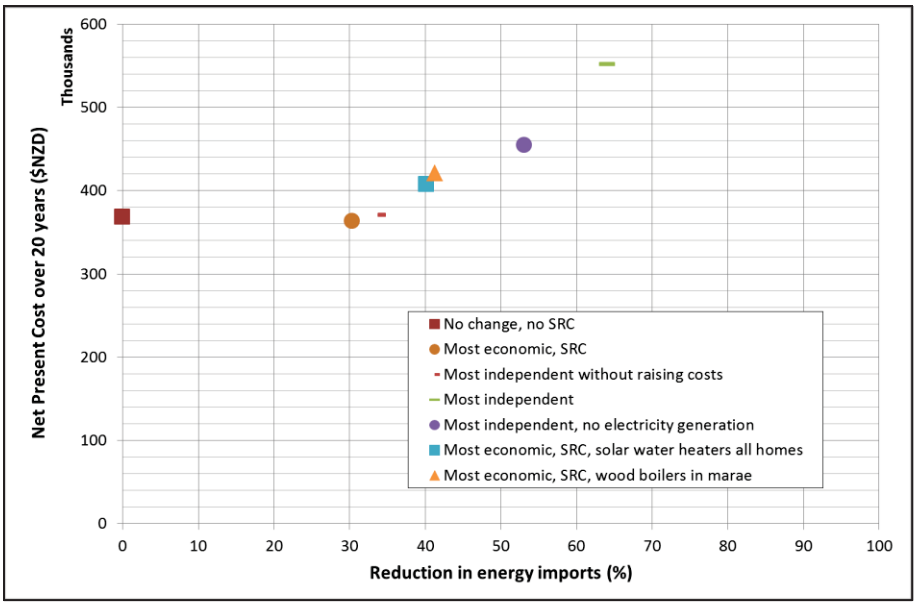

Figure 75: Cost of reducing community energy imports - individual approach

These results are now compared to distributing locally generated electricity amongst the community. Labels used in the legends in the following figures are explained as follows.

Individual building approach:	As per Fig. 75
Most economic:	Aggregations of individual buildings with the most economic configuration of each
Most independent:	Aggregations of individual buildings, the configuration of each is that which reduces its energy imports the most (grid connected PV on individual homes not included)
Thermal buildings:	Aggregations of individual buildings with a configuration of each with the highest level of thermal generation (biomass and solar water heating)
SWH residences:	Aggregations of individual buildings with the most economic configuration of each and also solar water heaters on each
WTG:	Wind turbine generator
NPV:	Net Present Value = NPC (base case) – NPC (proposed case). A positive value suggests an economic benefit.
SRC	SRC *Eucalyptus* firewood plantation
EWC	Electric water cylinder

Both the case where electricity generated behind the transformer on the north side of the river is unable to be self-consumed by buildings on the south side (Fig. 76 and 77) and the case where electricity can be traded across the river (Fig. 78 and 79) are shown.

Note that the base case considers all firewood as imported, but sourced from a local community scheme for all other solutions.

Due to the high number of solutions considered, those not along the least-cost curve have been removed from the graphs.

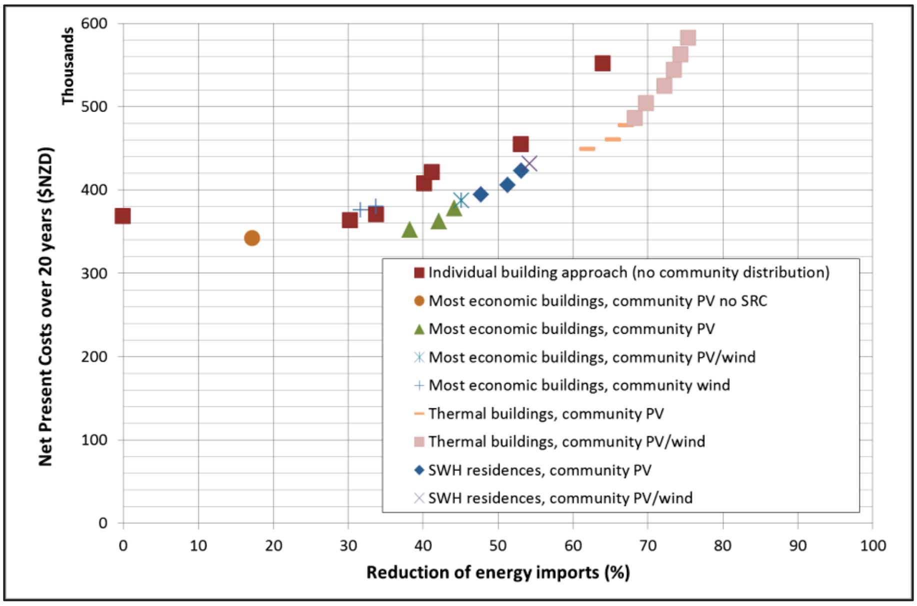

Figure 76: Cost of reducing community energy imports (electricity generation distributed north of river)

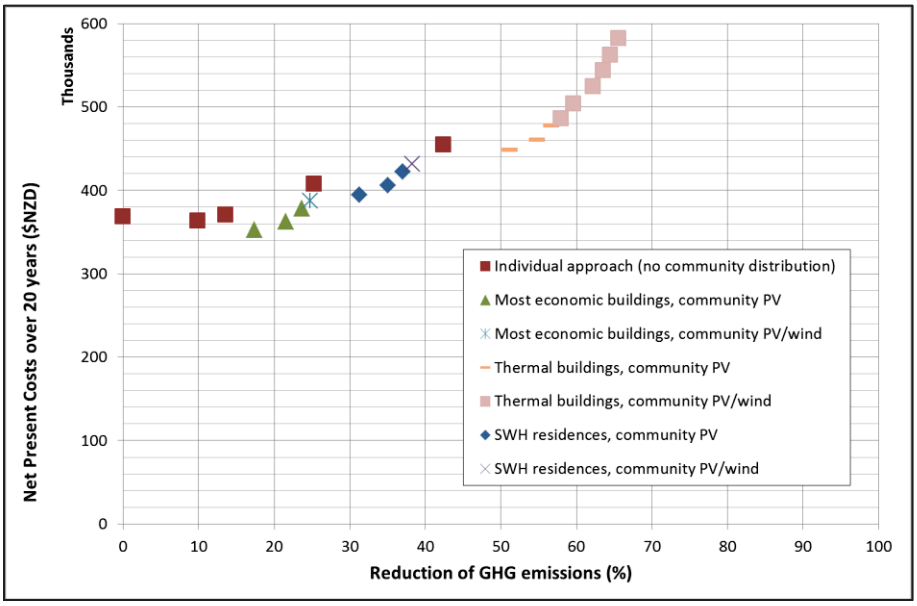

Figure 77: Cost of reducing community GHG emissions (electricity distributed north of river)

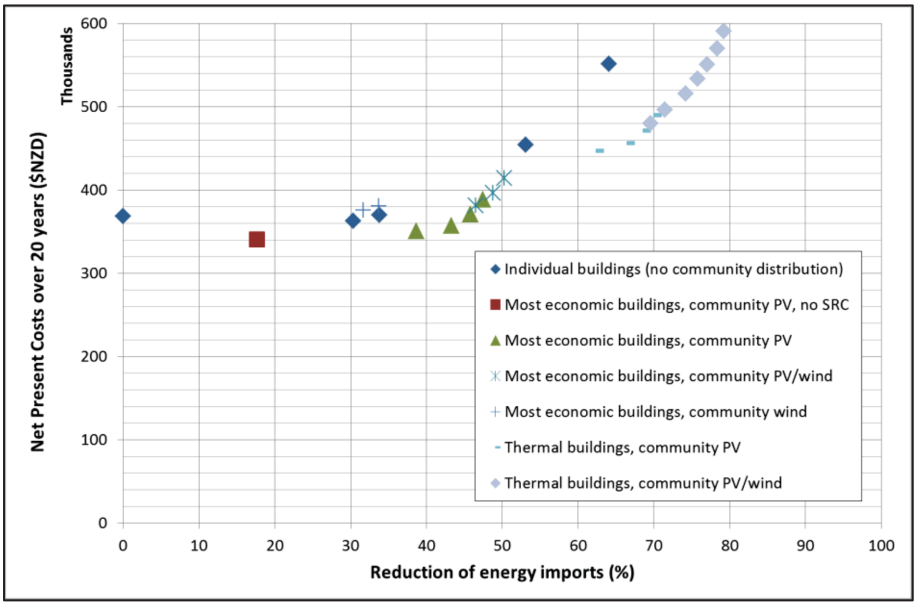

Figure 78: Cost of reducing community energy imports (electricity distributed north and south of river)

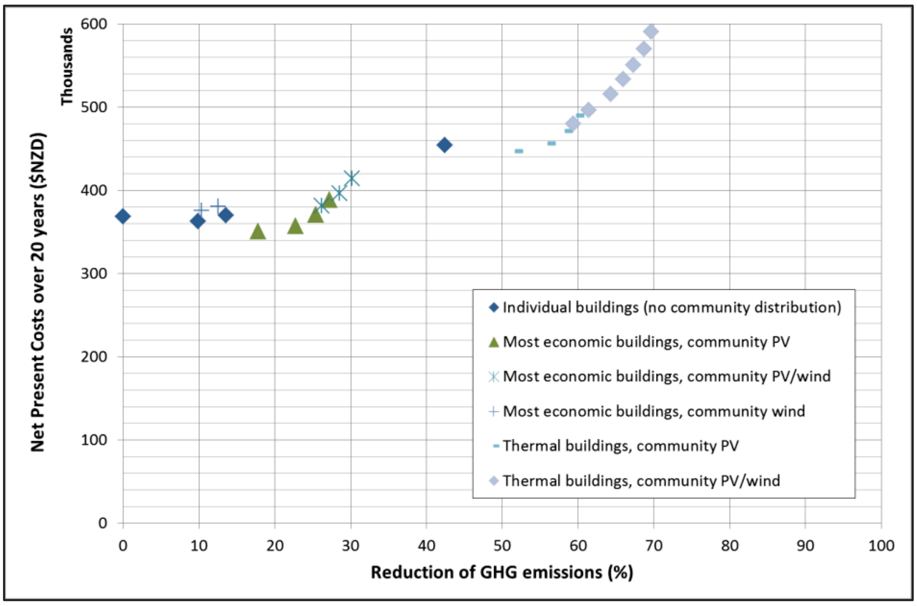

Figure 79: Cost of reducing community GHG emissions (electricity distributed north and south of river)

For every result presented in Fig. 75, there is a more cost-effective solution utilising community distribution of locally produced electricity. It also seems that a higher level of independence (more REI) can be gained with a grid connected community generation source than by investing in stand-alone off-grid homes, due to the fact that feasible off-grid solutions were not found for all homes. A community generation source charging multiple household battery banks or a community battery bank was not considered.

Micro-hydro does not appear on the least cost curve – there is always a more cost-effective option using PV or a PV/wind hybrid.

Again, any desired trade-off between cost and independence can be chosen but the following points are highlighted (Table 23). The favouring of solar PV technology over wind technology may be more a function of the technology costs used rather than a lack of wind resource.

Table 23: Summary of the most cost-effective technologies to reduce energy imports of the community (zero-growth scenario)

	Lowest NPC	Maximum REI without raising NPC	Significant REI	Maximum REI
Existing buildings	Most economic (Section 3.4.1)	Most economic (Section 3.4.1)	Maximum thermal generation (Section 3.4.1)	Maximum thermal generation (Section 3.4.1)
Community	10 kWp PV	20 kWp PV 0.5 ha woodlot	20 kWp PV 1.1 ha woodlot	20 kWp PV 10 kWp WTG 1.1 ha woodlot
Reduction in energy imports (%)	17	42 to 46	65	74 - 77
Reduction in GHG emissions (%)	17	21 to 25	55	64 - 67
Initial capital ($)	48 000	80 000	225 000	360 000
NPV ($)	26 600	5 800 to 11 000	-87 000 to -92 000	-183 000 to -194 000

Although the capital cost of installing PV was reasonably well known, the capital cost of wind energy is much more site specific (due to variables such as transport and access); in addition the capital cost of wind energy that was used (see appendix D) was reasonably generic and possibly out of date. To test the sensitivity of these results to the capital cost of wind, a sensitivity analysis was performed in HOMER, varying the installed cost of wind for the "Lowest NPC" case of Table 23. The least-cost form of community electricity generation using local renewable energy resources for various capital costs of wind energy is shown in Table 24.

Table 24: Results of sensitivity analysis of the capital cost of wind energy

Least cost form of renewable electricity generation at Parihaka (low penetration)	Installed cost of wind, including transmission ($/kWp)
PV	> 7 200
PV/wind hybrid	5 200- 7 200
Wind	< 5 200

If a wind turbine and transmission could be installed locally for less than NZD 7,200/kWp, then a combination of solar and wind is the least-cost option, otherwise PV is the least-cost option.

There is also uncertainty around the near-future growth in load, with three new homes considering connecting to the network and the possibility of six new homes and a community laundry in the near future. A sensitivity analysis was performed, using HOMER, by varying the increase in load for the "Lowest NPC" case of Table 23. The least-cost form of community electricity generation using local renewable energy resources for various growths in load are shown in Table 25.

Table 25: Results of sensitivity analysis of electricity demand growth

% growth in annual papakāinga electricity demand	Least-cost installed PV capacity (kWp)
20	11
40	13
60	15
80	17
100	19

If nine new homes added electricity demand equivalent to that of the study homes excluding house 6, the increase in papakāinga demand might be in the order of 57% (40 MWh annually added to 70 MWh, Table 12), then a 15 kWp community PV array would be the most cost-effective size.

3.4.3. Future buildings

Seeing as the results of Section 3.4.2 favour community distributed electricity over self-consumption in individual buildings, the latter is not considered when modelling future scenarios. However consideration is given to off-grid stand-alone homes. Note that the numbered building load types in Table 26 are future homes based partly on energy demand of these current buildings (Section 2.3).

Table 26: Expected cost of off-grid homes based on predicted future loads

Building load type	PV (kWp)	Batteries (kWh)	Total NPC over 20 years (NZD)	Initial capital costs (NZD)	Discounted replacement costs ($NZD)	NPC of other costs (NZD)	Annual wood usage (kg)	Annual LPG usage (kg)
1	5	16	34,900	26 200	4 800	3 900	440	64
2	5	216	94,300	88 900	3 700	1 700	440	9
3	5	324	124,700	118 800	4 200	1 600	400	6
4	Not feasible							
5	Unknown							
6	Not feasible							
7	2	16	31,500	22,700	5,100	3,700	440	15
8	5	16	37,600	28,500	6,100	3,000	440	51
9	5	24	44,600	35,100	7,200	4,800	640	72
10	3	16	37,500	27,400	6,000	4,100	640	54
Mean	**4.3**	**90**	**57,900**	**49,700**	**5,300**	**3,200**	**490**	**39**

For future growth scenarios following, all off-grid homes were assumed to have an NPC of NZD 57,900.

3.4.4. Community outcomes – mid-growth scenario

Figs. 80 and 81 show the results of the mid growth future scenario, Figs. 82 and 83 show the results which exclude the use of biomass in new homes, if the required land area is not available. Note that unlike Section 3.4.2, some energy for transport is included here, as the shared electric vehicle fleet proposed by Mohan (2016) would be charged from the electricity supply.

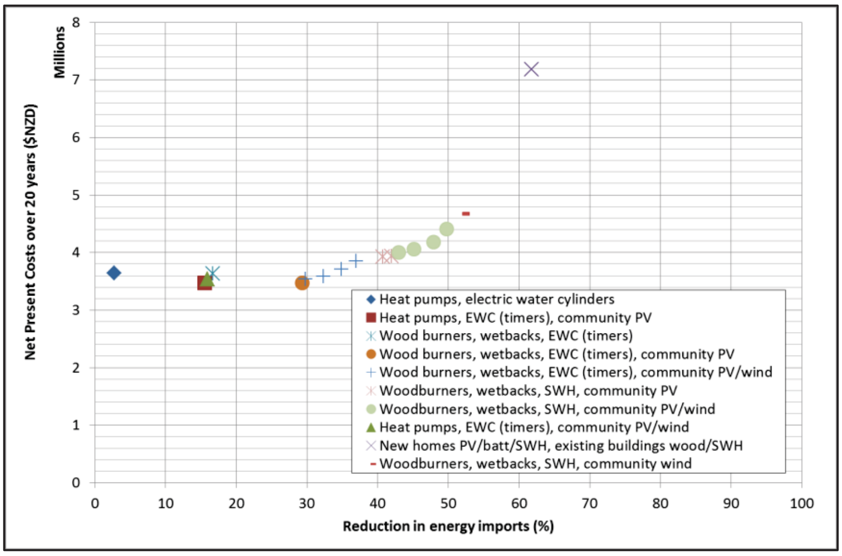

Figure 80: Cost of reducing community energy imports, mid growth scenario

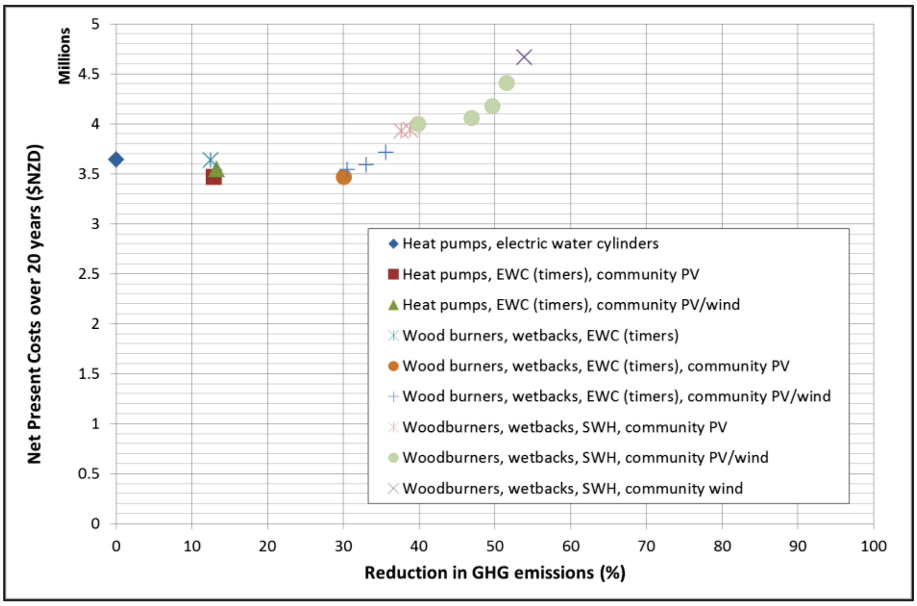

Figure 81: Cost of reducing community GHG emissions, mid growth scenario

The lowest NPC is expected with wood-burners, wetbacks, electric water heating cylinders with timers in all new buildings, and a 100kWp community PV array (Table 27). However 100 new homes with electric water cylinders would significantly increase peak loads, requiring a transformer upgrade (in turn potentially allowing more distributed generation capacity).

The highest reduction in energy imports is where all homes maximise thermal generation (biomass and solar water heating) and new homes are off-grid; a further benefit is that community peak loads are lower. However long run energy costs would be roughly doubled compared to not using local renewable energy. An option with slightly less REI but much less costly is wood-burners, wetbacks, solar water heaters for homes, marae wood boilers, 5.7 ha community firewood plantation, 100kWp community wind turbine.

Table 27: Summary of the most cost-effective technologies to reduce energy imports of the community (mid-growth scenario, 100kW grid-connect capacity constraint)

	Lowest NPC	Maximum REI without raising NPC	Maximum REI
Existing buildings	Most economic (Section 3.4.1)	Most economic (Section 3.4.1)	Maximum thermal generation (Section 3.4.1)
Future buildings	Wood-burners, wetbacks, electric water cylinders with timers in new homes	Wood-burners, wetbacks, electric water cylinders with timers in new homes	Wood-burners, wetbacks or boilers, solar water heaters in new homes
Community	100 kWp PV, 6 ha woodlot	80 kWp PV, 20kWp WTG 6 ha woodlot	100 kWp WTG, 5.7 ha woodlot
Reduction in energy imports (%)	29	32	52
Reduction in GHG emissions (%)	30	33	54
Initial capital ($)	525,000 (plus mounting for ground PV)	740,000 (plus mounting for ground PV)	2,426,000
NPV ($)	180,000	54,700	-1,025,000

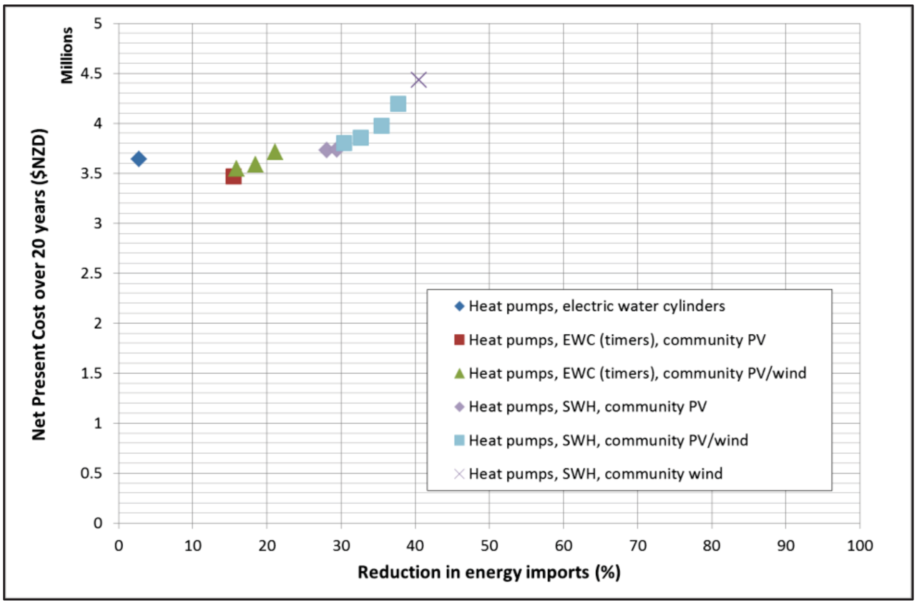

Figure 82: Cost of reducing community energy imports, mid growth scenario (land not available for biomass production)

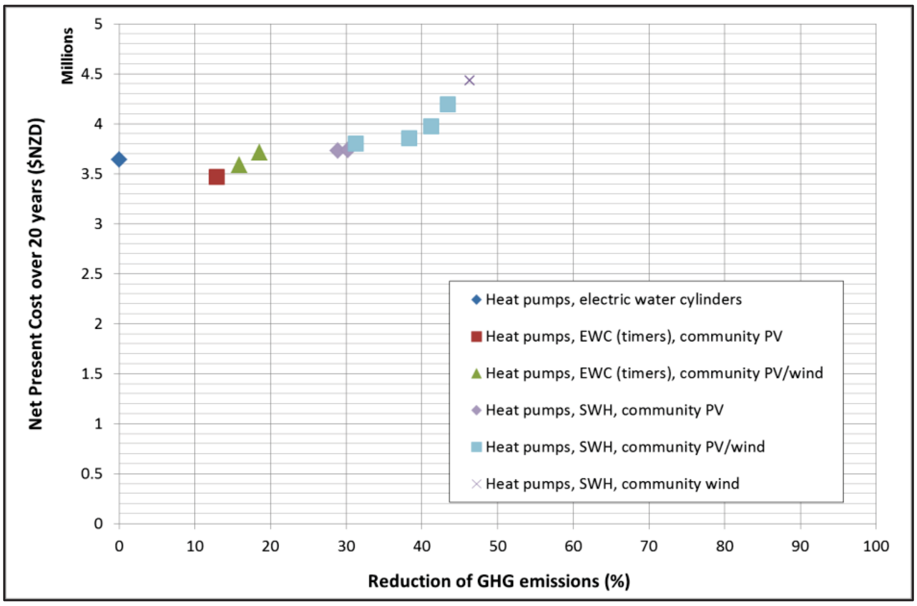

Figure 83: Cost of reducing community GHG emissions, mid growth scenario (land not available for biomass production)

If 6 hectares of land is not available for a community short rotation coppicing woodlot, the new homes can use heat pumps, imported or foraged firewood, or imported wood chips/pellets. The results if all new homes use heat pumps are shown in Table 28 (again a significant effect on peak loads).

Table 28: Summary of the most cost-effective technologies to reduce energy imports of the community (mid-growth scenario, 100kW grid-connect capacity constraint, land unavailable for biomass production)

	Lowest NPC	Maximum REI without raising NPC	Maximum REI
Individual buildings	Heat pump water heaters or solar water heaters for 10% of new buildings	Heat pump water heaters or solar water heaters for 10% of new buildings	Solar water heaters all buildings
Community	100 kWp PV	80 kWp PV 20 kWp WTG	100 kWp WTG
Reduction in energy imports (%)	16	18	41
Reduction in GHG emissions (%)	13	16	46
Initial capital ($)	333,100 (plus mounting for ground PV)	548,400 (plus mounting for ground PV)	1,360,300
NPV ($)	179,500	53,800	-790,800

3.4.5. Community outcomes – high-growth scenario

Figs. 84 and 85 show the results of the high growth future scenario, Figs. 86 and 87 show the results which exclude the use of biomass in new homes, if the required land area is not available. Electric vehicle charging loads are included.

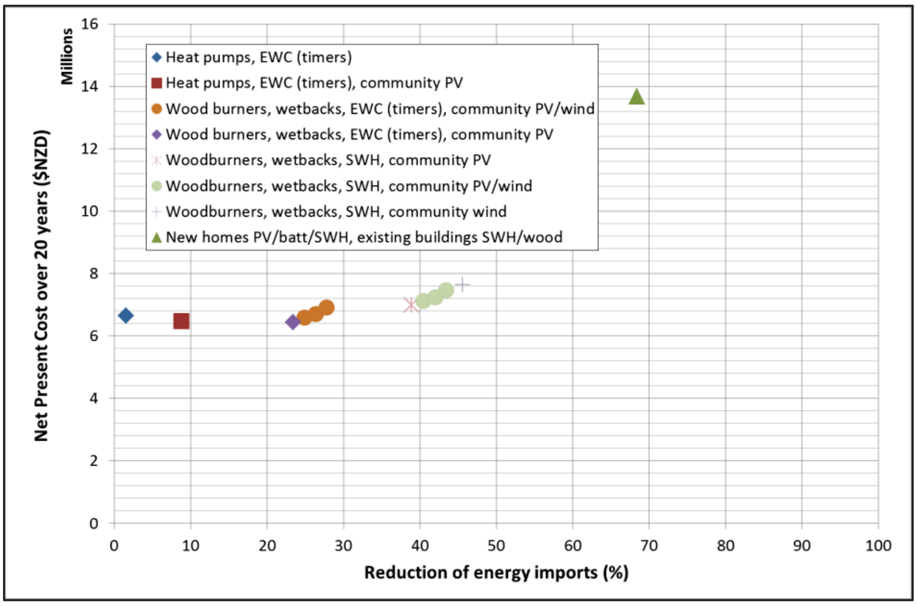

Figure 84: Cost of reducing community imports, high growth scenario

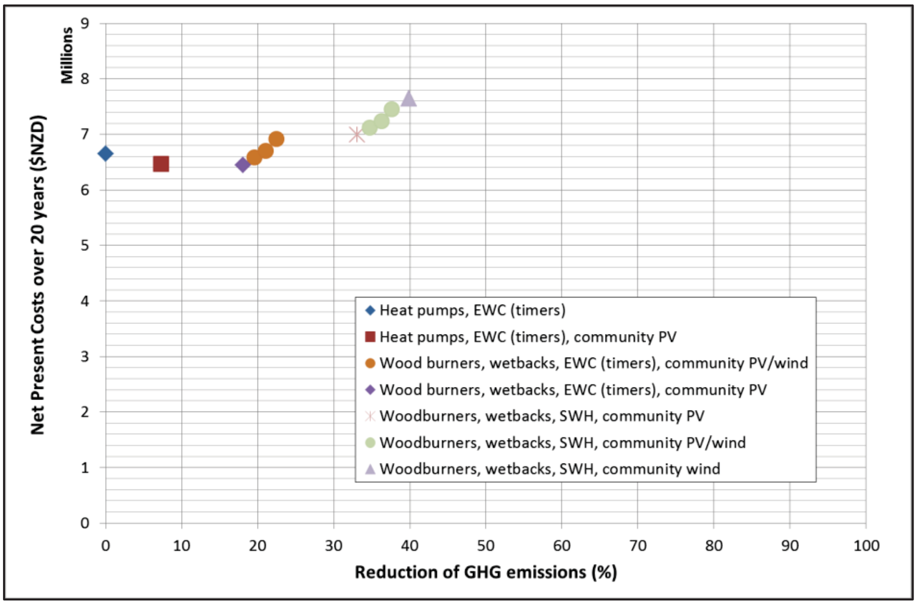

Figure 85: Cost of reducing community GHG emissions, high growth scenario

Having 200 new homes each with electric water cylinders would significantly increase peak loads, requiring a transformer upgrade (in turn potentially allowing more distributed generation capacity). The off-grid individual homes scenario is not included inTable 29.

Table 29: Summary of the most cost-effective technologies to reduce energy imports of the community (high-growth scenario, 100kW grid-connect capacity constraint)

	Lowest NPC	Maximum REI without raising NPC	Maximum REI
Existing buildings	Most economic (Section 3.4.1)	Most economic (Section 3.4.1)	Maximum thermal generation (Section 3.4.1)
Future buildings	Wood-burners, wetbacks, electric water cylinders with timers	Wood-burners, wetbacks, electric water cylinders with timers	Wood-burners, wetbacks or boilers, solar water heaters
Community	100 kWp PV 11.1 ha woodlot	80 kWp PV 20 kWp WTG 11.1 ha woodlot	100 kWp WTG 10.2 ha woodlot
Reduction in energy imports (%)	23	25	46
Reduction in GHG emissions (%)	18	20	40
Initial capital ($)	742,000 (plus mounting for ground PV)	950,000 (plus mounting for ground PV)	3,419,000
NPV ($)	209,000 (minus mounting for ground PV)	79,000 (minus mounting for ground PV)	-996,000

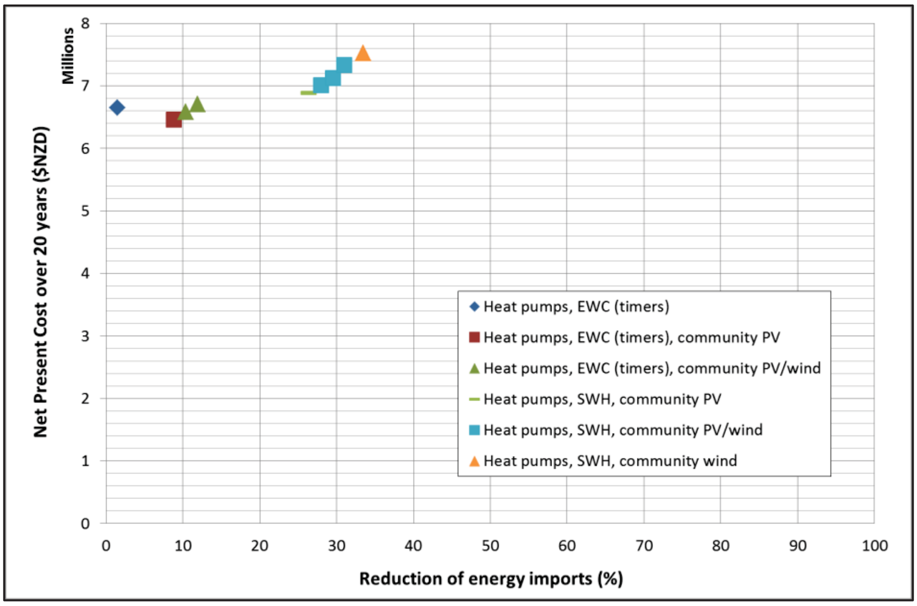

Figure 86: Cost of reducing community energy imports, high growth scenario (land area not available for biomass production)

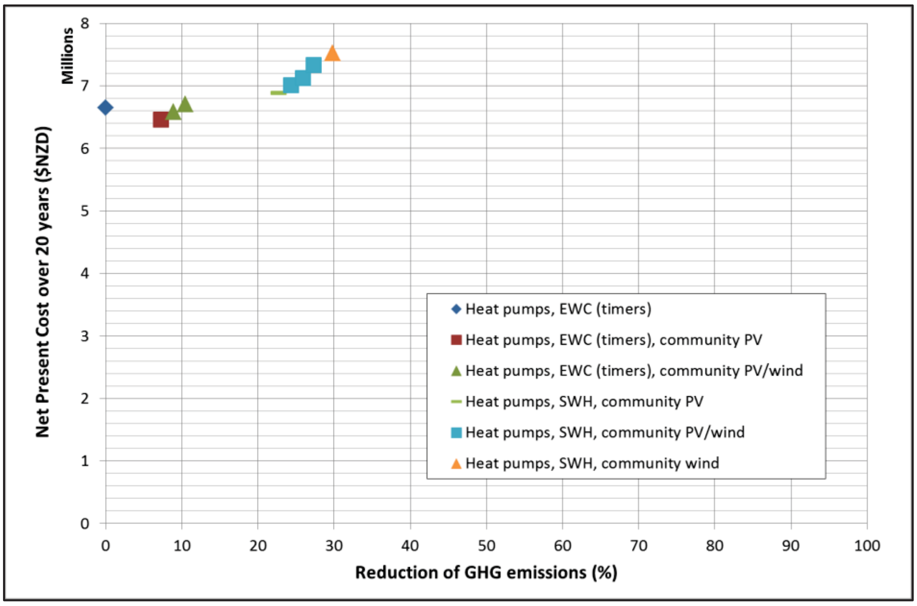

Figure 87: Cost of reducing community GHG emissions, high growth scenario (land area not available for biomass production)

If 11 hectares of land is not available for a community short rotation coppicing woodlot, the new homes can use heat pumps, imported or foraged firewood, or imported wood chips/pellets. The results if all new homes use heat pumps are shown in Table 30 (again a significant effect on peak loads).

Table 30: Summary of the most cost-effective technologies to reduce energy imports of the community (high-growth scenario, 100 kW grid-connect capacity constraint, land unavailable for biomass production)

	Lowest NPC	Maximum REI without raising NPC	Maximum REI
Individual buildings	Heat pump water heaters or solar water heaters for 10% of new buildings	Heat pump water heaters or solar water heaters for 10% of new buildings	Solar water heaters all buildings
Community	100 kWp PV	80 kWp PV 20 kWp WTG	100 kWp WTG
Reduction in energy imports (%)	9	10	33
Reduction in GHG emissions (%)	7	9	30
Initial capital ($)	413,000 (plus mounting for ground PV)	628,000 (plus mounting for ground PV)	2,996,000
NPV ($)	195,000 (minus mounting for ground PV)	65,000 (minus mounting for ground PV)	-872,000

3.4.6. Effect of population growth

A summary of Section 3.4 is presented to show the potential effect of population growth on the technology mix (Table 31).

Table 31: Summary of the most cost-effective technologies to reduce energy imports of the community under different growth scenarios

	Lowest NPC	Maximum REI without raising NPC	Maximum REI
Zero growth scenario	Energy efficiency measures, Heat pump waters or solar water heaters for very high users of hot water, 10 kWp community PV	Energy efficiency measures, Heat pump waters or solar water heaters for very high users of hot water, 20 kWp community PV, 0.5 ha SRC woodlot	Energy efficiency measures, solar water heaters, wood-burners with wetbacks if desired, wood boilers for marae and very high hot water users, 20 kWp community PV, 10 kWp community wind turbine, 1.1 ha SRC woodlot
Mid growth scenario	Energy efficiency measures, solar water heaters for very high users of hot water, new homes low energy design with wood burners with wetbacks if desired, controlled water heaters (subject to peak load limitations), 100 kWp community PV, 6ha SRC woodlot	Energy efficiency measures, solar water heaters for very high users of hot water, new homes low energy design with wood burners with wetbacks if desired, controlled water heaters (subject ot peak load limitations), 80 kWp community PV, 20 kWp community wind turbine, 6 ha SRC woodlot	Energy efficiency measures, new homes low energy design, solar water heaters, wood-burners with wetbacks if desired, wood boilers for marae and very high hot water users, 100 kWp community wind turbine, 5.7 ha SRC woodlot
High growth scenario	Energy efficiency measures, solar water heaters for very high users of hot water, new homes low energy design with wood burners with wetbacks if desired, controlled water heaters (subject ot peak load limitations), 100 kWp community PV, 11.1 ha SRC woodlot	Energy efficiency measures, solar water heaters for very high users of hot water, new homes low energy design with wood burners with wetbacks if desired, controlled water heaters (subject ot peak load limitations), 80 kWp community PV, 20 kWp community wind turbine, 11.1 ha SRC woodlot	Energy efficiency measures, new homes low energy design, solar water heaters, wood-burners with wetbacks if desired, wood boilers for marae and very high hot water users, 100 kWp community wind turbine, 10.2 ha SRC woodlot

The least cost way to reduce energy imports over time is to scale up a community PV sytem and SRC woodlot in step with population growth, heat any new homes with wood (including water), and shift electrical loads to coincide with PV generation.

Similar results apply to reducing energy imports as much as possible without raising the NPC of energy. Under both the mid and high growth scenarios a wind turbine features to allow more electricity under the 100 kW capacity constraint. However after 20 years, this limit may well increase, allowing further PV capacity, especially given that the predicted community peak loads in Table 15 and Table 16 well exceed 100 kW.

One way to significantly reduce energy imports as the population grows is to install solar water heaters together with wood-burners and wetbacks into new homes. Meeting any shortfall in water heating with an LPG boost heater means that water heating contributions to peak loads would be eliminated. A community wind turbine will produce the most electricity annually for a given capacity limit, and is well matched to the demand seasonally.

3.5. General Discussion

Any success with community engagement has been thanks to the hospitality and grace of the Parihaka community. A crucial success factor was having the guidance of a research assistant from within the community.

Due to the cautious approach taken seeking community approval for collaboration with the *100 homes* project, electricity monitoring was not finally installed until June/July 2015. The 12 months of consumption data become available significantly later than initially planned, which put time pressure on the data analysis. However this was considered a much better approach than proceeding quickly with a programme which was poorly understood and left the community uncomfortable or uncertain of the ramifications.

The workshops and focus groups proved very valuable, as they brought together community members (and friends) specifically interested in and focused on sustainable energy.

In general the measurement methods used resulted in robust data sets for a pre-feasibility or feasibility study. The lack of a measured community electricity load profile is not ideal as the results depend on the validity of the assumptions used in aggregating individual building loads (see appendix G). However the majority of individual buildings have been measured, and so the assumed and unmeasured load is not likely a high proportion of papakāinga demand.

The electricity monitoring devices, although ideal for an industrial setting, had some difficulty in the papakāinga where there were intermittent internet issues and power supply leads were susceptible to disruption. An alternative option may have been the use of devices powered directly from distribution panels, with data written to SD cards which could then be regularly swapped by the research assistant.

The meteorological data measured is expected to remain of value to the community for further investigations into renewable energy, particularly the two years of wind measurements as this resource is so site specific.

Although this specific study did not consider investment opportunities in more sustainable transport (Mohan (2016) assessed sustainable transport opportunities), the high proportion of papakāinga energy expended in transport (Figs. 39 to 41) suggests significant gains could be made in this area. In particular, ride sharing would likely produce the greatest gains in reducing energy use and emissions for the least investment.

All solutions for maximum independence included solar water heaters on homes and growing firewood locally for space and water heating. These are truly independent technologies which can provide useful energy regardless of outside disruptions, and can also help manage community peak loads as the population grows. However solar water heaters do not appear to provide an economic benefit to homes with low hot water use, and not all residents are willing to use firewood. More convenient forms of biomass exist, such as wood pellets, but local production would be expensive.

Providing household electricity with an off-grid system is only considered feasible if firewood is utilised for heating, and results suggest that long run energy costs would almost double. This does not appear to be the most cost effective way of reducing energy imports (unless energy use behaviours are drastically modified or battery storage costs reduce), but is an independent configuration.

The grid connected electricity source which would reduce energy imports the most, even with significant population growth, would be the largest community wind turbine allowable. However under current tariffs the investment would not be repaid, even with significant population growth.

For all scenarios, the lowest cost option over the long run is a combination of energy efficiency measures, and a community grid connected rooftop PV array of a capacity such that generation is consumed rather than exported. Further reduction of energy imports and emissions without increasing the cost of energy can be realised by incorporating more PV and establishing a short rotation coppicing woodlot. A community wind turbine could also feature under both the mid and high growth scenarios, however if it was installed now it may wear out before these scenarios eventuate. Controlled hot water cylinders can make use of variable generation and store energy for use later in the day, but would contribute to peak loading on the transformer as the community grows.

Peak loads currently occur at midday during large hui, related to the use of marae. However once population growth doubles and beyond, peak loads will shift to winter evenings, and any electric vehicles should charge outside of this time.

Grid connected solar PV or wind turbine generators cannot be relied on to reduce peak loads on the transformer due to the intermittency of the resource. Renewable energy technologies which can help reduce the community peak load are off-grid homes, space heating with wood, heating water with wood and/or solar with LPG boost or electric boost on a timer.

The results have shown a benefit of a community electricity generation source rather than distributed electricity generation installed behind individual building meters, due to the increased likelihood of self-consumption rather than exporting to grid. However the logistics and costs of metering and billing individual homes have not been taken into account, which may well affect these results. Potential methods of sharing electricity within the community include group billing, peer to peer trading, or a smart micro-grid.

Under the group billing scenario (Fig. 88), homes behind the main transformer are billed by a retailer as one customer. Another (possibly internal) entity bills homes based on meters at buildings. The discrepancy due to injected generation represents a revenue, which might be used to recoup the initial investment, cover meter reading and billing administration, or lower tariffs.

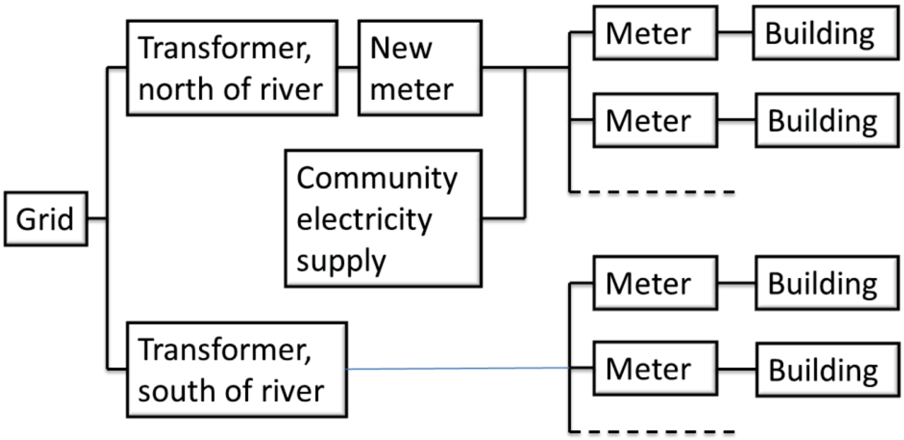

Figure 88: Group billing approach to community electricity distribution

The advantages to this approach are that the technology is available, and assumed to be affordable and reliable. Disadvantages include the lack of access for homes south of the river, there is more in-house responsibility for billing and collecting payment (prepay meters may reduce credit risks), and there is no explicit reward for households to coincide energy use with generation.

Peer-to-peer trading is where all residents purchase their electricity from a retailer who allows local trading of generated electricity, if it is used at the same time as it is generated. Smart meters track time of generation and use.

The advantages are that the generated electricity can be made use of throughout the whole papakāinga and also by family living nearby, a retailer handles all the billing logistics, and smart meters are already present. However this is not currently available locally (but is under trial elsewhere in the country), and is subject to whether rates are favourable. It also requires adequate 3G coverage for the meters, which is likely not currently the case at Parihaka.

Communications between electricity generation and use utilise IT technology within a smart micro-grid. Advantages are that internal metering and billing could be automated, demand management strategies could be implemented, and time of use tariffs could encourage the use of energy when generation is available. However this is new technology and may not be cost effective and capacity for operation and maintenance may not be present. Also a more reliable internet service may be a requirement.

As the feasibility and costs of sharing electricity within the papakāinga is likely to impact the results presented here, and have not been addressed by this study, further research is warranted in this area for Parihaka.

With the current population and existing buildings, any more than 30kWp roof top PV and a PV/wind hybrid may be more cost effective than PV alone. However with more population growth, it will be more cost effective to invest in more PV. Unlike a single wind turbine, PV systems are modular and can grow with the population. There is little point in installing excess PV initially as the cost of modules is still decreasing with time.

Costs considered here are for roof mounted PV, ground mounted arrays would cost significantly more and take up space. The best location for a community array would be the roof of Te Rānui (part of Toroanui marae), which faces near north, is in close proximity to the main transformer, and has space for approximately 20 kWp of PV (see Fig. 89). Steel girders supporting this roof suggests the structure is likely to be able to support such an array but an engineering assessment will be required.

Figure 89: Te Rānui roof, potential community PV array location[35]

Future expansion of community PV may be able to utilise the roofs of new homes if these face north and peer-to-peer trading becomes available, and it may be worth adding cable for rooftop PV within new home builds to allow for future PV expansion. If further papakāinga expansion is expected south of the river, a second community PV array might be considered there also (behind the transformer feeding that side of the river).

A community firewood plantation can also be scaled up over time in line with population growth, and a small trial may provide a valuable study in local factors – any shortfalls can be supplied from elsewhere.

The findings presented here depend upon reduced heating demand of low energy building designs which make direct use of (passive) solar energy.

Some further opportunities for study in this field at Parihaka include:

- managing the billing of community electricity;
- biogas production (from the anaerobic digestion of sewage waste, nearby dairy effluent or establishing a piggery) and utilisation;

[35] Image: Google Earth

- producing biomass for combined heat and power generation if producing biomass for heating demand proves successful;
- community scale energy storage potential e.g. pumped hydro or batteries;
- provision of hot water and drying heat for a community laundromat;
- a comparison of more refined site specific costs of wind turbines and ground mounted PV arrays (to compare with Table 24); and
- provision of energy for productive uses to encourage new small and medium enterprises into the community.

For example, to provide 42 MWh of electricity per year for the current population (Table 22), by wood gas generator may require an additional 7 hectares of plantation, assuming:

- internal combustion engine and alternator efficiency = 0.25 (Twidell & Weir, 2006);
- gasifier output = 2.2 m^3 gas per kg dry wood (Senelwa & Sims, 1999);
- energy content of gas = 4.6 MJ per m^3 of uncompressed gas (Senelwa & Sims, 1999);
- 9.2 odt/ha/yr yield (Section 2.4.4).

To provide 582 MWh of electricity per year for the mid growth scenario (Table 15) may require 90 hectares, and to provide 1051 MWh of electricity for the high growth scenario (Table 16) may require 160 hectares. In the unlikely case that this amount of land is available for short rotation forestry (no nearby forestry residue is available), then further study into the feasibility and economics of combined heat and power generation from biomass may be warranted.

4. Conclusions

Energy use in the papakāinga was assessed by measuring electricity, LPG, and firewood use in the majority of buildings over 12 months, and extrapolating this data to include some (but not all) of the buildings which were not measured. A better approach may have been to also include new buildings planned for the next few years within this extrapolation.

Renewable energy resources were assessed by measuring wind speed, wind direction, solar irradiance and ambient temperature at the wind tower location over 12 months; surveying the elevation change of three waterways in or near the papakāinga; and measuring the discharge of these waterways at various levels over 12 months. This short term measured data was compared to nearby long-term data to predict the long-term resources at Parihaka. Wind speed distribution predictions over the landscape near the papakāinga were made using WAsP software, and potential wind turbine locations identified. Potential locations for roof-mount (but not ground-mount) solar PV and/or water heaters were identified, as were potential locations for diverting water through turbines for electricity generation. Predictions of land area requirements for biomass production were made. An assessment of land available was not made as community land use preferences were not assessed.

Future energy demand scenarios assumed 100 – 200 new homes, 47 – 81 electric vehicles, and 23 – 40 plug in hybrid electric vehicles. New homes were assumed to have similar energy demands to the measured homes but with low energy building design and energy efficiency measures. Shortfalls in the future energy demand scenarios include not incorporating loads associated with increased marae use or with facilities such as a future café, museum, community laundry or office space.

Technologies assessed for expected performance and compared included wood burning appliances for space and/or water heating, air source heat pumps for space or water heating, solar water heaters, solar photovoltaics, wind turbine generators, micro-hydro turbines, lead acid batteries and controlled hot water cylinders. The modelled performance was quantified by net present cost, reduction in energy imports, and reduction in GHG emissions. For various levels of reductions of imports or GHG emissions, the most cost effective technology or combination of technologies was identified.

Findings include:

- Within the scope of technologies considered, a solution has not been identified which would completely eliminate importing some energy as electricity or liquid/gaseous fuels from outside the papakāinga.

- Approximately half of household energy use (excluding transport) is for heat (space heating and water heating), the majority of which can be supplied by a combination of solar water heating and direct combustion of biomass (firewood). In most cases retrofitting existing buildings to use such renewable heat is unlikely to provide an economic benefit.

- A micro-hydro scheme is likely too expensive to be worth considering, due to the nature of the landscape and the civil works required to develop the limited head.

- In most cases, installing rooftop grid-connected PV behind the meter of individual buildings (at current prices and assuming no buy-back rate) is unlikely to provide an economic benefit.

- An off-grid configuration of homes may reduce energy imports by 60 -70%, since this configuration is not feasible for all buildings - due to attitudes in some cases towards heating with firewood and the size of electricity loads. It is likely that reducing energy imports to this level or lower can be achieved at a lower cost than off-grid homes by implementing grid-connected community distributed electricity generation in combination with solar water heating and biomass for heating.

- If maximum electricity production is sought but network constraints on distributed generation capacity are a limiting factor, a wind turbine will generate more electricity annually than a PV array of the same nameplate capacity.

- The feasibility and costs of metering and billing individual buildings receiving shared electricity from a community generation scheme have not been addressed in this thesis. Seeing as community generated electricity has been identified as having potential for Parihaka, further enquiry is required in this area. Subject to the findings of that enquiry:

- The investment in renewable energy conversion technology for the current population with the largest economic benefit (including doing nothing) for the papakāinga is likely a 10 kWp grid-connected community PV array installed on the roof of Te Rānui, where the output would be available not just for the marae but for consumption by as many buildings in the papakāinga as possible. This should follow after investment in energy efficiencies and possibly sustainable transport options. Initial capital costs are expected to be in the order of $48,000 (including energy efficiency measures), with an expected net present value (NPV) of savings of $26,600 over 20 years (excluding metering and billing costs), and providing an expected reduction in energy imports and GHG emissions of 17% (Table 23).

- Further steps to reduce energy imports and reduce emissions would be an additional 10 kWp of PV on the roof of Te Rānui and the establishment of 0.5 hectares of short rotation coppicing firewood plantation. Total initial capital costs are expected to be in the order of $80 000 with an expected net present value (NPV) of savings of $5,800 over 20 years value (excluding metering and billing costs), and providing an expected reduction in energy imports of 42% and GHG emission reductions of 21% (Table 23).

- Further steps to achieve a high reduction in energy imports and emissions, but increasing the overall cost of energy would be to install solar water heaters on all homes, retrofit wood burners and wetbacks if feasible and desired (depending on building layouts and occupants), retrofit wood fired boilers with 1000l storage to marae (if acceptable for kitchen workers), and establish a further 0.6 hectares of short rotation coppicing firewood plantation. Solar water heaters and wood-burners can also reduce community peak electricity loads, thereby accommodating growth.   Total initial capital costs are expected to be in the order of $225,000 with an expected net present value of savings of -$92,000 (i.e. extra costs) over 20 years (excluding metering and billing costs), and providing an expected reduction in energy imports of 65% and GHG emissions of 55%. Further gains (with a further reduction in NPV) could be made by including a community wind turbine (Table 23).

- Future population growth should be accommodated by initially installing a system which can accommodate significant growth in PV capacity, installing more PV as costs reduce and population grows, and including solar water heaters and wood-burners with wetbacks in new low energy homes if appropriate. The area of a short rotation coppicing firewood plantation could be increased in step with growing demand by an increased population. It would need a three to four year lead time to anticipate the first harvest of a newly planted tree crop. Land area of up to 12 hectares may be required if available, subject to population growth and wood burner uptake.

The most cost effective combination of a range of available renewable energy technologies has been presented for various levels of reduction in energy imports and GHG emissions. The appropriate level of investment in renewable energy for Parihaka depends on community aims and preferences. The following recommendations detail one possible level of investment.

5. Recommendations

1. Based on the energy use results, the findings of Mohan (2016), Hernandez Pacheco (2016) and Lambert (2015) should be applied prior to these recommendations. (The design and build of a new home is an opportunity to incorporate low energy design principles at much lower cost than retrofitting. Obtain supplier's prices for energy efficient equipment and installations, which should precede generating renewable energy capacity installation).

2. Initiate a feasibility study into the costs, required structures, logistics and implications of sharing community electricity.

3. Based on 3), obtain supplier's quotes for a 10-20 kWp community PV array installed on the roof of Te Rānui.

4. Apply to Powerco for distributed generation connection permission.

5. Have a community discussion on the appropriateness of using land for biomass production, identifying any suitable areas.

6. If it is considered appropriate land use, establish an SRC trial of potential tree species (such as *Eucalyptus*) as a practical test to confirm feasibility. Obtain more specific prices/estimates for seedlings, labour, cultivation, planting, maintenance, small scale harvest and processing equipment, fuel requirements. For example, plant 500 – 1,000 *Eucalyptus* seedlings on 2,000 m^2 each year for 3 years to supply current wood heated homes. First harvest will be after 3 years but will require labour-intensive manual chainsaw felling and processing (possibly aided by a saw bench). Current wood heated homes would need to be willing to purchase wood at appropriate rates during the trial period to determine economic feasibility of processing and silviculture cost.

7. Include solar water heaters and wood burning appliances for space and water heating in new homes, to increase independence and reduce peak loads. Wood burning appliance selection should take into account the preferred fuel type (e.g. local firewood vs purchased forestry by-product).

8. While PV prices continue to decline, only expand the PV system to keep pace with population.

9. Monitor the price of battery storage as it declines since integrating storage may become more attractive at lower costs.

Glossary

anemometer:	A sensor for measuring wind speed
AWS:	Automatic Weather Station
BRANZ:	Building Research Association of New Zealand
capacity factor:	The ratio of electrical energy supplied by generating plant to the electrical energy which would be supplied if it constantly ran at maximum rated output
CO_2-e:	Carbon dioxide equivalent, a way of quantifying the climate effect of all emissions
COP:	Coefficient Of Performance, in this context the ratio of heat produced to electricity consumed
coppicing:	See SRC
CT:	Current Transformer, a sensor for measuring electrical curent in a conductor
culvert:	In this context, a pipe channelling water underneath vehicle access
demand:	The amount of power needed at any given point in time. Also, load.
discharge:	1) The flow (volume/time) of a water way, or 2) Water which has passed through a hydro turbine re-entering the original waterway
diverter:	In this context, a device which directs excess electrical energy to a resistive immersion element in a water storage cylinder
draft tube:	A conduit downstream of a hydro turbine
EV:	Electric Vehicle
f chart:	A method for estimating the performance of a solar water heater
flow duration curve:	A cumulative distribution chart which shows what proportion of time a given flow is exceeded in a waterway
flume:	In this context, an open channel for transporting water above ground level
GHG:	Greenhouse Gas - in this context, emissions which cause heat to be trapped in the atmosphere
GHI:	Global Horizontal Irradiance - the solar resource avalable on a horizontal surface
GJ:	Gigajoule - a unit of energy
grid-hub:	A device which forms part of the electricity monitoring system used
grid-node:	A device which forms part of the electricity monitoring system used
hāngi:	Traditional Māori method of cooking food using an earth oven
HHV:	Higher Heating Value (also gross calorific value), heat released during combustion of fuel (including the heat required to evaporate water in the fuel)
hindcast:	Predict what happened in the past
HOMER:	Hybrid Optimization Model for Multiple Energy Resources, computer software to model energy system performance
HPWH:	Heat Pump Water Heater (air source)
hui:	Meeting, social gathering or assembly
hybrid:	In this context, an electricity supply utilising a mix of energy resources
inclinometer:	Also clinometer, an instrument for measuring angles of slope with respect to gravity
kaupapa:	Topic, policy, matter for discussion, plan, purpose, scheme, proposal,

	agenda, subject, programme, theme, issue, initiative
kanohi kitea:	A seen (i.e. familiar) face
karakia:	Incantation or ritual chant
kaumātua:	Tribal elders
kW:	Kilowatt, a unit of power
kWh:	Kilowatt-hour, a unit of energy
kWp:	Nominal peak capacity in kW
kW_{th}	Kilowatts of heat rather than electricity
LiDAR:	Light Detection And Ranging, a surveying method using laser range finding
LINZ:	Land Information New Zealand
LHV:	Lower Heating Value (also net calorific value), heat released during combustion of fuel (excluding the heat required to evaporate water in the fuel)
load:	See demand
load profile:	A graph of load/demand vs time for an average day
LPG:	Liquid Petroleum Gas, in New Zealand a mix of propane and butane
mahi:	work
mahi aroha:	unpaid work
māra:	Community garden
marae:	In this (infrastucture) context, the complex of buildings associated with the marae proper (a communal meeting place)
MCP:	Measure-Correlate-Predict, a group of methods used to compare short term measurement data with nearby long term data, in order to hindcast long term data
MJ:	Megajoule, a unit of energy
MWh:	Megawatt-hour, a unit of power
NIWA:	National Institute of Water and Atmospheric research
NPC:	Net Present Cost, the total long term financial cost
η:	Efficiency of a conversion device, the ratio of power out to power in
NPV:	Net Present Value. In this cost the total long term financial savings expected by implementing a project, i.e. NPC(no change) - NPC(project)
NZ:	New Zealand, also Aotearoa
NZD	New Zealand Dollar. All monetary values are in New Zealand Dollars.
O&M:	Operation and Maintenance, ongoing costs as opposed to initial capital or replacement costs
odt	Oven dry tonnes, a unit of biomass yield excluding moisture content (also tonnes dry matter, tdm)
off-grid:	No supply available from the national electricity grid, also stand-alone
papakāinga:	A village on communal Māori land
pāhua:	Plunder, in this context a commeration event of the ransacking of Parihaka
penstock:	A pressure pipe which delivers water from a location of higher elevation to a hydro turbine
PHEV:	Plug in Hybrid Electric Vehicle - a vehicle which can store and use electrical energy and/or a hydrocarbon fuel
pōwhiri/mihi whakatau:	Welcome ceremonies to visitors
PPT:	Parihaka Papakāinga Trust

propellor turbine:	A reaction hydro turbine suited to low head applications
puanga:	A star marking the beginning of the year for Taranaki Māori
PV:	Photovoltaic - a technology which converts solar energy to electrical energy
pyranometer:	A sensor for measuring solar irradiance
rā:	Day, in this context the days of hui at Parihaka on the 18th and 19th of every month
RE:	Renewable Energy
REI:	used in this thesis for percentage Reduction of Energy Imported
reo:	language, in this context the Māori language
residual flow:	The minimum flow which must be preserved in a waterway fro environmental and/or regulatory reasons
RETScreen:	Computer software for pre-feasibility analysis of renewable energy technology projects
rose, wind: frequency	A diagram displaying how often the wind is coming from each direction sector
specific heat capacity:	The ratio of heat added to (or removed from) on object to the resulting temperature change, per unit mass
SRC:	Short Rotation Coppicing - harvesting trees every few years which resprout shoots from the cut stumps
staff gauge:	A ruler installed in a waterway to enable visual readings of stage
stage:	The level of a waterway
stand-alone:	see off-grid
SWH:	Domestic Solar Water Heating system
Taiepa Tiketike:	High or important fences, a reference to historic fences at Parihaka which followed the contours of the land
tangi:	Funeral
tikanga:	Correct cultural practice
timestamp:	Date and time attached to a particular measured value
TRC:	Taranaki Regional Council
TRNSYS:	Transient System Simulation Tool, computer software which can be used to model solar water heater performance
turgo turbine:	An impulse hydro turbine suitable for medium head applications
vane, wind:	A sensor for measuring wind (origin) direction
wānanga:	Educational/learning seminar
WAsP:	Wind Atlas Application and Analysis Program, computer software to model the wind resource over a landscape
wetback:	New Zealand specific term for a heat exchanger within a wood burning appliance to provide domestic hot water
whanau:	Extended family
wood burner:	Also stove, range, fireplace, fire; a space heating appliance which combusts wood in an controlled/enclosed space
WTG:	Wind Turbine Generator

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Appendices

A. Marae energy audit, 22/4/2015

Marae A

Electrical Equipment - Kitchen			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Walk in chiller	McAlpine Industries R380 E/F	1	
LPG instantaneous water heater	Rheem 27	1	175
Compact Flourescent Lamp		4	20
Incandescent lamp		2	100
Incandescent lamp		1	150
3 phase large electric range. 4 elements 1 hotplate 1 oven	Blue Seal E56C	1	21 150
Electric range	Fisher and Paykel OR61	1	
Conveyor Belt toaster	Delta TS-2002?	1	2 800
Warmer oven		1	
Fridge/freezer	BJ504BK-RWZ	1	360 (450 defrost)
Large chest freezer	Fisher and Paykel Kelvinator	1	
Large chest freezer	Fisher and Paykel	1	
Dish Steriliser	Electrolux	1	5 350
Coffee grinder	Carimal	1	
Microwave	Breville BMO300	2	1 500
Expresso coffee machine	WEG	1	3 300
Water heater ("zip")	Birko		2 400

Electrical Equipment - Laundry			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Clothes washing machine	Fisher and Paykel MW513	1	450
Dryer	ELBA DE45F56A	1	1800
Incandescent lamp		1	100

Electrical Equipment - Dining Room			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Incandescent lamp		6	200
Urn water heater	Birko	1	1450

Electrical Equipment - Wharenui			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Incandescent lamp		5	200
Incandescent lamp		1	100
Incandescent lamp		1	50
Compact Flourescent lamp		1	
PA system		1	25
Wifi receiver		1	
Radiant heater with fan	Evantair TWD31	1	2 200
Radiant heater	Evantair TWHH11ARC	1	1 600
Wall mounted heater		1	3 000

Electrical Equipment - Wharepaku			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
LPG Instantaneous water heater	Paloma PH-241CWHA	1	62
Incandescent lamp		1	50
Compact Flourescent lamp		3	20

LPG Equipment - Kitchen 2x45kg bottle changeover and regulator			
Appliance	**Model**	**Quantity**	**Power rating (MJ/h) according to nameplate**
Instantaneous water heater	Rheem 27 874027LFZ	1	205

LPG Equipment - Wharepaku 2x45kg bottle changeover and regulator			
Appliance	**Model**	**Quantity**	**Power rating (MJ/h) according to nameplate**
Instantaneous water heater	Paloma PH-241CWHA	1	188

LPG Equipment - with portable 9kg bottle			
Appliance	**Model**	**Quantity**	**Power rating (MJ/h) according to nameplate**
Patio heater for heating wharenui	Gascraft	1	40
Large cooking ring		1	

Marae B

Electrical Equipment - Kitchen			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Large chest freezer	Fisher and Paykel H510	1	276
Medium chest freezer	Frigidaire	1	
Large walk in chiller	McAlpine Industries R680	1	
Compact Fluorescent lamp		2	18
Compact Fluorescent lamp		2	14
Incandescent lamp		3	140
Incandescent lamp		3	75
Double tube fluoro 35W/tube		3	70
Microwave	National NN-7506	1	1400
Fridge	Kelvinator	1	
Vacuum Cleaner		1	
Toaster/griller	Blue seal	1	
Oven	Smeg	1	
Water heater ("zip")	Rheem lazer	1	
Bain Marie, 3 trays	Metaltecnica 035.AC	1	2500
LPG Instantaneous water heater	Rinnai infinity 24 REU-2425W-ZK	1	161

Electrical Equipment - Dining Room			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Compact Fluorescent Lamp		10	13
Incandescent lamp		3	75
Wifi node		1	

Electrical Equipment - Wharenui			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Incandescent lamp		8	75
Compact fluorescent lamp		2	20
Fan heater	Goldair 9700	1	2000

Electrical Equipment - Wharepaku			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
LPG Instantaneous water heater	Rinnai infinity 20 REU-2020W-ZK	1	161
Compact Fluorescent lamp		6	
Extractor fan		6	
Halogen downlight		10	
Compact Fluorescent lamp		1	18

Electrical Equipment - Outdoor			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Compact Fluorescent Lamp		2	23
Compact Fluorescent Lamp		1	24

LPG Equipment - Kitchen 2 sets of 2x45kg bottle changeover and regulator			
Appliance	**Model**	**Quantity**	**Power rating (MJ/h) according to nameplate**
LPG Instantaneous water heater	Rinnai infinity 24 REU-2425W-ZK	1	188
Large gas range, oven and 6 elements	Blue seal	1	
Large gas ring		3	

LPG Equipment - Wharepaku 2x45kg bottle changeover and regulator			
Appliance	**Model**	**Quantity**	**Power rating (MJ/h) according to nameplate**
LPG Instantaneous water heater	Rinnai infinity 20 REU-2020W-ZK	1	160

Marae C

Electrical Equipment - Kitchen			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Microwave	Sanyo EM-X412	1	1300
LPG instantaneous water heater	Rinnai Infinity VT24	1	130
Compact Flourescent Lamp		1	20
Incandescent lamp		5	100
Large double tube fluoro (54W/tube)		1	108
Large halogen lamp/spotlight		1	
cake mixer	Sunbeam MX5950	1	400
Conveyor Belt toaster	Cater master TT-WE1029B	1	1940
Electric range	Fisher and Paykel Paprika	1	
Rice cooker	Cascade CE946RC	1	770
Kettle	Red stamp	1	2200
Slow cooker		1	180
Microwave	Sharp Carousel	1	1100
Water heater ("zip")	Super heat BU10	1	2400
Electric range	Westinghouse Gemini	1	12100
Small chest freezer	Fisher and Paykel Kelvinator	1	
Water heater ("zip")	Zip	1	
Large chest freezer	Frigidaire	1	
Walk in chiller	McAlpine Industries R380	1	
Toaster	Red stamp RS2201TR	2	1400
Toaster	Budget B04391	1	750
Refrigerator	Fisher and Paykel Kelvinator	1	

Electrical Equipment - Laundry			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Clothes washing machine	Fisher and Paykel MW512	1	450
Dryer	Fisher and Paykel AD39	1	1800
Compact Fluorescent Lamp		1	20

Electrical Equipment - Dining Room			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Large double tube fluoro		8	120
Wifi node		1	

Electrical Equipment - Wharenui			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Circular tube flourescent lamp		4	32
Halogen downlights		12	
Vacuum cleaner	Pullman Janitor A-031B	1	1000
Radiant heater with fan	Goldair GIR400	1	2400

Electrical Equipment - Mahi Kuare Wharepaku			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
LPG Instantaneous water heater	Rheem Integrity 26	1	64
Extractor fan		2	
Incandescent lamp		1	100
Compact Fluorescent lamp		5	20

Electrical Equipment - Wharepaku by river			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Low pressure hot water cylinder (immersion heater)	Rheem 14T180	1	3000
Incandescent lamp		2	100
Compact Fluorescent lamp		1	20

Electrical Equipment - Outdoor			
Appliance	**Model**	**Quantity**	**Power rating (W) according to nameplate**
Compact Flourescent Lamp		0	20
Incandescent lamp		1	75
Incandescent lamp		2	100
Incandescent lamp		1	200
Large double tube fluoro (58W/tube)		2	116
Large double tube fluoro (65W/tube)		2	130
Large halogen spotlight		1	

LPG Equipment - Kitchen 2x45kg bottle changeover and regulator			
Appliance	**Model**	**Quantity**	**Power rating (MJ/h) according to nameplate**
LPG instantaneous water heater	Rinnai Infinity VT24	1	188
Large gas range, oven and 6 elements	Indesit	1	
Large gas ring		5	

LPG Equipment - Mahi Kuare Wharepaku 2x45kg bottle changeover and regulator			
Appliance	**Model**	**Quantity**	**Power rating (MJ/h) according to nameplate**
Instantaneous water heater	Rheem integrity 26	1	188

LPG Equipment - with portable 9kg bottle			
Appliance	**Model**	**Quantity**	**Power rating (MJ/h) according to nameplate**
Patio heater for heating dining hall	Gascraft	3	39.6

B. Energy monitoring points

Electrical circuits monitored

House 1	Incomer (all), lighting, oven & cooktop, general power
House 2	Incomer ph1, incomer ph2, kitchen appliances, washing machine/heater/water pump, lighting, hot water
House 3	Incomer ph1, incomer ph2, Incomer ph3, hot water, lounge lighting, kitchen/freezer/clothes dryer
House 4	Incomer ph1, incomer ph2, kitchen & bathroom lighting, dining & lounge lighting, kitchen appliances, dining room
House 5	Incomer (all), oven, general, lighting
House 6	Incomer ph1, incomer ph2, incomer ph3, house lounge, bedroom, hot water, shed lighting, shed general, freezer, laundry, shed entertainment, shed bedroom, house lighting 1, house lighting 2, house lighting 3, oven, cooktop, kitchen appliances
House 7	Incomer (all), bedroom, lighting/bathroom heater, kitchen/lounge, oven/cooktop
House 8	Incomer (all), oven, kitchen appliances, lighting, heat pump, shed/laundry
House 9	Incomer (all), lighting, general, kitchen/laundry, oven/cooktop
House 10	Incomer ph1, incomer ph2, cooktop, kitchen appliances, hot water
Marae A	Incomer ph1, incomer ph2/attached residence, incomer ph 3, oven & cooktop ph1, oven & cooktop ph2, oven & cooktop ph3, lighting, walk-in chiller/clothes drier/ fridges, wharenui outlets, kitchen appliances 1, dishwasher, kitchen appliances 2
Marae B	Incomer ph1, incomer ph2, incomer ph3, wharenui lighting, bainmarie/zip boiler/appliances, oven, freezer 1, freezer 2, kitchen appliances, wharekai lighting 1, wharekai lighting 2
Marae C	Wharekai incomer ph1, wharekai incomer ph2, wharekai incomer ph 3, wharenui incomer (all), kitchen appliances 1, kitchen appliances 2, wharekai lighting 1, wharekai lighting 2, oven & cooktop 1, oven & cooktop 2, wharenui outlets, wharenui lighting, wharepaku lighting, wharepaku outlets, wharepaku water heater ignition

LPG regulator locations

House 1	Water heater (portable cylinders)
House 4	Water heater
House 7	Water heater
House 8	Water heater, cooktop
Marae A	Wharekai water heater, wharenui water heater
Marae B	Wharekai shared water heater & cooking, wharekai cooking, wharepaku water heater
Marae C	Wharekai shared water heater & cooking, wharepaku water heater

Buildings with wood consumption estimated

Houses 5, 6, 9, 10

C. Powerspout turbine type selection chart

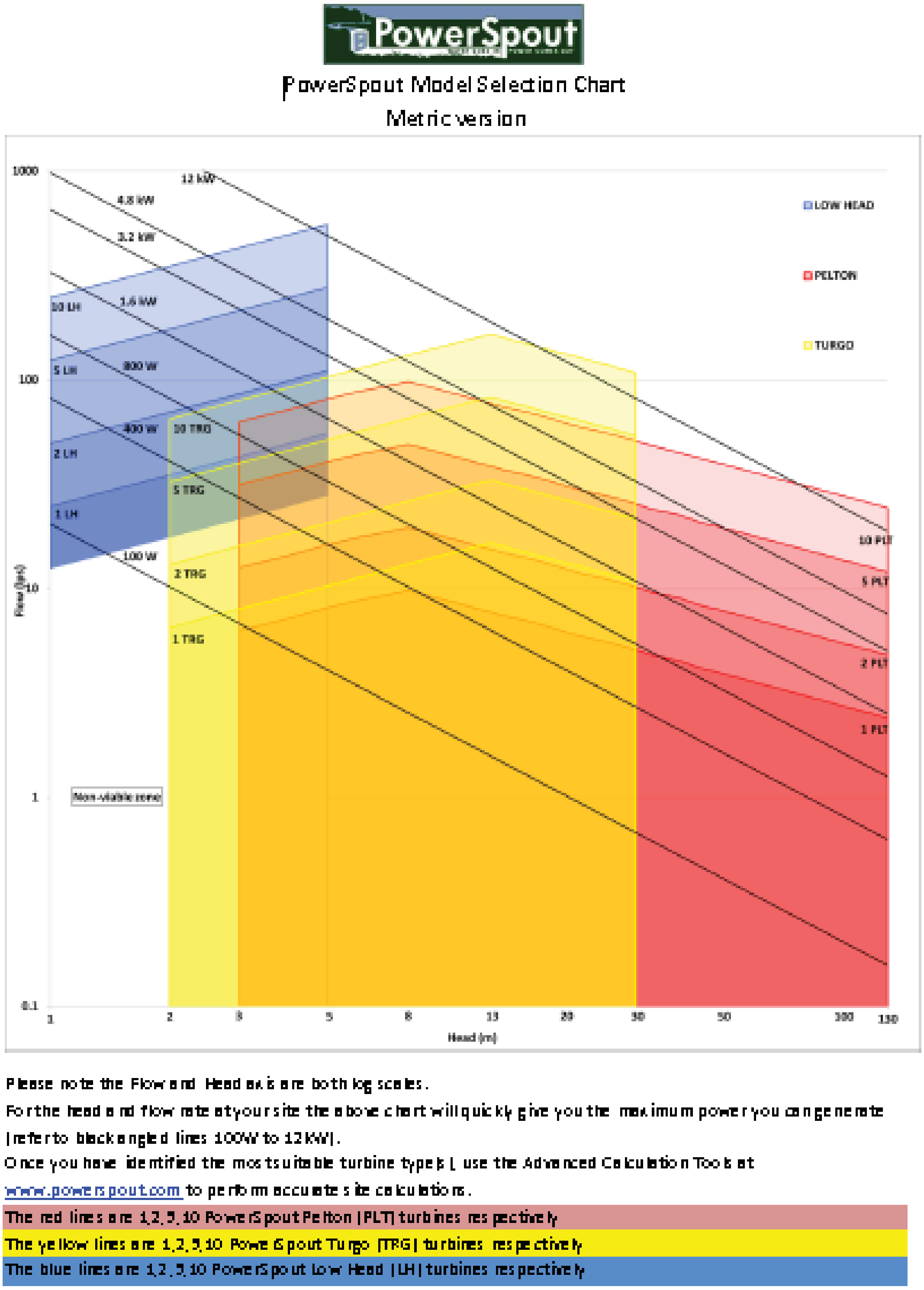

Figure C1: Powerspout turbine type selection chart[36]

[36] Reproduced from http://www.powerspout.com/assets/Published/public/PowerSpout-Model-Selection-Chart-Metric.pdf, Accessed Jan 2016

D. Indicative prices of renewable energy technologies in NZ in 2016

Prior to investing in renewable energy technology at Parihaka detailed design, specification and costing will be required, which has not been provided in this study. Here a rough indication is given of what some major costs were assumed to be, in order to evaluate different technologies against each other. Costs are given in New Zealand dollars and include tax (GST). Note that not all costs were taken into account for each technology.

Energy efficiency measures:

Refer to Hernandez Pacheco (2016).

Grid connected solar photovoltaic systems (with micro-inverters):

Residential scale, first floor corrugated iron roof:

Table D1: Expected installed costs of roof mounted grid-connected PV systems, residential scale[37]

PV Capacity (kW)	Complete system installed cost ($)
1.16	4,995
2.03	7,795
2.9	9,995
4.06	13,095
5.22	16,195

Community scale grid connected solar photovoltaic systems, roof mounted (ground mount array costs not included), including 40m underground cable at $25/m:

Table D2: Expected installed costs of roof mounted grid connected PV systems, community scale[38]

PV Capacity (kW)	Complete system installed cost
20	52,750
150	346,000

Inverter replacement cost: $1,000/kW[39], micro inverter replacement expected after 15 years (manufacturers claim 20+ years, but has not been verified as existing installations are less than 20 years old)

Operational and maintenance costs per year: $0, assuming system owner cleans and checks array free of charge

PV array assumed to last more than 20 years with less than 20% reduction in output

[37] Reproduced from http://www.whatpowercrisis.co.nz/SolarPVPackages.html, accessed September 2016
[38] Costs excluding cable based on personal communications with Solarcity, September 2016
[39] Based on a selection of currently available devices, September 2016

PV/battery stand alone system

As previous (includes PV, mounting, wiring, inverter etc), but an additional:

Battery charge controller: $300/W[40]

Battery SOC meter: $300[41]

Lead acid batteries: $300/kWh (Trojan T105) or $290/kWh (larger Trojan IND29-4V)[42]

Inverter/charger replaced after 10 years at $1,000/W[43]

Operational and maintenance costs per year: $0, assuming system owner maintains battery electrolyte etc free of charge

Community grid connected wind turbine:

Table D3: Expected installed costs of community scale wind turbines[44]

Turbine capacity (kw)	Turbine installed cost ($/kW)
1 - 10	13,340
10 - 100	12,500

Plus 420m of underground cable at $25/m

Annual average operating and maintenance costs of $55/installed kW, based on $0.021/kWh[45]. In reality these costs could be much higher for a small wind turbine generator. Assuming no replacement within 20 years is also likely quite optimistic. Note that the ocean is visible from wind turbine sites and is less than 10km away, with prevailing onshore winds. Significant corrosion on the wind monitoring tower has been observed, and any wind turbine generator will likely need to be rated for a marine type environment.

Note that these costs do not take into account local site-specific issues such as access, transport, soil type etc and as such are very approximate.

40 Based on a selection of currently available devices, September 2016
41 Based on a selection of currently available devices, September 2016
42 Based on prices provided at www.bestbatteries.co.nz, accessed September 2016]
43 Based on a selection of currently available devices, September 2016
44 Based on $10 000 – $15 000/kW installed www.energywise.govt.nz, and $26 680 for a 2kW machine www.powerhousewind.co.nz as 75% (Jain, 2011) of installed cost, accessed September 2016]
45 USD$ 0.015/kWh in 2011, (Jain, 2011) and RETScreen help file

Community grid connected micro-hydro turbine:

All micro-hydro component costs listed here[46] exclude GST (tax). All pipe diameters are assumed internal diameters.

Low pressure pipes (for channel diversion in difficult terrain or low head flumes)

Polypropylene

diameter (mm)	$/6m length	$ /coupling	total $/m
225	215.27	8.49	37.29
300	416.62	26.55	73.86
375	702.58	43.57	124.36
450	1,175.96	81.27	209.54

Galvanised steel

diameter (mm)	$/6m length	$ /coupling	total $/m
300	486.68	158.29	107.50
375	651.06	162.34	135.57
450	746.24	162.34	151.43
600	1,112.86	177.48	215.06
750	1,780.15	190.65	328.47
900	2,188.96	207.44	399.40
1 050	2,712.4	402.15	519.09
1 200	3,083.36	417.38	583.46

Aluminium

diameter (mm)	$/6m	$ /coupling band	$/m
300	601.31	212.85	135.69
375	750.56	211.01	160.26
450	912.79	211.03	187.30
600	1,303.21	216	253.20
750	1,861.26	236.53	349.63
900	2,252.76	239.64	415.40
1,050	2,677.79	267.33	490.85
1,200	3,403.48	327.54	621.84

[46] Based on Humes Price Book, November 2015.

Polyethylene

diameter (mm)	$/2.7m length		$/m
330	376.6		139.48
450	627.67		232.47
600	1,004.25		371.94
750	1,548.25		573.43
900	2,092.23		774.90
1,200	2,970.95		1,100.35

Concrete

diameter (mm)	$/2.44m length	$ /coupling	$/m
300	232.19	7.68	98.31
375	286.88	9.17	121.33
450	407.62	12.2	172.06
525	529.39	13.67	222.57
600	644.97	20.37	272.68
675	755	16.26	316.09
750	895	25.22	377.14
825	1,045	26.8	439.26
900	1,363	36.95	573.75
975	1,620	43.37	681.71
1,050	1,875	46.13	787.35
1,200	2,125	50.85	891.74
1,350	3,524	57.22	1,467.71
1,600	4,609	79.73	1,921.61
1,800	6,505	89.52	2,702.67

High pressure pipe (for penstock)

MDPE (by roll, no joins)

diameter (mm)	$/m
40	2.91
50	4.51
63	6.81
110	12
125	17

PVC (coupled lengths)

diameter (mm)	$/m
50	3.96
65	5.43
80	6.95
100	9.77
125	14.76
150	18.68
175	27.36
200	33
225	41.7
250	55.38
300	67.55

Electrical cable

Wire gauge	$/m
2 x 1 mm^2	0.97
2 x 1.5 mm^2	1.44
2 x 2.5 mm^2	2.52
2 x 4 mm^2	3.77
2 x 6 mm^2	4.89
2 x 16 mm^2	9.58
2 x 25 mm^2	14.21

[47]

Turbine costs

The cost of a turbine is assumed to be equivalent to multiple Powerspout turbines (Appendix B), where each turbine costs $2,800[48]. The equivalent quantity of turbines is found using the online calculator http://www.powerspout.com/calculators/.

Various other costs

Open channels are assumed lined with concrete 75mm thick at $400 /$m^3$

The cost of excavation is assumed to be $50 /$m^3$

Annual operating and maintenance costs are assumed to be $1,000 per year, the majority is likely to be labour for checking and clearing blockages etc.

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[47] Based on prices supplied at www.electricaldirect.co.nz, accessed September 2016, and Nexans Price List November 2013

[48] www.powerspout.com, May 2016

Table D4 shows the indicative costs of the micro-hydro schemes modelled, these costs are based on the layouts described in Section 3.3.3.

Table D4: Calculated indicative capital costs of micro-hydro schemes

Scheme	Waitotoroa, low head propellor	Otahi-iti, turgo
Channel cost ($)	86,250	64,490
Penstock or flume/pipe cost ($)	40,440	1,160
Turbine cost ($)	8,400	5,600
Cable cost ($)	890	6,960
Total indicative cost, including GST ($)	156,400	89,930

Solar water heaters:

Table D5: Expected installed cost of residential scale solar water heaters[49]

Collector size (m^2)	Cylinder size (l)	Cost of collector and balance of system ($)	Cost of cylinder ($)	Cost of installation ($)	Total cost ($)
2	150	2,800	2,000	2,000	6,800
3	225	3,500	2,400	2,000	7,900
4	300	4,300	2,800	2,000	9,100
6	450	5,800	4,600	2,000	12,400
10	750	8,800	6,800	2,000	17,600

Yearly maintenance considered negligible and assume no replacement needed over 20 years[50]

Storing excess energy in an electric water cylinder:

Any existing water cylinder is assumed to be not suitable for dual element operation

Hot water cylinder costs (including installation):

Volume	Cost ($)
135	2,400
180	2,500
250	2,900
300	3,000

[51]

PV diverter: $600[52]

[49] Based on costs provided at www.abwelectric.co.nz, www.hotwatercylinders.com, www.energywise.govt.nz, www.consumer.org.nz, accessed September 2016
[50] RETScreen help file
[51] Based on costs provided at www.abwelectric.co.nz, www.hotwatercylinders.com, www.energywise.govt.nz, www.consumer.org.nz, accessed September 2016
[52] Based on personal communications, Solarcity

Wood burning appliances:

Wood burner: $4,000 installed[53]

Wetback and piping: extra $500

Wood boiler with integrated 1,000l storage: $14,000 installed[54]

Short rotation coppicing firewood plantation:

Cost of seedlings: $10,000 per hectare ($2 per seedling, 5,000/ha)[55]

Cost of planting: $5,000 per hectare ($1 per seedling)[56]

Replanting required after 15 years

All other costs are assumed to be covered by charging residents market rates for firewood

Other:

Air source heat pump water heater (small): $6,000 installed[57]. Assuming no replacement over 20 years may be overly optimistic.

Air source heat pump water heater (large): $8,000 installed[58]

Air source heat pump space heater: $4,000 installed[59]

LPG instant water heater (for stand-alone home): $2,000 installed

LPG range (for stand-alone home): $2,000 installed

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[53] Based on costs provided at www.climate.net.nz, accessed September 2016
[54] Based on personal communications with Marshall Heaters, July 2016
[55] Based on personal communications with various nurseries, National Field days, June 2016
[56] Based on labour costs of riparian planting at Parihaka in 2016
[57] Based on costs provided at www.energywise.govt.nz, accessed September 2016
[58] Based on costs provided at www.energywise.govt.nz, accessed September 2016
[59] Based on costs provided at www.energywise.govt.nz, accessed September 2016

E. HOMER model inputs

Individual building distribution

Each HOMER model run was as follows. Unless specifically mentioned, all financial cost inputs are as per appendix D. Ten minute time steps were used.

Location 39° 17.209'S, 173° 50.498'E

Time zone UTC + 12

Discount rate 8%

Inflation rate 2%

Annual capacity shortage 0% (2% for off-grid buildings to relax constraints on battery bank size, assuming occupants can modify behaviour)

Project lifetime 20 years

System fixed capital cost

For existing buildings, the sum of whichever of the following costs are applicable (to the specific HOMER model):

- Retrofitting a
    - heat pump
    - wood-burner
    - wetback plumbing
    - wood fired boiler
    - hot water cylinder
    - solar hot water system
    - LPG cooking range
    - LPG instant water heating
    - heat pump water heater
- Energy efficiency measures
- Battery monitor

For future buildings, the same as above, but any heating appliances or water heating appliances (other than solar water heaters, wood fired boilers and heat pump water heaters) are not included, being considered a normal part of a new home build.

System fixed O&M

The sum of whichever of the following costs are applicable (to the specific HOMER model):

- annual fixed charge for LPG delivery
- annual consumption of LPG

- annual consumption of firewood (a market cost of $0.269 per kg *Eucalyptus* is used, based on local prices)
- annual fixed electricity charge

Table E1: Fixed charges ($NZD) to study buildings, grid electricity and delivered LPG

Building	Annual fixed LPG charge	LPG cost per kg	Annual fixed electricity charge ($)
1	N/A	3.33	405
2	N/A	N/A	140
3	N/A	N/A	140
4	103	1.84	140
5	N/A	N/A	140
6	N/A	N/A	321
7	103	1.84	140
8	118	2.06	140
9	N/A	3.33	104
10	N/A	N/A	140
A	102	2.87	102
B	161	2.87	140
C	161	2.87	102

Note that even though residents currently source and process their own firewood at no cost, a market cost is attached to it. This is to recognize that if a biomass plantation is established, residents can either purchase the wood at market rates, or continue to process it at no charge. In other words processing and storing wood already happens whether the plantation is present or not. If significant uptake of firewood occurs with population growth, then “free” firewood may no longer be feasible.

Electric Load #1 The appropriate 10 minute averages load data time series (as described previously) was imported.

Electric load #2 Additional load was created as required (e.g. heat pump water heater as per Section 2.5.5)

Deferrable load

The deferrable load functionality of HOMER was used to model storing excess PV generation in a hot water cylinder using a PV diverter. These electronic devices provide a variable voltage (and hence variable power) to an additional resistive element in a dual element water cylinder.

For scenarios considering a PV diverter, the average water heating load (kWh/day) was entered for each month. The storage capacity was calculated using the method described in Section 2.5.6. The peak load is set as 3 kW (corresponding to a 3 kW element), and the minimum load ratio as 0% (a variable voltage output means that basically any excess generation can be applied to the water heater).

Solar GHI resource

The 10 minute averages time series over 12 months measured by the pyranometer was converted to kW/m^2 and imported into HOMER. A scaled annual average of 3.86 kW/m^2 was applied to account for long term variation in the solar resource (see 7.1.2)

Temperature resource

The 10 minute averages time series over 12 months measured by temperature sensor was imported.

Grid

The electricity tariff (set by the retailer) of the building informs the grid power price. The grid sellback price is set at 0. Currently retailers supply a payment of ≈7 c/kWh for electricity exported to the grid. However this payment was not applied because 1) retailers can change this rate at very short notice and 2) a goal of independence suggests that external payments should not be relied upon for economic viability; rather self-consumption of generation should be aimed for.

Daily charges are not included here, but under fixed O&M costs

Table E2: Electricity tariffs for study buildings

Building	$/kWh
1	0.346
2	0.333
3	0.333
4	0.315
5	0.333
6	0.315
7	0.333
8	0.333
9	0.280
10	0.333
A	0.350
B	0.333
C	0.350

Grid connected PV

The generic flat plate PV model in the HOMER library was used (rather than a specific manufacturer's product). Seeing as panels with an integrated micro inverter are considered, the PV is modelled on the AC bus. Capital and O&M costs include the whole installed system. Replacement costs are inverter replacements after 15 years. A derating factor of 82% is applied:

$f_{PV} = f_{man} \times f_{dirt} \times f_{degradation} \times f_{temp} \times \eta_{inv} = 0.82$

f_{PV} = derating factor to account for loss of output of AC modules due to manufacturing tolerance (f_{man}) = 0.95 (+/- 5% tolerance)

soiling (f_{dirt}) = 1 (assume high annual rainfall keeps modules clean)

degradation over time ($f_{degradation}$) = 0.9 (assume 20% degradation over 20 years, hence average of 10% over that time)

module temperature (f_{temp}) = 1 (accounted for elsewhere in HOMER so not used here)

inverter efficiency (η_{inv}) = 0.957[60] (seeing as the microinverters were not modelled explicitly)

4-6 sizes were considered, from 1 kWp up to the maximum which could fit on the roof space. The maximum was assumed to be 130Wp/m^2 (based on a typical module efficiency of 13%), where roof size was calculated as per Section 2.4.2.

The effect of the imported temperature data (see following) was included, using (the default values):

- Temperature effect on power = -0.5 %/°C
- Nominal operating cell temperature = 47°C
- Efficiency at standard test conditions = 13%

Ground reflectance = 20% (grass surroundings).

Slope of panel = pitch of roof. PV arrays for individual buildings are assumed to be flush roof mounted with no tracking or tilting.

Panel azimuth = building orientation, found using Google Earth.

In some cases, if buildings did not have a north facing roof, two different roof surfaces were used (e.g. NE and NW), modelled as two separate arrays.

Off-grid PV

As per grid-connected PV, with the following differences:

The PV is modelled on the DC bus rather than the AC bus. Capital costs have the inverter cost removed (transferred to converter), and charge controller cost added. Replacement costs are charge controller replacement.

Derating factor = 83%

$f_{PV} = f_{man} \times f_{dirt} \times f_{degradation} \times f_{temp} \times \eta_{cc} = 0.83$

where charge controller efficiency (η_{cc}) = 0.97 (inverter efficiency covered elsewhere)

Converter (for off-grid buildings)

Lifetime 10 years

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[60] Source: Enphase M250 dataseheet

Efficiency 93%

One size of inverter only was included for each HOMER model, a size sufficient to meet the peak load. The peak load was assumed to be the highest 10 minute average recorded, with higher spikes within this 10 minute period covered by the surge capabilities of the inverter. The highest 10 minute average was found within the measured data (prior to transformation), and any corresponding corrections made such as removing/adding hot water element, oven etc.

Batteries (for off-grid buildings)

Lead acid batteries only were considered, two specific available products in particular as a way to model battery storage in general. Trojan T-105 (6 V, 230 Ah) batteries were used in the model. If larger batteries were required then Trojan IND 29-4V (4 V, 2166 Ah) batteries were used. These were selected because they are both available in the HOMER library and are available in New Zealand.

The string size (number of batteries in series) was chosen to provide the minimum voltage needed to maintain inverter input current below 120 A, but not exceeding 120 V (Extra Low Voltage). 1,2,3 and 4 strings were modelled.

Batteries are replaced after their lifetime throughput is exceeded (810 kWh T-105, 11,760 kWh IND 29-4V[61]), constrained at a minimum life of 5 years and maximum of 10 years. Although the manufacturer recommends not discharging below 50% SOC regularly, a minimum SOC of 30% was chosen because HOMER only simulates this deep discharge a handful of times per year.

Community distribution

The HOMER models for community distribution were configured as previous, with the following differences:

System fixed capital costs and system O&M costs

As previous, but as aggregations of the buildings included (see Sections 2.2 and 2.3).

Electric Load #1 The appropriate aggregate of buildings (see Sections 2.2 and 2.3) was imported.

Electric load #2 Additional load was created as required (e.g. EV charging and hot water cylinder loads as per Section 2.3)

Grid: A tariff of 0.33 $/kWh was used, being the mode of individual building tariffs (table E2). In reality, if the community was billed as a group a lower tariff may be able to be negotiated (especially if peak loads can be managed).

[61] From battery datasheets, available www.trojan.com. Accessed June 2016.

Wind resource

Although the wind resource in the surrounding area was estimated using WAsP (Section 2.4.1.2), WAsP does not output a time series. Instead the 10 minute averages time series over 12 months measured at 15m was imported. A scaled annual average of 6.59 was used to apply the temporal and spatial extrapolation detailed in Sections 2.4.1.1 and 2.4.1.2 .

Because variation in height has been managed by WAsP rather than HOMER, both the anemometer and hub height in HOMER are set to 30m.

Hydro resource

As only one hydro turbine can be modelled, separate HOMER models were run for each waterway.

Modelling a "typical" year of hydro resource is a special case. Rainfall patterns by month can vary significantly from year to year. If a design flow is chosen from the flow duration curve, the percentage of time this flow is exceeded will vary from year to year. For this reason, a daily time series (assuming steady flow over a day) for 12 months (in l/s) was constructed to reflect flow duration over the long run rather than over a year, as follows:

- For each year of the 15 year hindcast prediction, the monthly mean flows were found (i.e. 15 x 12 values).
- The mean flow for each calendar month over the 15 year period was found (i.e. 12 values).
- For each calendar month, the year was identified with the most typical flow for that month (least difference between the 15 year mean and that year).
- A daily time series for a typical year was made on a month by month basis. For each month, daily mean flows were taken from whichever year had the most typical flows for that month.
- The 365 dates of this typical year were reordered by magnitude of flow.
- 365 equally spaced flow values were taken from the Flow Duration Curve (which describes flow distribution over the long term) and matched to the 365 dates.
- The data set was then reordered into chronological order.

This time series was then imported into HOMER.

Residual flow is

Waitotoroa: 60 l/s

Otahi-iti: 23 l/s

Wind turbine

Different wind turbine generators placed in the same wind resource will produce different amounts of annual energy, due to having different power curves. Without yet having a particular model in mind, the generic wind turbines available in the HOMER library are used

Due to the shape of the landscape (hillocks with small summit areas), a single wind turbine is considered more likely than a cluster. However, because the optimal size of turbine is not known prior to modelling, different size turbines are simulated by including different quantities (0, 1, 2, 6, 10) of the generic 1 kW and 10 kW machines. The assumption is that HOMER will treat ten 10kW turbines in the same way as one 100 kW turbine.

No turbine losses or maintenance down time are included. The wind turbine is placed on the AC bus (inverter – if applicable - included).

Hydro turbine

The hydro turbine is also on the AC bus (inverter included).

System efficiency is 50% (Harvey, 1993).

No replacement is modelled.

Pipe head loss is 0%, as dynamic head loss has already been calculated.

Available head (see Section 3.3.3):

Waitotoroa: 2.27 m

Otahi-iti: 10.23 m

Awa-iti: 2.38 m

Design flow rate (see Section 3.3.3):

Waitotoroa: 115 l/s

Otahi-iti: 18 l/s

Awa-iti: 30 l/s

Minimum and maximum flow ratios are both 100%, conservatively assuming that the turbine is producing maximum output at design flow, and that output is negligible under part flow conditions.

F. Individual building results

The results of modelling various renewable energy conversion technologies for individual buildings, using the measured and modified load profiles and resource data, are presented in Figs. F1 through F24.

In some cases an economic (cost), social (reduced dependence) and environmental (reduced emissions) benefit is expected. Where there is no direct economic benefit expected, the desired trade-off between cost and the social and environmental benefits can be selected from the charts. As the desired trade-off (if any) for the community is unknown, three specific solutions are detailed further:

1. the solution with the lowest NPC;
2. the solution which would reduce energy imports (REI) as much as possible without raising the NPC;
3. the solution which would maximise the REI.

Labels in the legends are defined as follows:

No change:	No changes to the appliances or installations. However any firewood sourced is assumed to have been supplied from a community biomass scheme (hence some buildings showing a reduction in energy imports for no change – current firewood use is treated as imported). A market value has been applied to this rate to help finance such a scheme.
Energy efficiencies:	Measures proposed and detailed by Hernandez Pacheco (2016) –see Section 2.5.3. These are applied to all architectures other than "no change".
Heat pump:	Air source heat pump
PV:	Solar photovoltaic electricity generation. If no battery is listed, then the PV is grid connected.
SWH:	Solar water heater
HPWH:	Air source heat pump water heater
Diverter + water cylinder:	A controller feeds excess PV electricity to a variable voltage element in a hot water storage cylinder in preference to exporting to grid.
Wood-burner:	Freestanding wood burning appliance for space heating
Wetback:	Heat exchanger installed in wood burner to heat water and thermosiphon to water cylinder (assuming building layout permits this)
PV/batt:	Off-grid stand-alone electrical system with lead acid batteries, PV, charge controller, inverter, SOC meter

House 1

Current configuration

Space heating: Electric heater
Water heating: LPG instant
Cooking: Electric
Roof pitch: 11°
Roof orientation: 4°T
Available roof area: 14 m^2

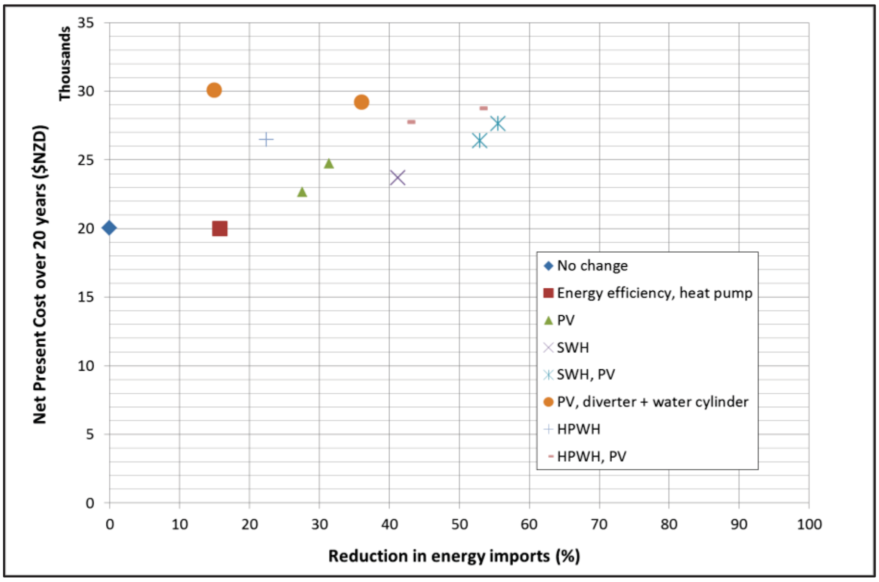

Figure F1: Cost of reducing energy imports, house 1

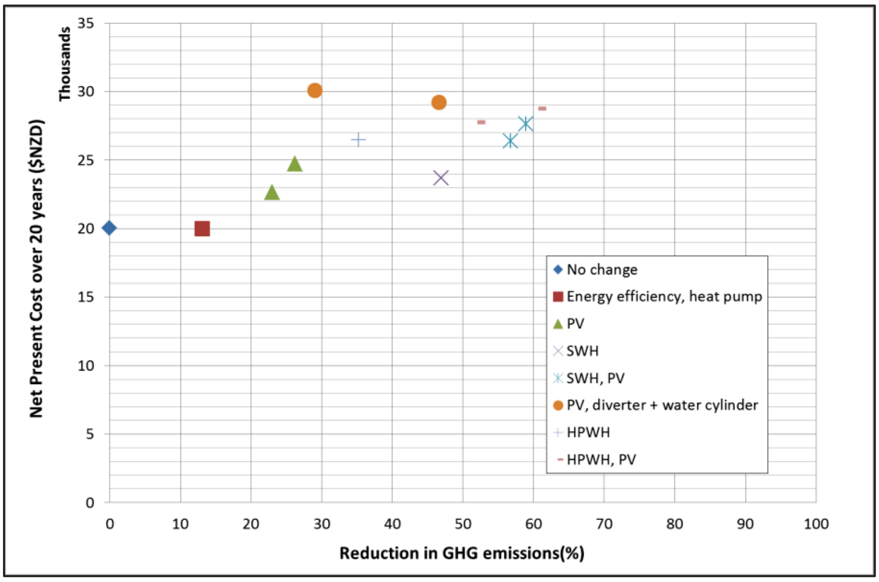

Figure F2: Cost of reducing GHG emissions, house 1

Results

Lowest NPC:	Energy efficiencies, heat pump
Most REI without raising NPC:	Energy efficiencies, heat pump
Most REI:	Heat pump, heat pump water heater, 1.8 kW PV

House 2

Current configuration

Space heating: Electric heater
Water heating: Electric water cylinder
Cooking: Electric
Roof pitch: 7°
Roof orientation: 18°T
Available roof area: 32 m^2

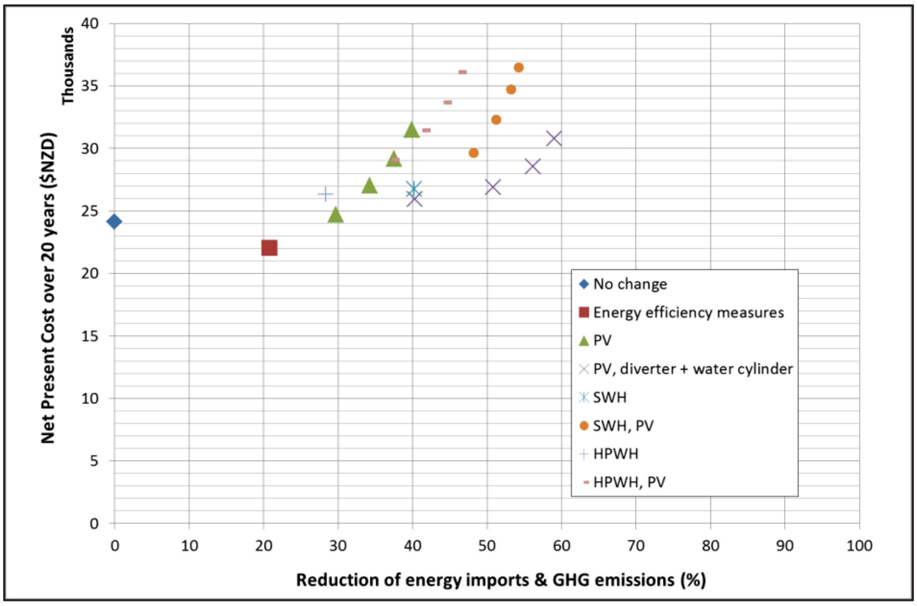

Figure F3: Cost of reducing energy imports and GHG emissions, house 2

Results

Lowest NPC: Energy efficiencies, heat pump
Most REI without raising NPC: Energy efficiencies, heat pump
Most REI: Heat pump, 4 kW PV, diverter to 270 l water cylinder

House 3

Current configuration

Space heating: LPG portable, unmeasured. Instead a retrofit of either heat pump or wood burner was assumed, based on total heating load of house 10 (similar size building) and heat pump time-of-use of house 8. Note that the base case thus includes the capital investment in a space heating appliance.

Water heating: Electric water cylinder
Cooking: Electric
Roof pitch: 27°
Roof orientation: 17°T
Available roof area: 85 m^2

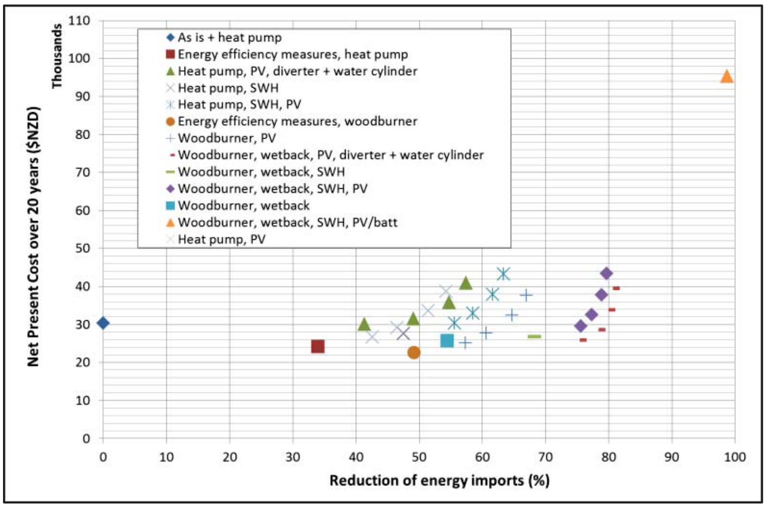

Figure F4: Cost of reducing energy imports, house 3

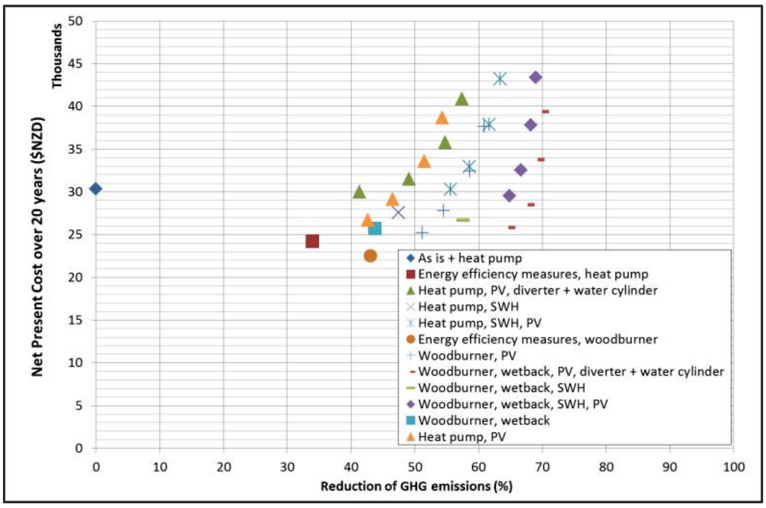

Figure F5: Cost of reducing GHG emissions, house 3

Results

Lowest NPC:	Energy efficiencies, wood-burner
Most REI without raising NPC:	Wood-burner, wetback, 2 kW PV, diverter to 180 l water cylinder.
Most REI:	Off-grid, Wood-burner, wetback, SWH, 8 kW PV, 162 kWh batteries

House 4

Current configuration

Space heating: Electric heater
Water heating: LPG instant
Cooking: Electric
Roof pitch: 19°
Roof orientation: 290°T and 20°T
Available roof area: 37 m^2 and 24 m^2

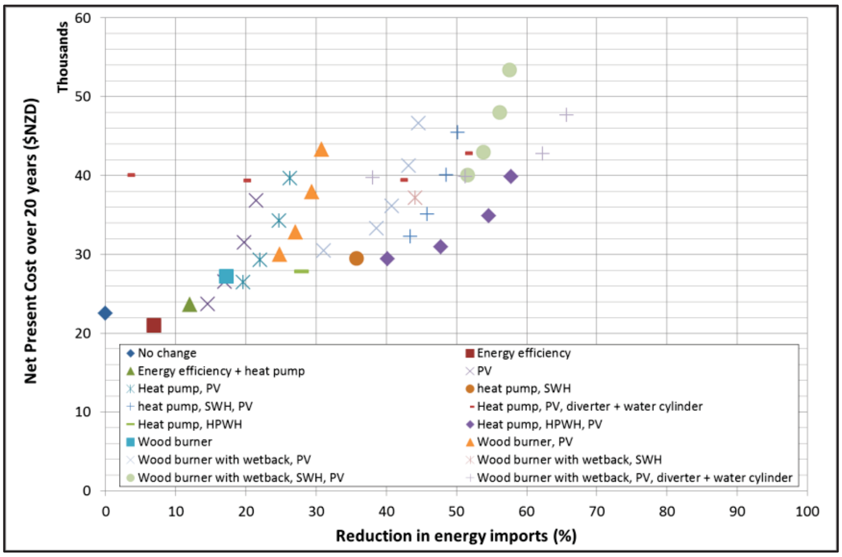

Figure F6: Cost of reducing energy imports, house 4

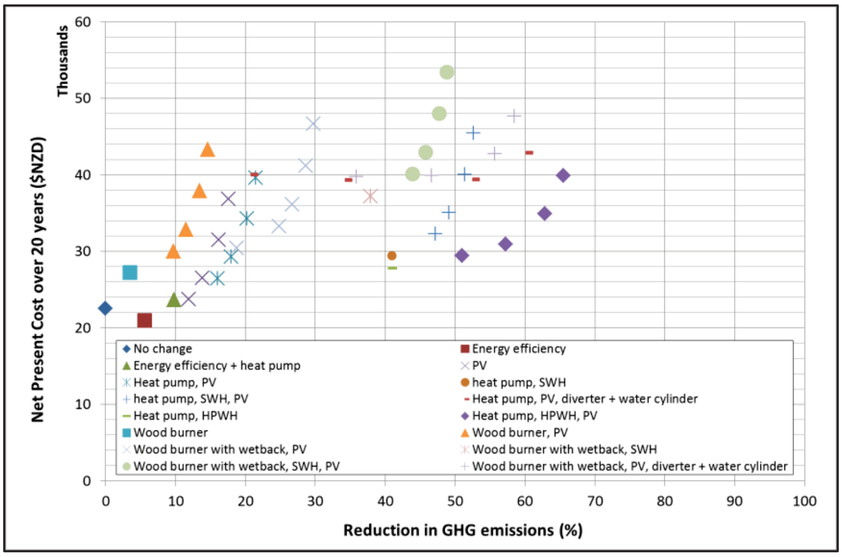

Figure F7: Cost of reducing GHG emissions, house 4

Results

Lowest NPC:	Energy efficiencies
Most REI without raising NPC:	Energy efficiencies
Most REI:	Wood-burner, wetback, 6 kW PV, diverter to 400 l water cylinder

House 5

Current configuration

Space heating: Wood burner

Water heating: Not defined in the data. Initially this building had a non-functioning LPG instant water heater, which was replaced by an electric water cylinder. As a result, specific water heating technologies are not examined.

Cooking: LPG cooktop. The LPG cylinder was located inside the kitchen, and after a short period of measurements the decision was made that entering the home to remove the cylinder from the appliance on a regular basis was too intrusive. Not measured.

Roof pitch: 27°
Roof orientation: 0°T
Available roof area: 16 m^2

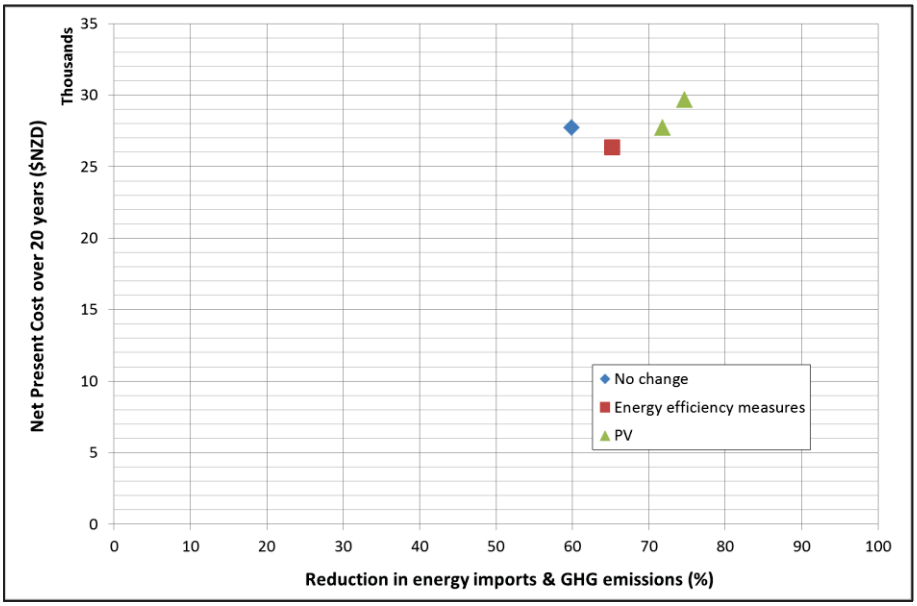

Figure F8: Cost of reducing energy imports and GHG emissions, house 5

Results

Lowest NPC:	Energy efficiencies
Most REI without raising NPC:	Energy efficiencies, 1 kW PV
Most REI:	Energy efficiencies, 2 kW PV

House 6

Current configuration

Space heating: Two wood burning appliances, one per building (this home is made up of two adjacent buildings).

Water heating: Electric water cylinder with wetback. Inspecting the water heating data, there are significant water heating loads, including through winter despite the wetback. As a result, a central wood boiler was investigated, to heat water and also distribute heat via radiators to both buildings.

Cooking: Electric
Roof pitch: 13°
Roof orientation: 319°T
Available roof area: 79 m^2

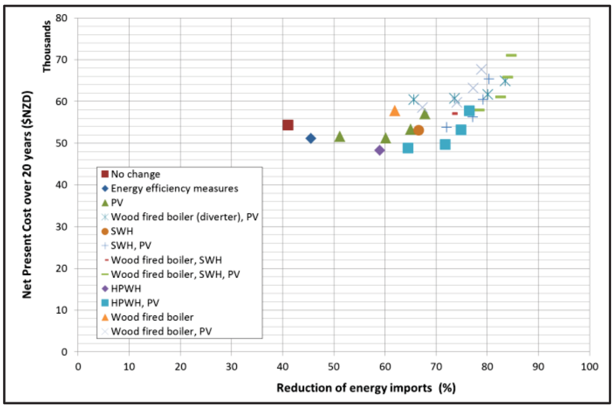

Figure F9: Cost of reducing energy imports, house 6

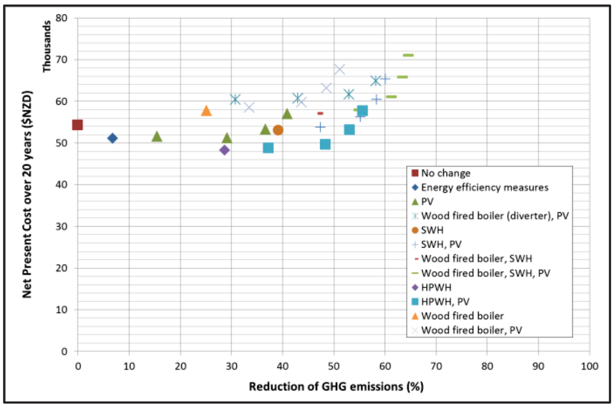

Figure F10: Cost of reducing GHG emissions, house 6

No replacement cost is included for a heat pump water heater, however it may be unrealistic to assume a lifetime of 20 years. A replacement would significantly alter these results, and alternate technologies such as solar water heaters (with proven longevity) may be preferred.

Results

Lowest NPC: Heat pump water heater or 1 kW PV
Most REI without raising NPC: Heat pump water heater, 5 kW PV or solar water heater, 2 kW PV
Most REI: Wood boiler, solar water heater, 5 kW PV

House 7

Current configuration

Space heating: Heat pump
Water heating: LPG instant
Cooking: Electric

This building has limited suitable roof space; the roof connects to the roof of house 8. It was assumed that a solar water heater can be mounted on the roof of house 7 roof and half of roof 8 is available for PV.

Roof pitch: 12°
Roof orientation: 322°T
Available roof area: 23 m^2

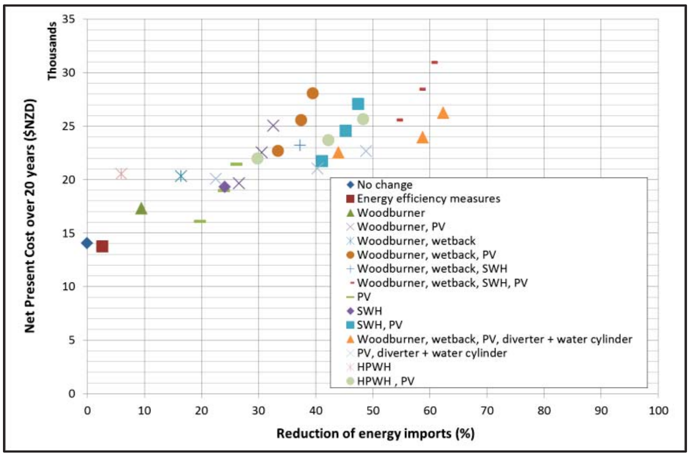

Figure F11: Cost of reducing energy imports, house 7

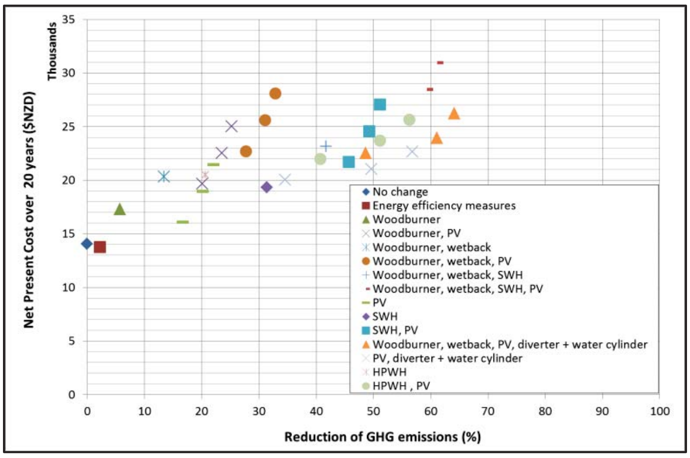

Figure F12: Cost of reducing GHG emissions, house 7

Results

Lowest NPC:	Energy efficiencies
Most REI without raising NPC:	Energy efficiencies
Most REI:	Wood-burner, wetback, 3 kW PV, diverter to 180 l water cylinder

House 8

Current configuration

Space heating: Heat pump
Water heating: LPG instant
Cooking: LPG cooktop, electric oven
Roof pitch: 12°
Roof orientation: 322°T
Available roof area: 46 m^2

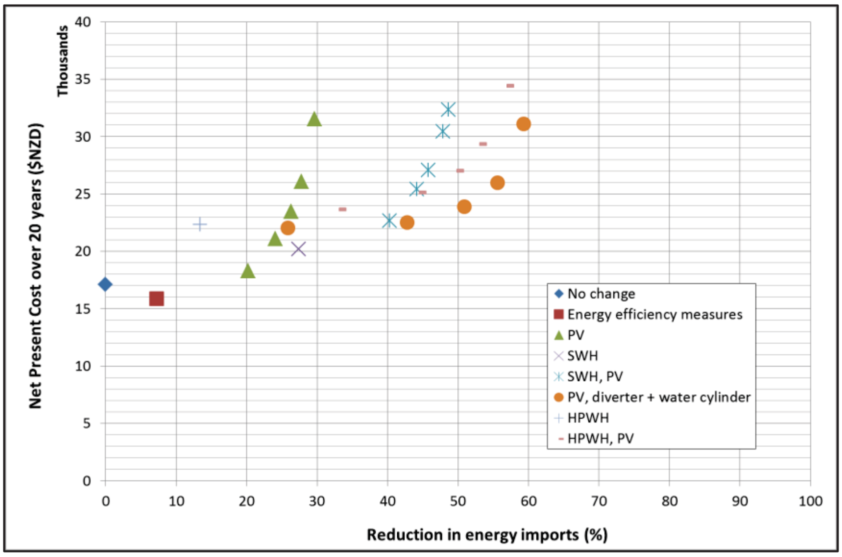

Figure F13: Cost of reducing energy imports, house 8

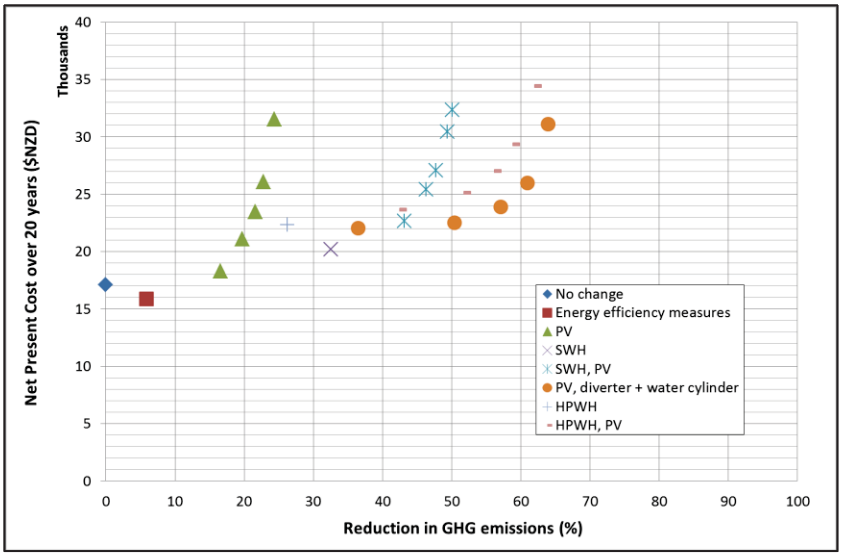

Figure F14: Cost of reducing GHG emissions, house 8

Results

Lowest NPC:	Energy efficiencies
Most REI without raising NPC:	Energy efficiencies
Most REI:	4 kW PV, diverter to 180 l water cylinder

House 9

Current configuration

Space heating: Wood burner
Water heating: LPG instant
Cooking: Electric
Roof pitch: 29°
Roof orientation: 297°T
Available roof area: 108 m^2

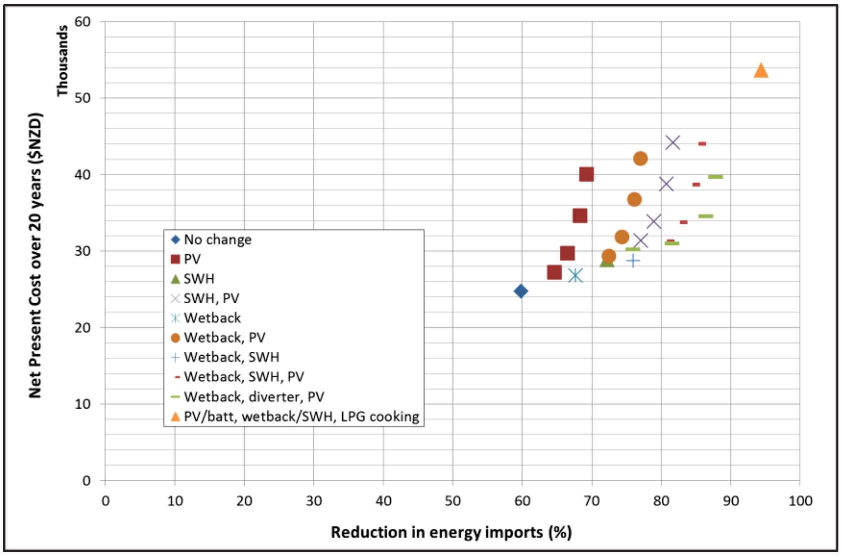

Figure F15: Cost of reducing energy imports, house 9

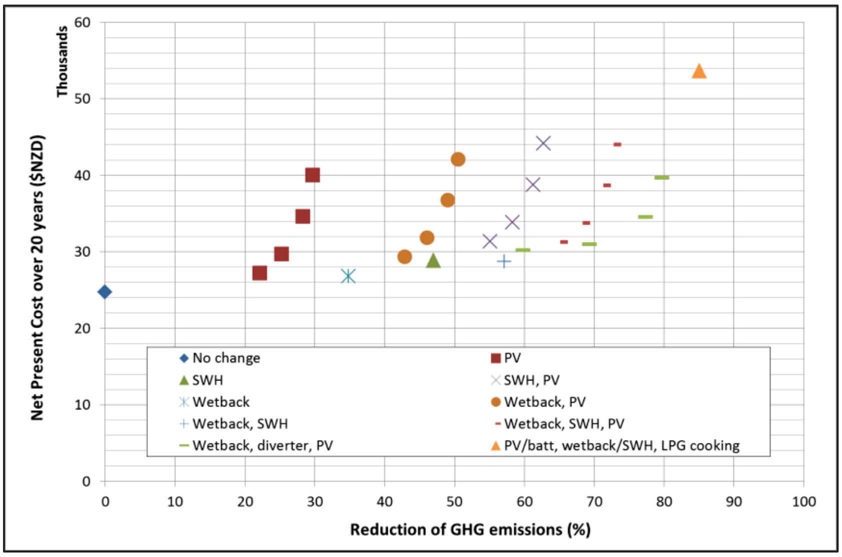

Figure F16: Cost of reducing GHG emissions, house 9

Results

Lowest NPC:	No change (wood sourced from local source)
Most REI without raising NPC:	No change (wood sourced from local source)
Most REI:	Off-grid, wetback, solar water heater, 6 kW PV, 24 kWh batteries

House 10

<u>Current configuration</u>

Space heating: Wood-burner (this has since been replaced for a more efficient model)
Water heating: Electric
Cooking: Electric

Due to a combination of a change of occupancy and access to the electricity consumption data (which that highlighted the majority of electricity went to water heating), towards the end of monitoring the occupants switched from electric water cylinder to batch heating water on the wood-burner. The water heating data was altered to simulate the original energy use of the home during this period.

Roof pitch: 18°
Roof orientation: 262°T
Available roof area: 54 m^2

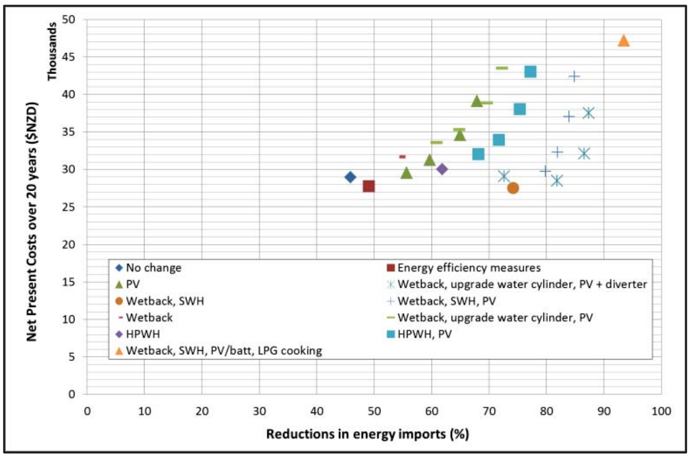

Figure F17: Cost of reducing energy imports, house 10

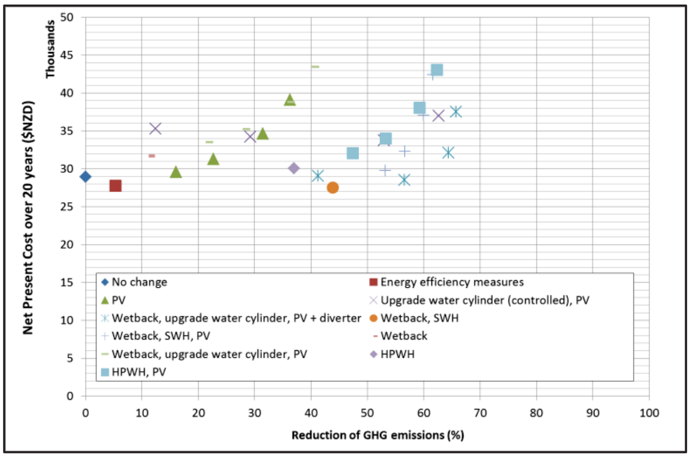

Figure F18: Cost of reducing GHG emissions, house 10

<u>Results</u>

Lowest NPC:	Wetback, solar water heater
Most REI without raising NPC:	Wetback, 2 kW PV, diverter to 400 l water cylinder
Most REI:	Off-grid, wetback, solar water heater, 4 kW PV, 16 kWh batteries

Marae A

Current configuration

Space heating: Electric heater
Water heating: LPG instant
Cooking: Commercial grade (3 phase) electric oven and cooktop

Although the roof faces east-west, there is a large low pitch roof to the north of the building – space for up to 3 rows of 2kW arrays facing North tilted to 40°.

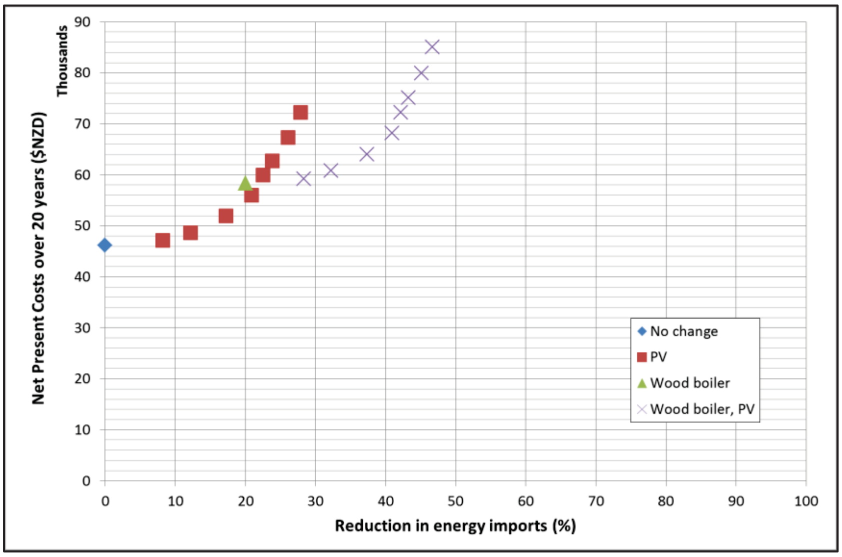

Figure F19: Cost of reducing energy imports, marae A

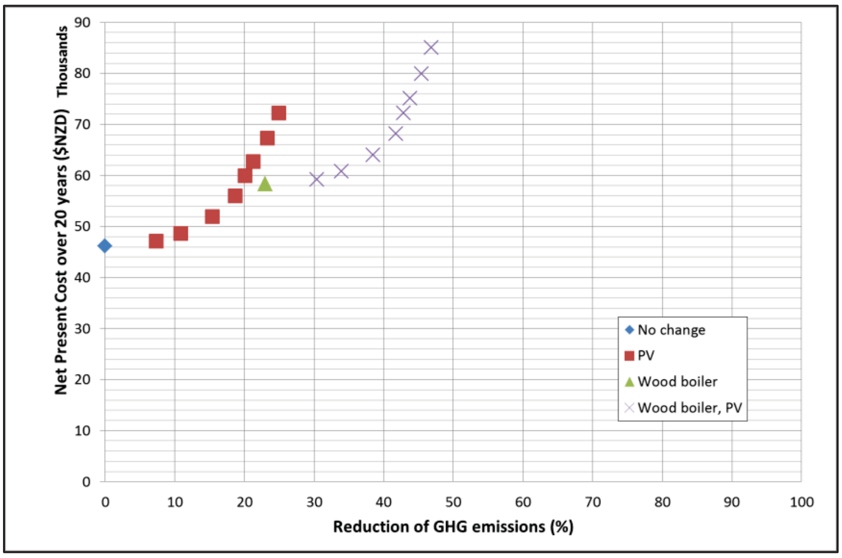

Figure F20: Cost of reducing GHG emissions, marae A

Results

Lowest NPC:	No change
Most REI without raising NPC:	No change
Most REI:	50 kW wood boiler with 1000 l storage, 6 kW PV

Marae B

Current configuration

Space heating: Electric heater
Water heating: LPG instant
Cooking: Predominantly LPG, some electric
Roof 1 pitch: 13°
Roof 1 orientation: 9°T
Roof 1 area: 15m^2
Roof 2 pitch: 13°
Roof 2 orientation: 279°T
Roof 2 area: 82 m^2

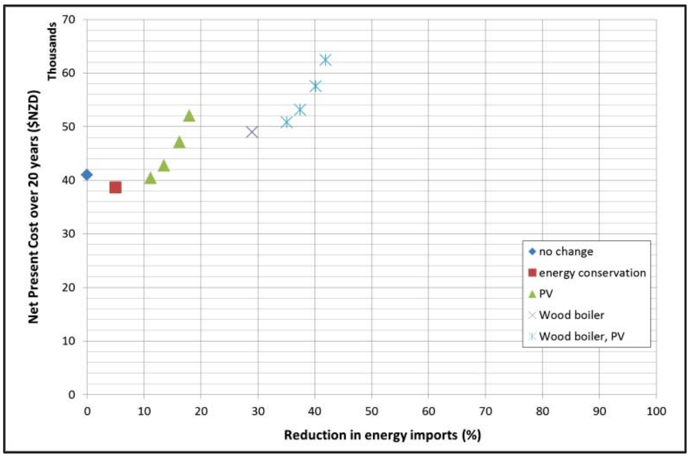

Figure F21: Cost of reducing energy imports, marae B

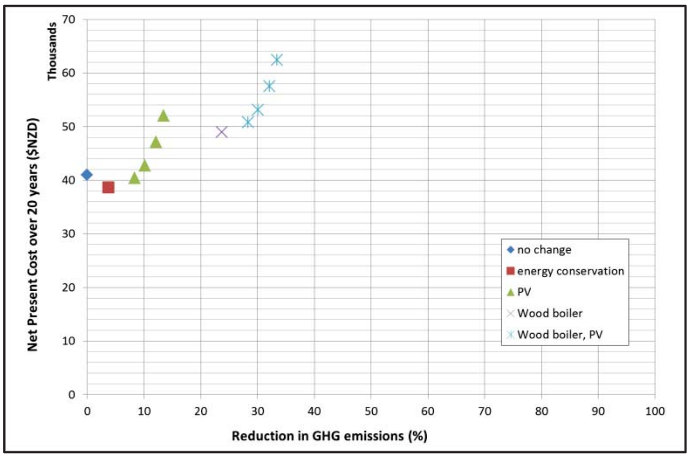

Figure F22: Cost of reducing GHG emissions, marae B

A “zip” heater providing instant boiling water for hot drinks runs constantly. The energy conservation scenario models switching this off between hui – savings representing a net present value of $2 390 over 20 years.

Results

Lowest NPC:	Energy conservation
Most REI without raising NPC:	1 kW PV
Most REI:	50 kW wood boiler with 1000 l storage, 6 kW PV

Marae C

Space heating: Electric heater (wharenui) - measured, portable LPG patio heaters (wharekai) – not measured

Water heating: LPG instant
Cooking: Predominately LPG but also two electric ovens
Roof pitch: 15°
Roof orientation: 12°T
Available roof area: 167 m^2

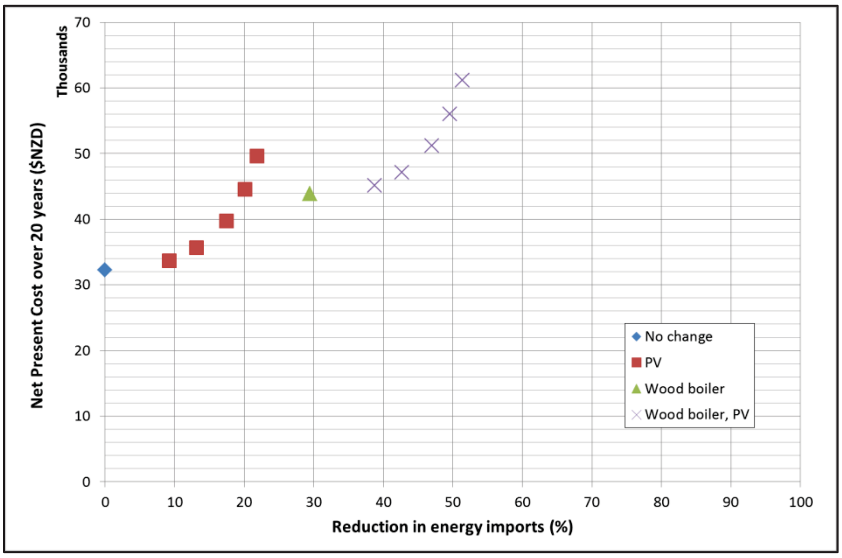

Figure F23: Cost of reducing energy imports, marae C

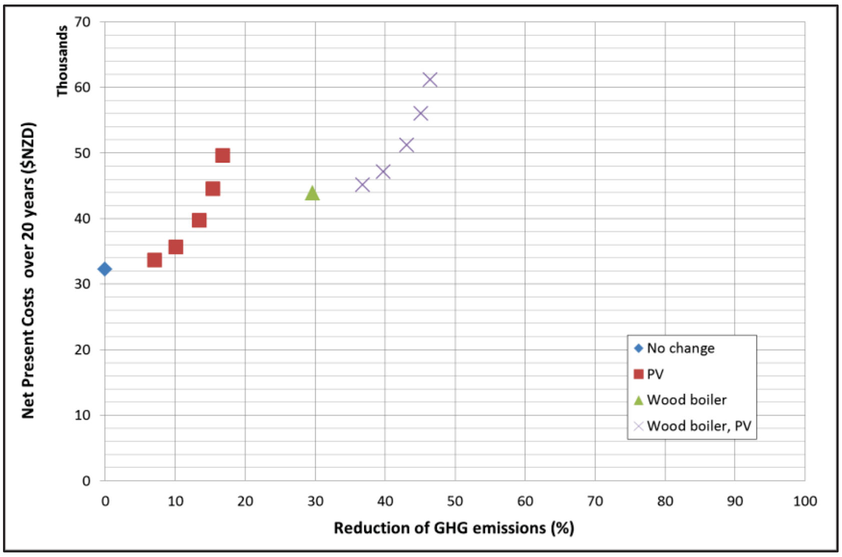

Figure F24: Cost of reducing GHG emissions, marae C

Results

Lowest NPC:	No change
Most REI without raising NPC:	No change
Most REI:	50 kW wood boiler with 1000l storage, 4 kW PV

G. Comparing aggregated and measured community electricity demand

Community energy demand was assumed to be the aggregation of a certain combination of measured individual buildings (see Section 2.2). This assumption is here tested to some degree by comparing the currents measured through one of the distribution transformers (see Section 2.2.1) over a short period of time to the modelled demand.

Fig. G1 shows the currents through the three phases over the period 5/2/2016 – 11/2/2016, supplied by Powerco. The corresponding raw data is not available, however the average voltages and currents are supplied, corresponding to an mean total power of 8.01 kW (ignoring power factor).

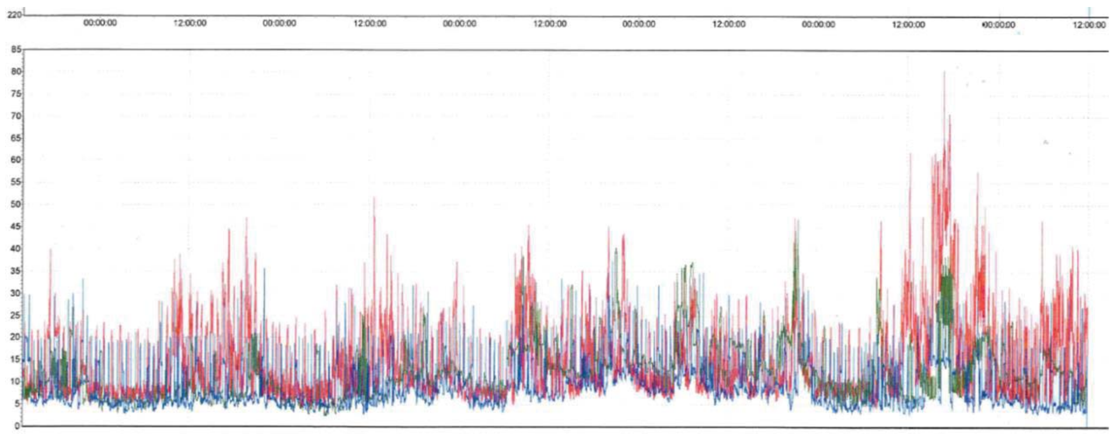

Figure G1: Electrical currents measured through the nothern distribution transformer, 5/2/2016 – 11/2/2016

The modelled dataset corresponding to this area of the papakāinga is shown in Fig. G2.

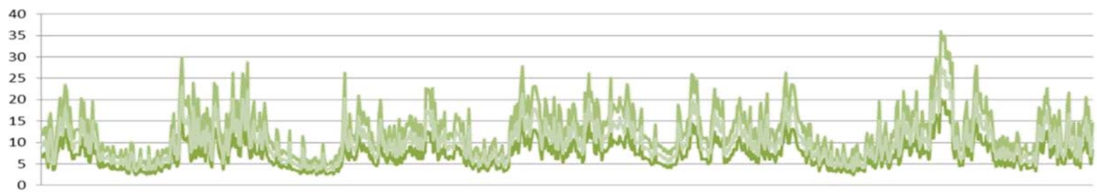

Figure G2: Currents modelled at northern distribution transformer, 5/2/2016 – 11/2/2016

This was constructed by splitting the modelled power into 3 phases proportional to the average measured power of each phase, then converting to currents by dividing by the average measured voltages.

Fig. G3 shows the measured and modelled results superimposed. The modelled results are 10 minute averages, and as such filter out the instantaneous spikes present in the measured results. In light of this, the modelled and measured datasets visually appear a reasonable match.

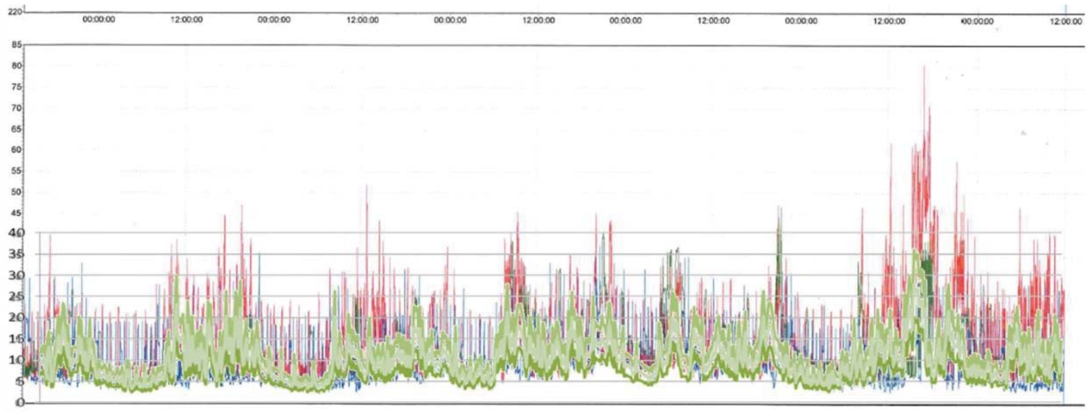

Figure G3: Measured and modelled transformer currents superimposed

The measured data has a mean of 8.01 kW (ignoring power factor), and the modelled data has a mean of 7.24 kW, underestimating the load by 9.6% over this period. If the load was under estimated by 9.6% on both sides of the river over the 12 month period, the economic NPV savings will remain valid (as at least the same amount of generated electricity will be made use of), but the reductions in energy imports and GHG emissions will be overestimated by a factor of 1.096.