Consumer Energy Options:

An evaluation of the different fuels and technologies for providing water, space, and process heat

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Prepared for Gas Industry Co

concept

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Contents

Executive summary...2
1 Introduction...5
1.1 Purpose of study...5
1.2 Framework for analysis...5
1.3 Earlier studies and peer review...6
2 Water heating...8
2.1 Key factors affecting the relative benefits of water heating options...8
2.1.1 Consumer situation factors...8
2.1.2 Fuel + water heater appliance technology characteristics...13
2.2 Water heating results...22
2.2.1 Determination of least cost water heating options...23
2.2.2 Consideration of the different 'quality' aspects of water heating options...28
3 Space heating...31
3.1 Key factors affecting the relative benefits of water heating options...31
3.1.1 Consumer situation factors...31
3.1.2 Fuel + space heater appliance technology characteristics...40
3.2 Space heating results...50
3.2.1 Determination of least cost water heating options...50
3.2.2 Consideration of the different 'quality' aspects of space heating options...56
3.3 Public versus private benefit outcomes...58
4 Industrial / commercial boilers...60
4.1 Approach and assumptions...60
4.2 Industrial process heat results...63
4.3 Possible future fuel and CO_2 prices...70
4.3.1 Gas prices...70
4.3.2 Coal prices...71
4.3.3 CO_2 prices...72
Appendix A. Determination of which energy end-use requirements to study...75
Appendix B. Fuel and CO_2 prices...81
Appendix C. Determination of the relative carbon intensities of the different fuels...89

Executive summary

- Although relative fuel prices and appliance efficiencies are important determinants of the most cost-effective energy option, the relative capital costs of appliances are just as important. Indeed, for small to medium-sized consumers they become the dominant factor.
- For residential water heating:
  - For new-build situations, the most cost-effective option in most cases is instant gas water heating. This is because the low capital cost of instant gas outweighs the relatively higher running costs compared with hot water heat pumps or solar water heating.
  - For someone with an existing functional hot water system (of whatever type), it is generally not cost-effective to incur the capital costs involved in switching to a new system, as this will outweigh any potential benefit from reduced running costs.
  - There are material differences in non-price 'quality' attributes of different systems. In particular, never running out of hot water is a key benefit of instant gas water heating compared with all other options (all of which are cylinder-based). Another benefit of instant gas hot water compared to cylinder-based systems is freeing-up internal storage space that would otherwise be occupied by a cylinder. Heat pump systems can also have noise issues.
- For residential space heating,
  - The significant variance in the size of consumers' heat loads, coupled with the significant variance in appliance capital costs (exacerbated by variance in house-specific drivers of heating costs), means that the most cost-effective option is very situation specific.
  - That said, for a new-build requirement for medium to large heat loads, log burners are often the most cost-effective (ignoring the quality aspects noted below), followed by heat pumps and flued gas heating.
  - If a consumer is going to have gas anyway (e.g. for water heating), then the daily fixed charges of gas supply should be excluded from an evaluation of the different space heating options. In such cases gas heating options become cheaper than the equivalent heat pump option for new-build situations.
  - For new-build requirements for small heat loads, free-standing resistance electric heaters (e.g. fan or oil column heaters), or LPG cabinet heaters, are most cost effective as their very low capital cost more than outweighs their higher running costs. However, the un-flued nature of LPG cabinet heaters means they may not be appropriate for people with respiratory health issues.
  - For someone with an existing functional space heating system, it is generally not cost-effective to incur the capital costs involved in switching to a new system as this will outweigh any potential benefit from reduced running costs. The exception to this is for large heating loads supplied by resistance electric heaters or LPG-fired heaters, where the relatively high running costs of such systems can make it cost-effective to switch away.
  - Different space heating options also have different quality attributes. 'Area' heating options consisting of a few large heaters in central areas of the house do not heat the house as evenly as central heating options. Heat pumps also give space cooling benefits in summer. Log burners are not as controllable as other heating options and can be slow to heat the home from cold. Log and pellet-burner options require fuel storage spaces and involve carrying fuel to the appliance. The aesthetics of a real flame are considered a benefit for some solid fuel and gas-fired heating options. For large

properties, heat pump heating may require multiple external units which can be visually unattractive. Noise has also been identified as a problem with some heat pumps.

- For industrial process heat:
  - For new boiler requirements, gas boilers are currently significantly cheaper than coal and biomass options. This is because:
    - Coal and biomass boilers have significantly higher capital and non-fuel operating costs
    - Current gas, coal and biomass fuel prices are resulting in gas-fired boilers overall being materially cheaper than coal and biomass alternatives.
  - It is appears cost-effective to switch away from existing coal-fired boilers to new gas-boilers for many large industrial heat loads, but for smaller heat loads the capital costs of such a switch can outweigh any reduced running cost benefits.
  - An investment in gas boilers made today is likely to remain cost-effective unless there is a substantial shift in relative coal : gas prices, coupled with CO_2 prices remaining close to zero. It appears unlikely that such a scenario will emerge in the short to medium-term[1].
  - Gas-fired process heat boilers also offer quality benefits in terms of precise heat control, and no dust or ash. For process heat requirements requiring precise control and/or involved in food processing, such attributes can be important.
- There are some dislocations between the price signals consumers face for different energy options, and the underlying resource costs for New Zealand.
  - The most significant relates to electricity and gas having strong seasonal and within-day cost drivers, while most consumers face a single whole-of-year average price for their space and water heating. For space heating in particular, which has very pronounced seasonal and within-day 'shape' of demand, this can affect the apparent cost to consumers for electricity and gas options relative to the 'true' cost of such options from a whole-of-New Zealand perspective. However, while this will act as a barrier to energy efficiency investments, it does not appear to affect the relative cost-effectiveness of the different space heating options to such an extent that materially 'wrong' choices will be made. Further, as initiatives to improve the structure of the prices for electricity and gas networks are implemented, coupled with increased roll-out of time-of-use metering and tariffs, this distortion will progressively be corrected.
  - The New Zealand Emissions Trading Scheme effectively halves the price of CO_2 faced by NZ participants – and caps this at NZ$12.5/t$CO_2$. While such measures are in place, this will distort the economics towards more CO_2 intensive options. However, given that the proportion of CO_2 costs to

[1] A recent "Gas Supply & Demand" study published by Gas Industry Company looking at the future for gas in New Zealand found that we are enjoying a buoyant supply outlook, with the current gas supply position stronger than it has been for many years. New Zealand has moved from dependence on a single major field, Maui, to drawing supply from a diverse range of onshore and offshore fields. The level of on-going exploration success is such that the size of New Zealand's gas reserves relative to its gas demand in 2011 was roughly the same as in North America and Western Europe.

The study also detailed how the dynamics of the major gas uses of methanol production and power generation are such as to help keep this 'reserves to production ratio' at stable levels which are comparable with mature overseas gas markets.

overall costs for heating is relatively small, the scale of distortion is unlikely to result in materially 'wrong' choices being made – unless international CO_2 prices rise to much higher levels (≈ NZ$50/t$CO_2$ and above).

- The carbon footprint of gas-fired space and water heating options is much less than standard resistance electric heating options, and broadly similar to heat pump heating options. Only renewable options such as wood, pellet, and solar have lower emissions profiles.
  - The reason why gas has such a comparatively good emissions profile compared to electricity options, even though it is a fossil fuel, is that the emissions intensity of electricity generated to meet a heating demand profile is likely to be very high – particularly for space heating. This is because heating demand is relatively 'peaky' (i.e. only required for a relatively small amount of time such as in the winter and during morning and evening peaks), and generating electricity to provide low capacity-factor demand is most cost-effectively met by relatively low capital cost fossil-fuelled power stations, rather than higher capital cost renewable power stations[2]. However, the very high efficiency of heat pumps means that the emissions intensity of heat pumps is roughly similar (indeed, slightly better in many cases) to that of gas-fired heating.
  - Despite this similarity in emissions profiles, it appears that heat pumps are marketed by many organisations as being significantly "cleaner" than gas heating.

[2] An additional factor is that the geothermal power stations which are being built to meet the growth in baseload demand also emit CO_2, at a level which is approximately 40% of that of a combined-cycle gas turbine (CCGT).

1 Introduction

1.1 Purpose of study

This study examines the different fuel and technology options for three energy uses:

- Residential water heating;
- Residential space heating; and
- Industrial / commercial industrial process heat.

These three energy uses were chosen as they are responsible for the vast majority of energy consumption where there are genuine fuel + technology alternatives that consumers can choose between. As set out in Appendix A, other energy end-uses either represent a very small proportion of New Zealand's overall energy consumption (e.g. cooking), and/or they have process-specific factors which result in a particular fuel option being dominant (e.g. transport fuels, lighting, motors, and steel manufacture) .

The principal purpose of this study is to determine which fuel + technology options are likely to be best for these energy end-uses.

The secondary purpose of this study is to determine whether there is a difference between:

- the options which appear to be best from a ***consumer's perspective*** based on the price signals they face; and
- the options which are best from a broader ***whole of New Zealand perspective*** based on the underlying resource cost implications of the different fuel + technology options.

Where there is a disconnect between the 'private' benefit faced by consumers, and the 'public' benefit faced by the whole of New Zealand, the study identifies the cause of such dislocations, and puts forward possible policy options to correct for them.

1.2 Framework for analysis

Determination of which fuel + technology option is likely to best for the provision of a heating energy service is non-trivial. This is because the economics of the different options can be very situation specific as they are driven by several key factors which exhibit significant variation. These key factors are:

- ***Different consumer situations***:
  - the quantity of heat desired;
  - the geographic location of the consumer (given that outside temperature is a significant space heating driver, and the availability and price of fuels can vary materially with location);
  - the size, type, and energy efficiency characteristics of a property (for space heating); and
  - the presence and type of any existing heating appliances.
- ***Different characteristics of the different fuel + technology options***:
  - Capital intensity
  - Fuel efficiency

- Fuel costs, including:
  - The absolute level of costs;
  - The structure of such costs, including variance over different times of the day and year, and the nature of any network costs and fixed costs.
- Fuel emissions intensities; and
- Non-price 'quality' characteristics of the different fuel + technology options.

Such differences mean that the best option for one consumer situation may be very different to that for another consumer situation (e.g. large versus small heating loads, Auckland versus Dunedin, an existing heating appliance versus a new-build situation, etc.).

Accordingly, the analysis framework was developed in a way which could consider all of these different situations in an internally consistent fashion.

In addition, the modelling framework enabled the cost analysis to be considered from two different perspectives:

- ***The Consumer***, where the costs were based on published prices of the various fuels and appliances.
- ***Whole of New Zealand,*** where adjustment to the costs of various options are made to take into account:
  - The extent to which international CO_2 costs faced by New Zealand are not reflected in domestic fuel prices;
  - The extent to which electricity and gas costs vary according to the time-of-day and year, yet consumer prices may be flat across the year;
  - The extent to which some electricity and gas network costs charged to consumers on a variable basis may be unavoidable from a whole of New Zealand perspective because they are sunk;
  - Conversely, the extent to which other costs which are charged on a fixed basis to consumers (i.e. charged on a $/day basis), may be avoidable from a whole of New Zealand perspective;
  - The fact that consumers typically evaluate investments over a shorter timeframe than that which may be appropriate for a whole of New Zealand evaluation; and
  - GST. (This is a cost to consumers, but a transfer from a New Zealand perspective).

1.3 Earlier studies and peer review

This study is an update of the 2009 "Direct use of gas" study for Gas Industry Company. As well as updating the analysis with latest information on fuel and technology costs, this study has undertaken some new analysis, including:

- Considering the implications of the non-price 'quality' aspects of the different fuel + technology options on energy choices;
- Determining the emissions intensity of electricity for space & water heating;
- Including capital & maintenance costs in the evaluation of different industrial process heat options. (The 2009 study only considered the fuel & CO_2 costs of the different options);
- Improved analysis on the level and variance in capital & installation costs for different consumer situations for space & water heating;
- Inclusion of appliance maintenance costs for evaluation of the different space & water heating options; and

- Updating the assumptions relating to the 'peakiness' of gas prices.

The analysis has been peer reviewed by a variety of individuals within EECA, the Electricity Authority, and the gas industry.

Concept would like to thank those individuals who provided much useful information and insightful analysis, particularly Hamish Trolove, David Rohan, Bruce Smith, Ray Ferner, and Peter Gilbert.

2 Water heating

2.1 Key factors affecting the relative benefits of water heating options

As set out in section 1.2 above, there are many different factors relating to the consumer situation and the fuel + technology characteristics which will affect the relative benefits of the different water heating options. These are detailed in the following sub-sections.

2.1.1 Consumer situation factors

Size of heat load

There can be considerable variation in the quantity of useful[3] water heat that is required in different properties. This is principally driven by variation in the number of occupants, but is also driven by occupant behaviour (e.g. whether they prefer baths or showers, and for how long and often) as well as appliance water efficiency characteristics (e.g. flow rates of shower heads, washing machine and dishwasher efficiencies, etc.)

For the purposes of this analysis, three representative useful water heating loads (Small, Medium and Large) have been chosen, whose values have been based on analysis set out in the HEEP study[4].

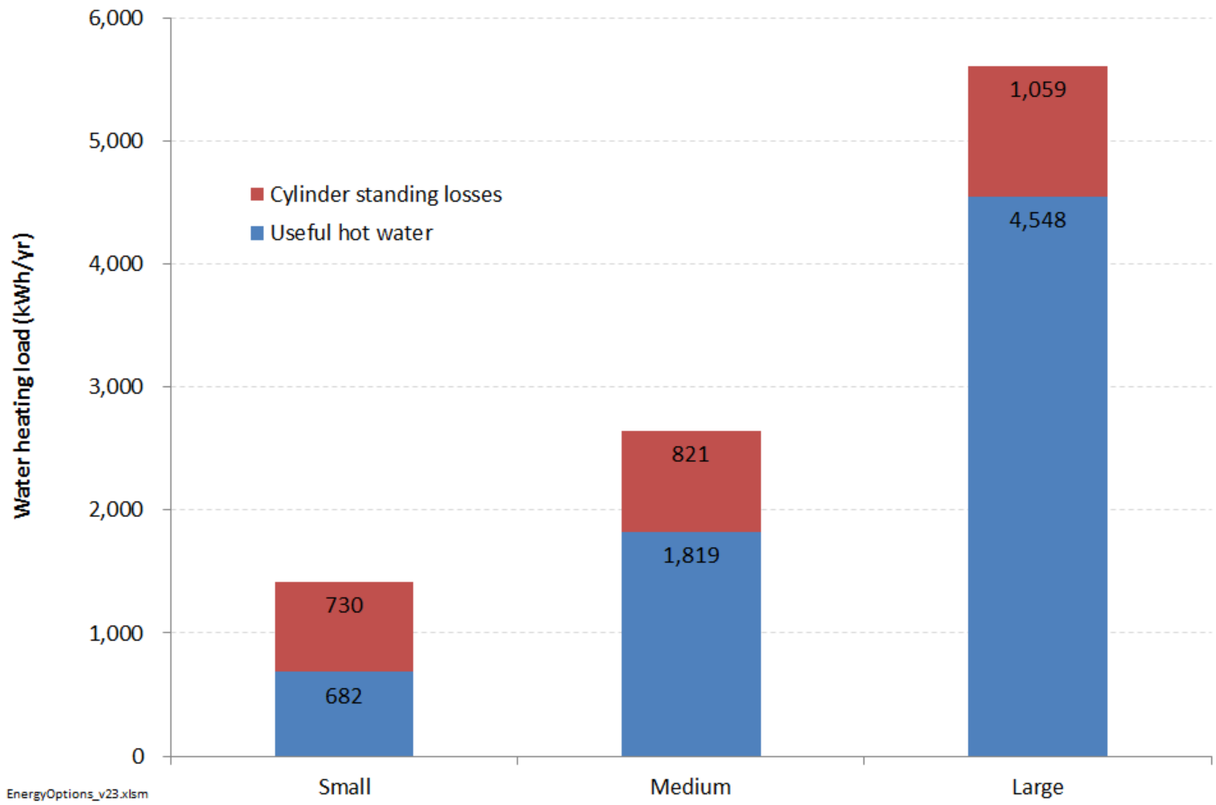
A significant complication in considering water heating loads relates to the standing losses for options which use a cylinder – i.e. the losses from a cylinder standing with hot water and losing heat through radiation. Such losses need to be added to the useful heat load requirement to give an overall heating load requirement. Again, HEEP data was used as the basis for the estimates.

The resulting water heating load requirements considered in the study are presented in Figure 1, below.

[3] This report distinguishes between *useful* energy and *consumed* (a.k.a. 'delivered') energy. For example, if a consumer has a requirement for 1,000kWh of useful hot water, but an appliance which is only 85% efficient, then they must consume 1,000 ÷ 85% = 1,175 kWh of fuel.

[4] "*Energy use in New Zealand households – Final report on the household energy end-use project (HEEP)*", 2010, BRANZ.

Figure 1: Water heating load requirements considered in the study



Source: Concept estimates based on HEEP data

As can be seen, for small heat load requirements standing losses can be larger than the actual useful heat requirements.

A further complication is that the standing losses for some cylinder-based options need to be factored to take account of:

- being located outside (as is the case for many gas cylinder options and some heat pump options), which will increase standing losses; or
- storing the water at a lower temperature (as is the case for solar options with gas boost), which will decrease standing losses[5].

This factoring is included in the analysis, but has not been shown in the above figure.

Similarly, there is some variation in the amount of heating required due to the varying temperatures of cold water entering properties around the country. For example, Auckland has an average cold water temperature of 15^{o}C, whereas Christchurch has an average cold water temperature of 8^{o}C. This means it will take 14% more energy to raise cold water to a cylinder temperature of 65^{o}C in Christchurch than it will in Auckland. Such geographic variations are not shown in Figure 1, but have been included in the analytical framework.

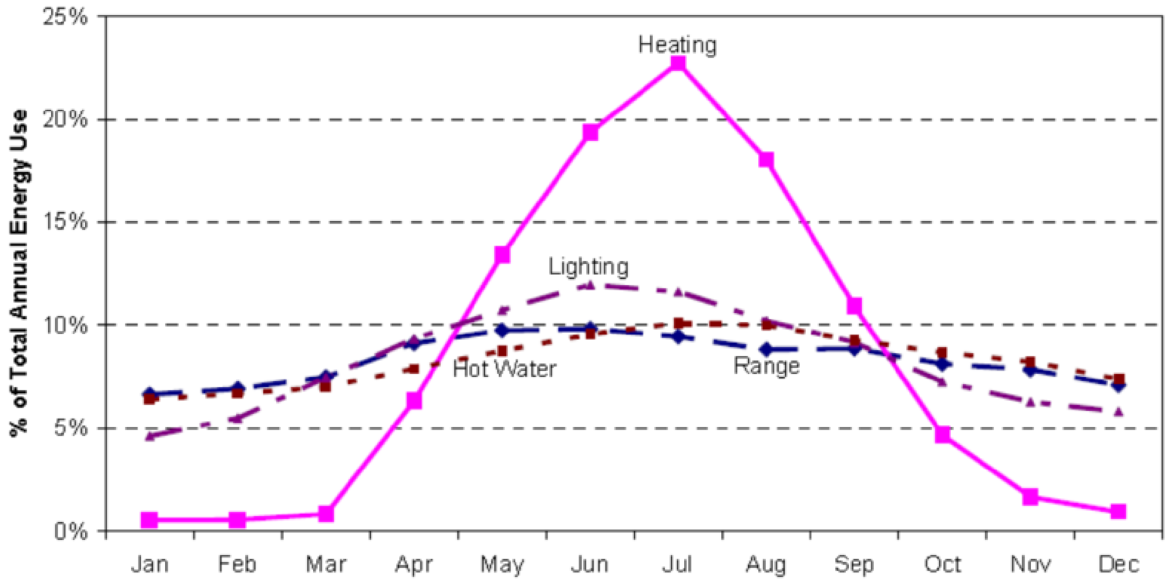
[5] The water can be kept at a lower temperature in the cylinder because it is brought to above the required temperature to kill legionella bacterium when it passes through the gas / electric boost heating stage.

Shape of heat load

The 'shape' of demand – i.e. how much demand varies on a within-day and within-year basis – can have a material impact on electricity and gas price outcomes due to factors such as peaking wholesale costs, network costs, and emissions factors.

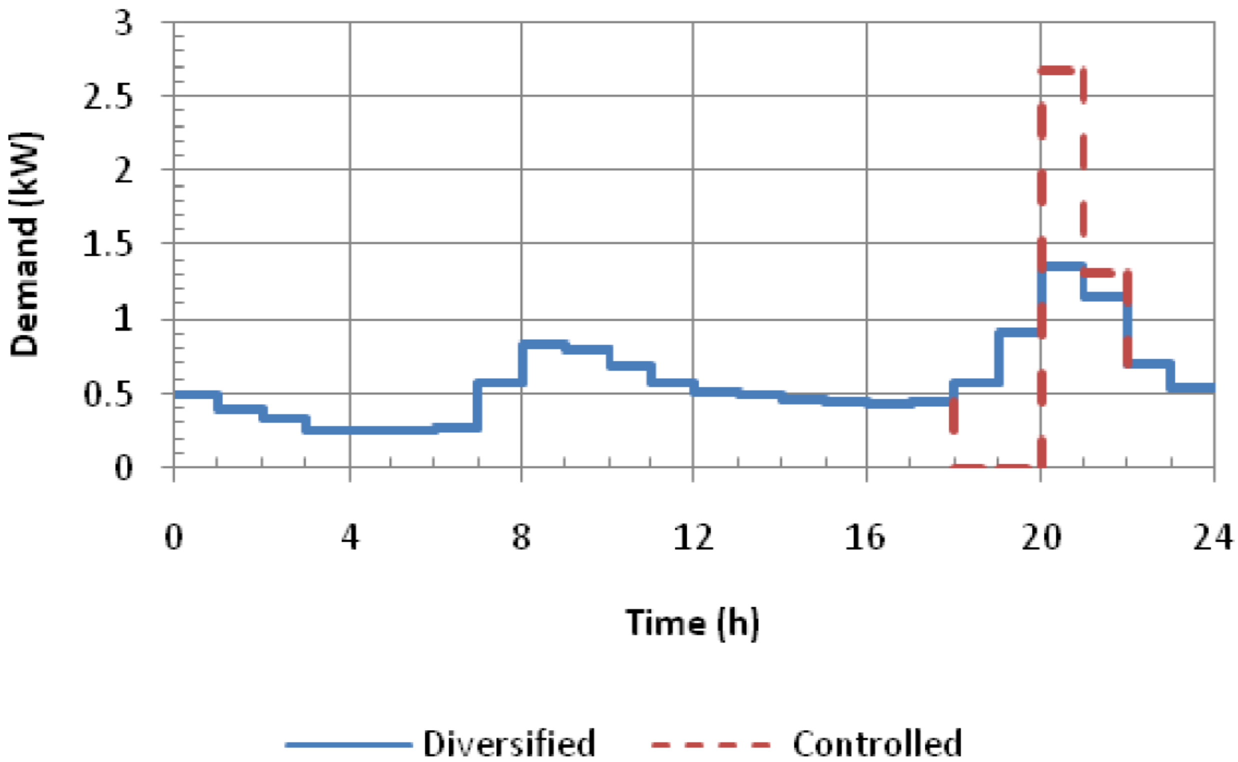
For water heating, the monthly water heating consumption profile given in the HEEP report (shown in Figure 2 below) was used to determine the monthly shape of the heating load.

Figure 2: HEEP analysis of energy use by end-use and month (Figure 17 of HEEP 10 report)



This monthly profile was cross-multiplied with a within-day water heating profile based on research published by Meridian and shown in Figure 3 below:

Figure 3: Diversified water heater demand

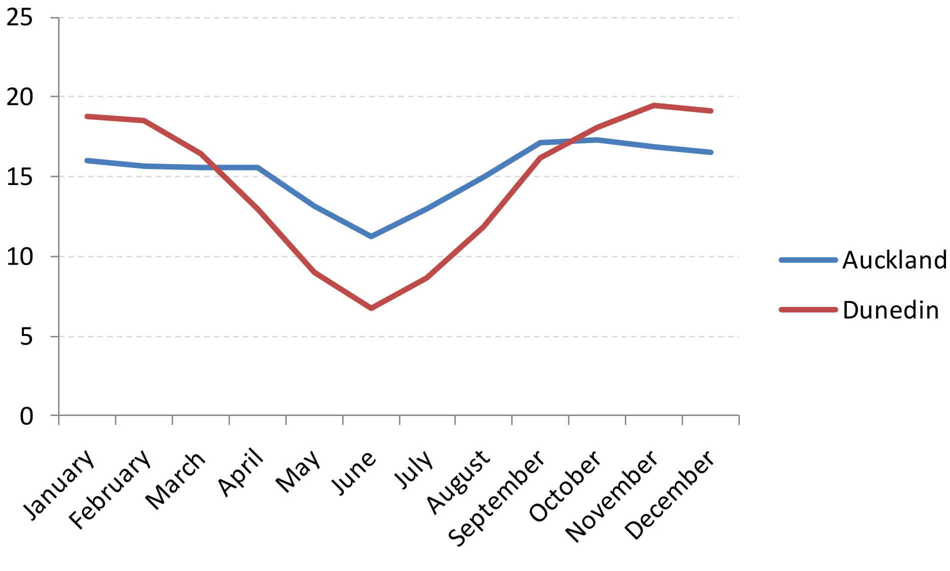


Source: "*Smart New Zealand Energy Futures: A feasibility study*", Meridian Energy, January 2012

In order to simulate the 'peakier' load of instant gas water heaters, the water heating profile shown in Figure 3 was used as the starting point and simply skewed.

In order to determine a residual load for solar water heating, a further model was used. This Retscreen model is a freely available model (www.retscreen.net) which can be used to calculate the performance of various solar water heating situations. The model assumed the use of evacuated tube solar panels with the same collection area and orientation for each location. The collection area was 2.7/5.4/8.1m^2 for a small, medium and large hot water load respectively. The output from the model was used to determine the within-year solar contribution to heating load. The output from this model is shown in Figure 4 below.

Figure 4: Average daily MJ solar water heating for a typical solar panel in two representative locations

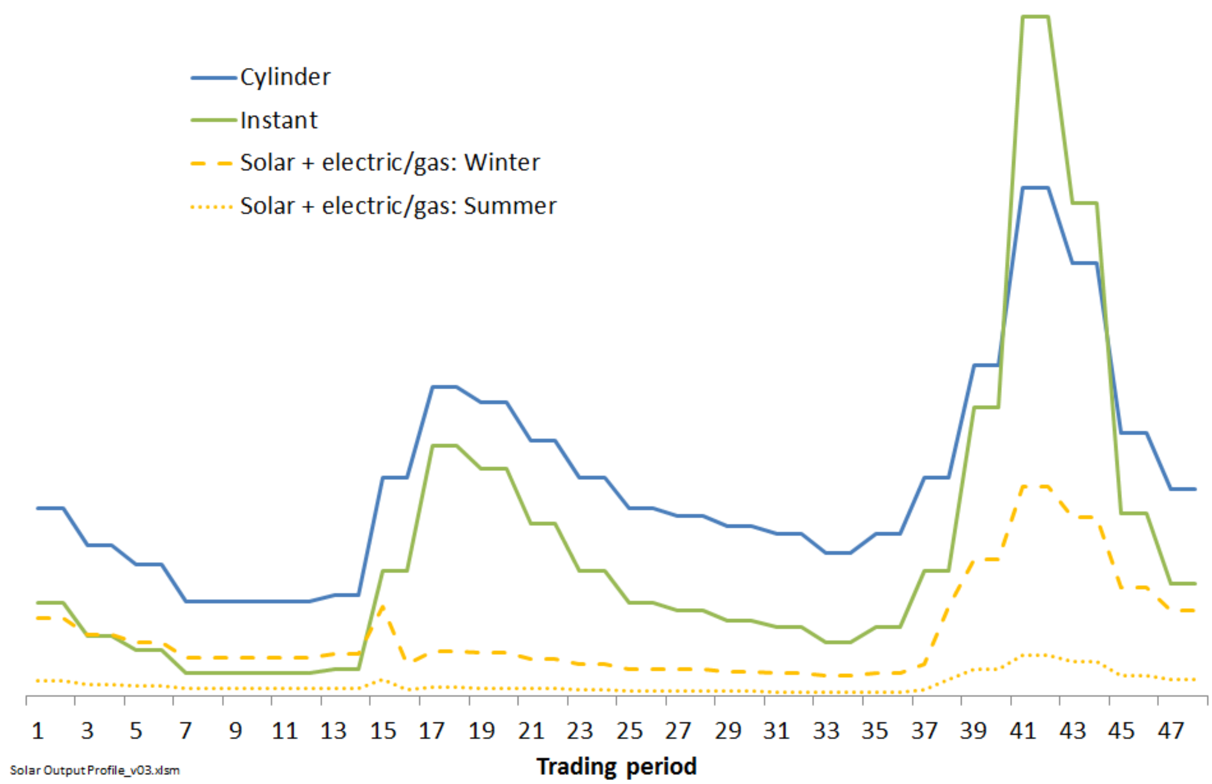


Source: Concept analysis

This solar heating contribution was then netted off the monthly heating load, to enable derivation of a final within-day and within-year residual heating load for solar water heating options.

Figure 5 below illustrates the final modelled curves for the three main types of water heating option.

Figure 5: Modelled water heating load curves



Source: Concept analysis

2.1.2 Fuel + water heater appliance technology characteristics

This section describes the various cost and performance characteristics of the different heating appliances that will affect which option is best for a particular consumer situation.

The analysis focused on a wide variety of different fuels and appliances. However, it was limited to those appliances which were considered sufficiently mature to be practicable options for consumers. Accordingly it did not consider a number of emerging technologies such as ground source heat pumps, and micro cogeneration. Instantaneous electric water heating was not considered because it is a 'point' solution appropriate for a specific use (e.g. a shower), and doesn't do away with the need for water heating for the rest of the house (e.g. kitchen taps). Similarly, condensing hot water boilers were not considered because the savings in fuel costs from increased appliance efficiency compared to conventional instant gas water heaters were more than outweighed by the extra capital costs for such technologies[6].

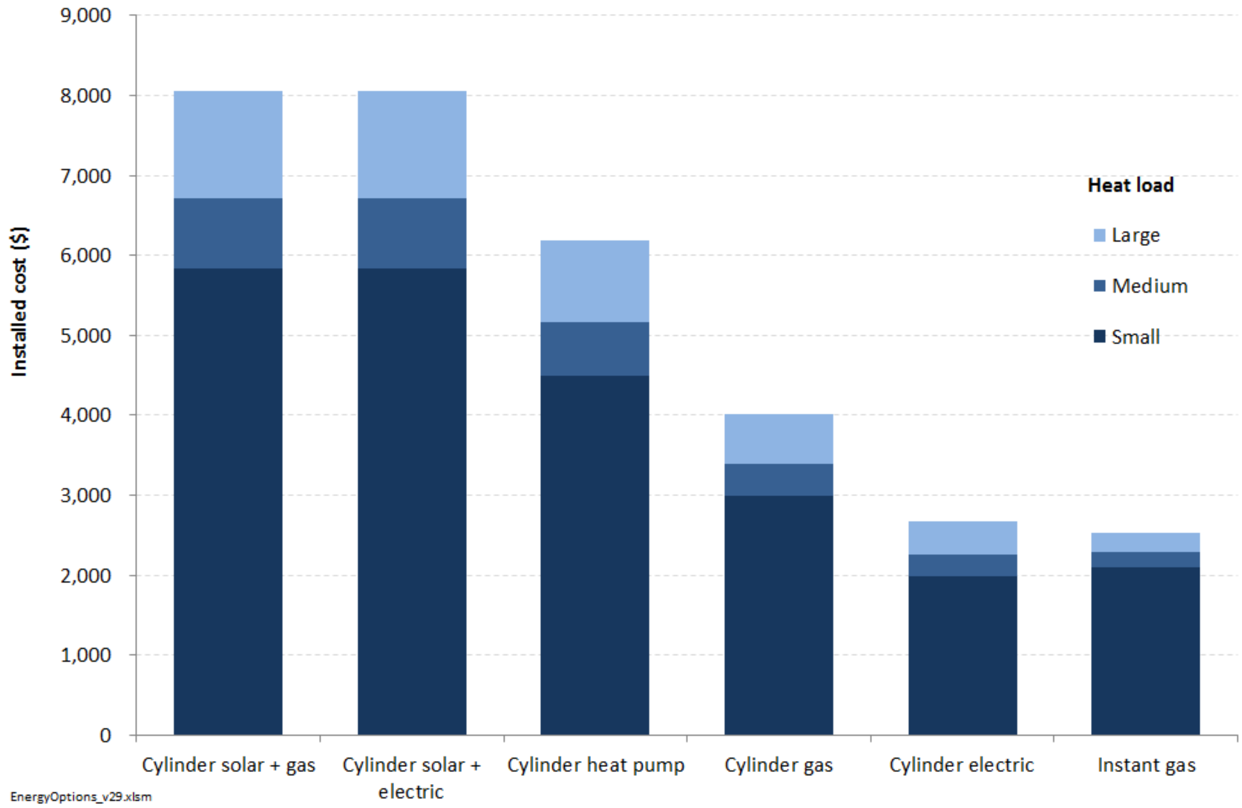
Capital and on-going maintenance costs

Capital costs can have a huge impact on the relative economics of the different water heating options due to the variation in heating load. Thus, some of the options which have the lowest running costs, such as solar water heating and heat pump water heating, also have the highest capital costs. This higher up-front cost may be outweighed by the benefit of lower running costs for consumers with a very large water heating load, but it may not be worth it for consumers with a smaller heating load.

The research for this study highlighted that there is significant variation in the purchase and installation costs for a given type of appliance across different brands, retailers and fitters. The values shown in Figure 6 below have been chosen as representative median values based on data sourced from a variety of retail websites and discussions with representatives from companies that install such appliances.

[6] Industry figures suggest that for a medium-sized domestic water heating load the extra capital cost of a condensing boiler compared to a conventional instant gas water heater is $640 in order to deliver 12% extra efficiency (95% instead of 83%). For a medium-large useful heating load of 3,000 kWh/annum, this extra 12% efficiency reduces gas consumption by 457 kWh/annum. At a variable gas price of 0.085 $/kWh, this is worth $40/annum. Which, when compared to the $640 extra capital cost, gives a payback of ≈ 16 years. In order for condensing boilers to deliver a positive 10 year NPV for such a heat load, it would require variable gas costs to be approximately 2.5x greater than their current value of ≈ 0.085$/kWh.
That said, LNG is currently priced at such a level, so these higher efficiency options would start to be economic for consumers in the South Island who don't have access to reticulated natural gas.
Also, commercial consumers with larger water heating loads would likely benefit from these higher efficiency options even with natural gas.

Figure 6: Estimated water heating capital + installation costs



Source: Concept estimates based on a variety of different sources

A further factor which needs to be considered in relation to the capital cost of the different options, is that those options which have a cylinder located in a cupboard within the house (as opposed to being located outside or in the roof space) are taking up useful house space. Indoor cylinders are typically associated with standard electric cylinder water heating, solar + electric water heating, and some gas cylinder and heat pump water cylinder options[7].

Typical costs for building a house are approximately $1,500 to $3,000/m^2. Based on such costs, and the space taken up by a cylinder, the useful house space taken up by a cylinder is likely to be 'worth' approximately $1,500. This would represent a material extra cost for such options. However, for the economic evaluation in this study such costs have not been included. This is because there is a degree of subjectivity to valuing this benefit. For example, some people may be willing to spend more than $1,500 to free-up useful cupboard space, whereas others may not be willing to spend much money at all.

Another complication is that the expected useful life of appliances (i.e. the time they are expected to last before they will need replacing) varies between appliances. Thus, relatively complex appliances which have a lot of moving parts and/or those which are located outside, generally require replacement much earlier than those which are relatively simple and/or are located inside. This has been addressed within the analysis by applying different end-of-life factors to the up-front-costs of the different appliances to reflect the time-discounted replacement costs that will likely be incurred in the future. Simple appliances such as electric

[7] Many gas cylinder and heat pump cylinder options have the cylinder located outside. This reduces installation costs but, as discussed on page 9, increases standing losses.

cylinders are assumed to have much longer useful lives than more complex (and exterior located) appliances such as heat pumps.

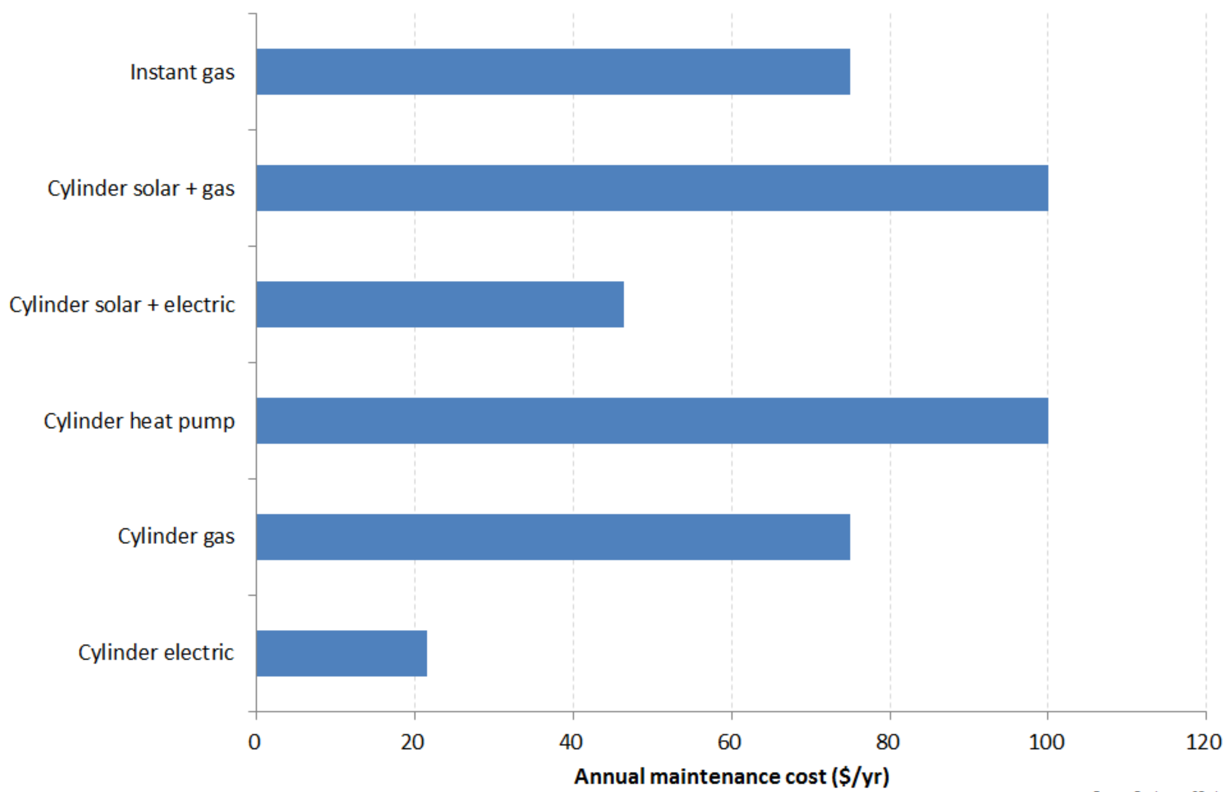
Table 1: Assumed end-of-life factors to apply to the initial capital and installation costs of water heating appliances

Appliance	End of life (years)	Proportion of costs requiring replacing	Resultant end of life factor[8]
Cylinder electric	30	90%	9%
Cylinder gas	25	90%	13%
Cylinder heat pump	14	60%	20%
Cylinder solar + electric	25	70%	10%
Cylinder solar + gas	25	70%	10%
Instant gas	25	90%	13%

Source: Concept estimates

Lastly, different appliances have different costs associated with on-going servicing and maintenance. These are set out in Figure 7, below.

Figure 7: Assumed annual maintenance costs of the different water heating options



[8] This is the percentage of the initial capital and installation costs which added to calculate an appropriate 'whole-of-life' capital and installation cost estimate.

Source: Concept estimates

Appliance efficiencies

The efficiency of water heating is most usefully expressed as the 'coefficient of performance' (COP). This is simply a measure of the kWh of useful water heat provided divided by the kWh of input fuel consumed.

For instant gas water heaters this is simply calculated as:

$$\frac{\textit{Useful load}}{\left(\textit{Useful load}/\textit{Heater efficiency}\right)}$$

Equation 1

As can be seen, this makes the COP of instant gas water heating equivalent to the heater efficiency.

For cylinder-based options, it is necessary to take account of standing losses:

$$\frac{\textit{Useful load}}{\left((\textit{Useful load}+\textit{standing losses})/\textit{Heater efficiency}\right)}$$

Equation 2

And for solar options, it is also necessary to take account of the contribution of the solar panels:

$$\frac{\textit{Useful load}}{\left((\textit{Useful load}+\textit{standing losses}-\textit{solar contribution})/\textit{Backup heater efficiency}\right)}$$

Equation 3

For most appliances, heater efficiency in the above equations is relatively straightforward to determine. E.g for an electric cylinder it is 100%, and for standard instant gas water heaters it is approximately 85%.

However, for heat pumps the efficiency will depend on the geographic location. This is because the efficiency of a heat pump water heater is a function of

- the desired hot water temperature and the average cold water temperature (which together determines the amount of heating required); and
- the ambient outdoor air temperature (which is effectively the heat source)

The COP for heat pumps deteriorates as the ambient outdoor temperature decreases, and also as the cold water input temperature decreases. Both of these exhibit regional geographic variation. Thus the average cold water temperature in Auckland is estimated to be 15^{o}C, whereas in Christchurch it is 8^{o}C. There is similarly significant geographic variation in ambient air temperatures.

Different models of heat pump exhibit different levels of performance at different temperatures. In particular, different models suffer different degrees of degradation in performance due to freezing around the 'dew point' of air (in the 0˚C to 5˚C range).

All of the above factors affecting heat pump performance have been incorporated within the model which has different heat pump coefficients of performance for different geographic locations.

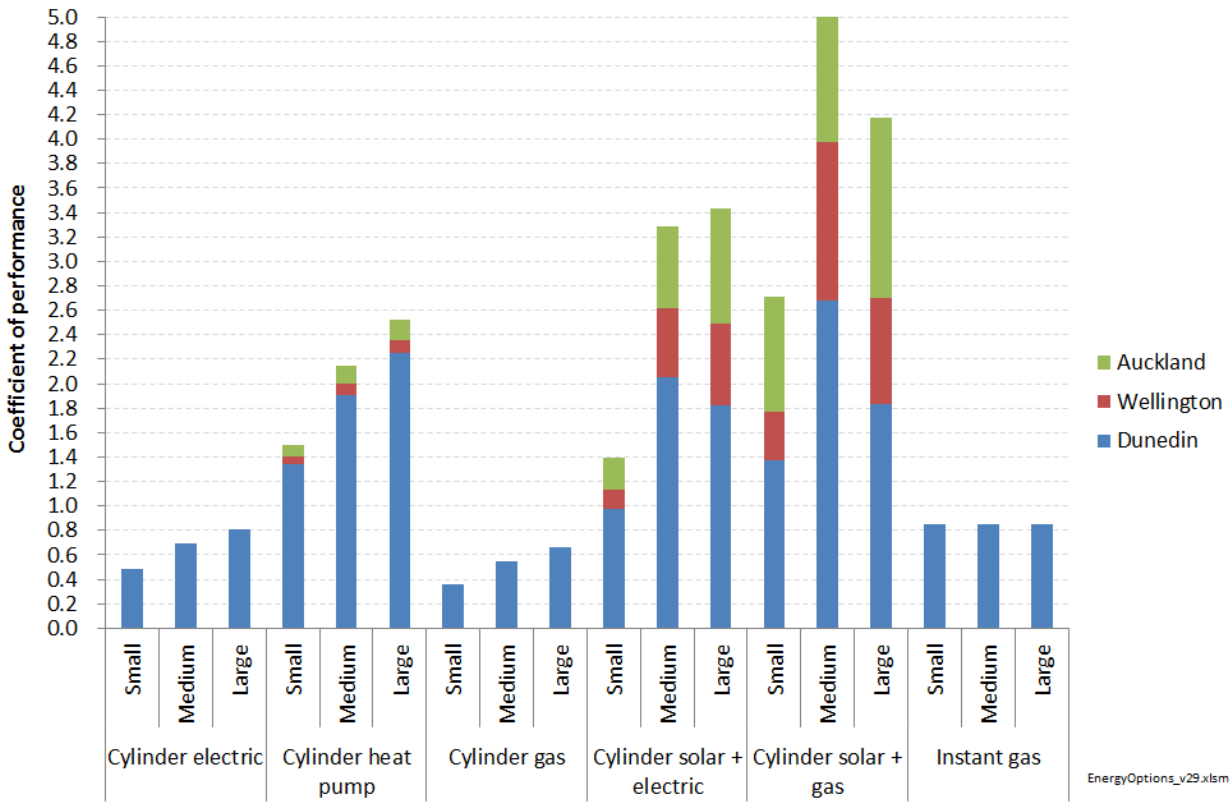
Solar water heaters also exhibit variation in effective coefficients of performance due to variations in the degree of solar contribution around the country.

For a Medium sized consumer the effect of the solar contribution is to reduce electricity consumption by about 75% for a Medium Auckland consumer and by 62% for a Medium Dunedin consumer. (For Small consumers (for whom standing losses account for a greater proportion of overall water heating requirements), the reduction in electricity consumption is 59% and 53% for Auckland and Dunedin locations, respectively). Again, this has been incorporated within the model by explicitly modelling the likely solar contribution for different geographic locations.

As noted on page 9, a further complication is that the standing losses for some options need to be factored to take account of being located outside or storing the water at a lower temperature. Again, such aspects are captured within the model.

Figure 8 below shows the overall coefficients of performance for the different water heating options taking into account all the above factors.

Figure 8: Water heating appliance coefficients of performance considered in the study



Source: Concept estimates

As can be seen, the options which have the highest COPs (and thus the lowest fuel requirements) are solar water heating options, followed by heat pumps.

The effect of standing losses reduces the coefficient of performance for smaller heat loads (as can be inferred from examination of Figure 1 previously), but for instant gas water heating (which does not have a cylinder), there is no variation in COP with size of heat load.

Fuel & CO_2 costs

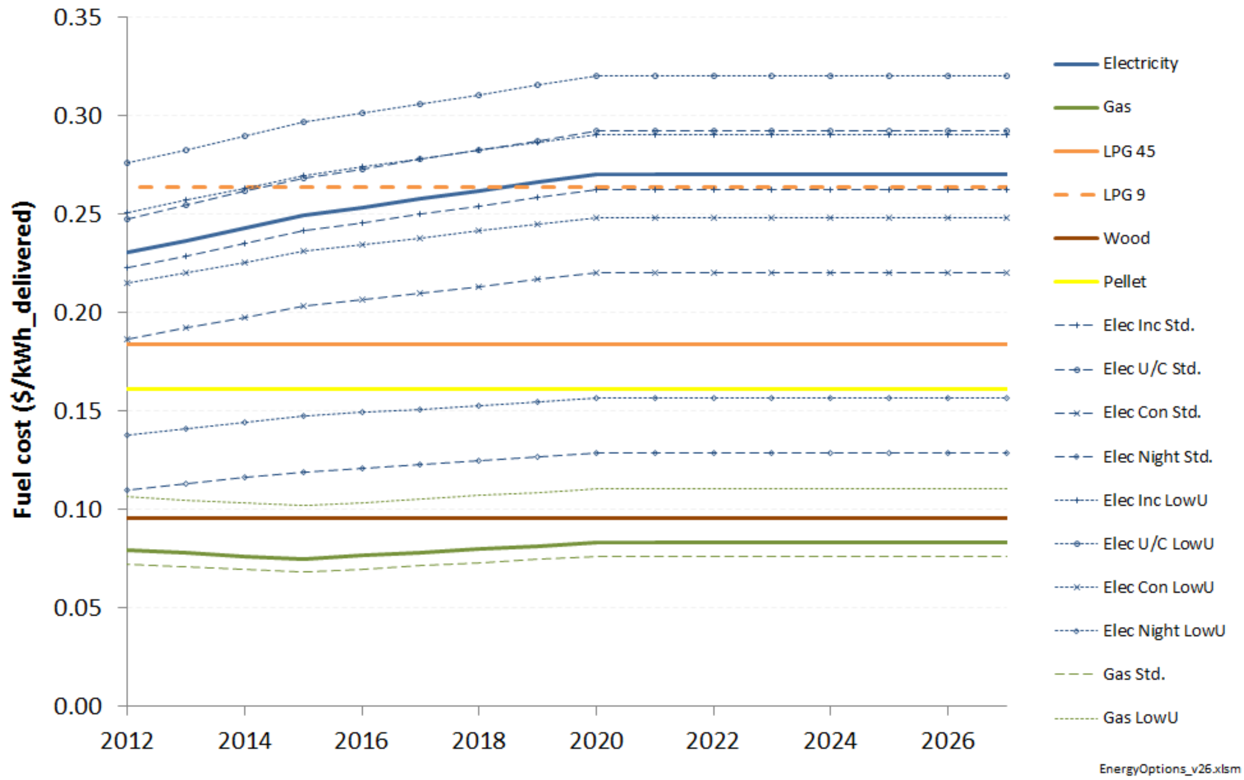
Appendix B and Appendix C set out the assumptions and analysis in relation to fuel and CO_2 costs.

As is detailed in such appendices, consideration of such factors is decidedly non-trivial due to:

- Variations in the cost structures between the different fuels including factors such as:
  - fixed versus variable charges
  - different rates for different types of electricity control tariffs
  - low-user versus standard user variants for electricity and gas tariffs
  - different costs at different times of the day and year for electricity and gas
  - the extent to which the split between fixed and variable costs may differ between the prices charged to consumers, and the underlying resource costs faced by New Zealand
- The likelihood that some fuels are likely to see prices move in the future by a greater amount than other fuels
- The fact that different types of electricity generation are likely to operate to meet different types of load, and thus result in different CO_2 emissions intensities. (i.e. an increase in electricity demand which only occurs in winter is likely to result in a different change in generating patterns (and hence emissions) than an increase in electricity demand which occurs at all times of the day and year).

Figure 9 below illustrates the variation in variable fuel prices between the different fuels.

Figure 9: Delivered consumer fuel price projections used within the study (incl. GST)[9]



Source: Concept estimates

As can be seen, on an input fuel basis, gas and wood are relatively cheap compared to electricity and LPG.

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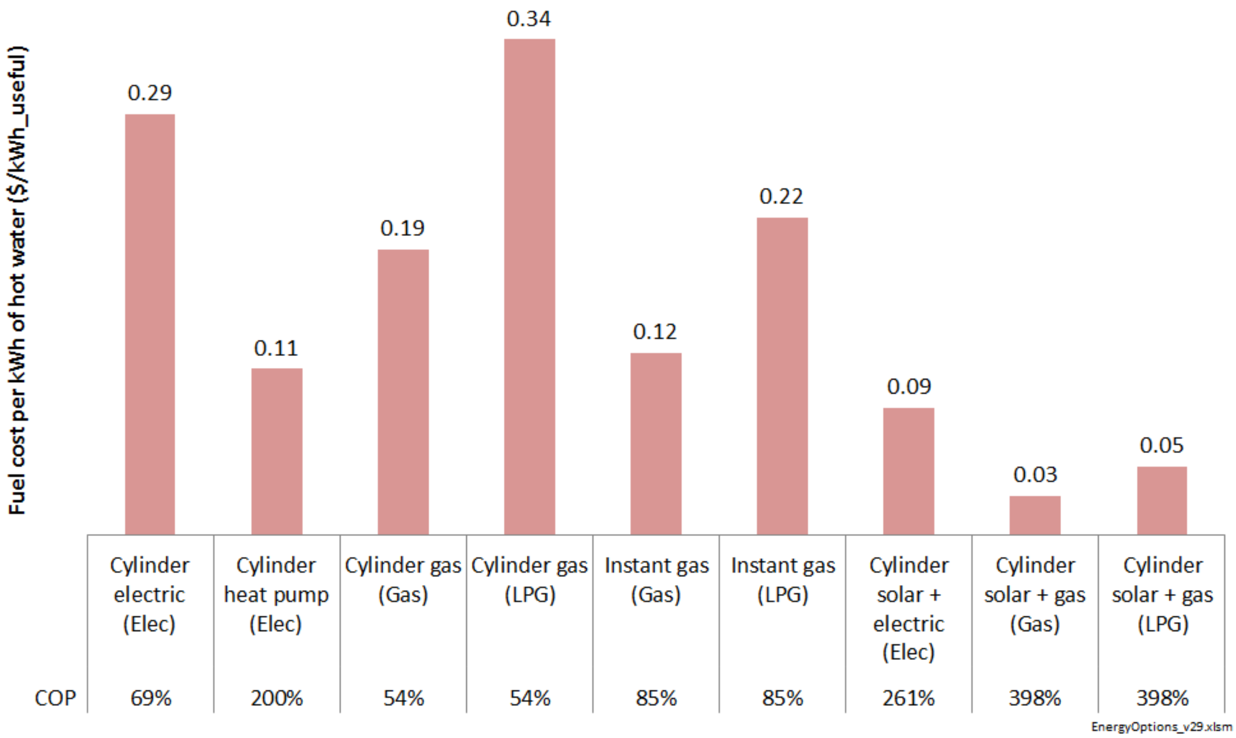
[9] For electricity and gas, the heavy solid lines represent the average price across the range of different tariffs, while the light dotted line represent the specific different prices for the different options. "Std" and "LowU" distinguish between standard and low-user options. For electricity the control types are defined as: "U/C" = uncontrolled, "Inc" = Inclusive control (i.e. for a single meter which has a mixture of controlled and uncontrolled load beneath it), "Con" = Controlled (i.e. all load beneath the meter is controlled), and "Night" = Night-only consumption. "LPG45" and "LPG9" refer to the price of 45kg and 9kg cylinders, respective. (With 9kg only being used for cabinet heaters).

However, once the coefficient of performance of the difference appliances is taken into account, the relative running costs of the different options can be vary significantly, as is shown in Figure 10 below.

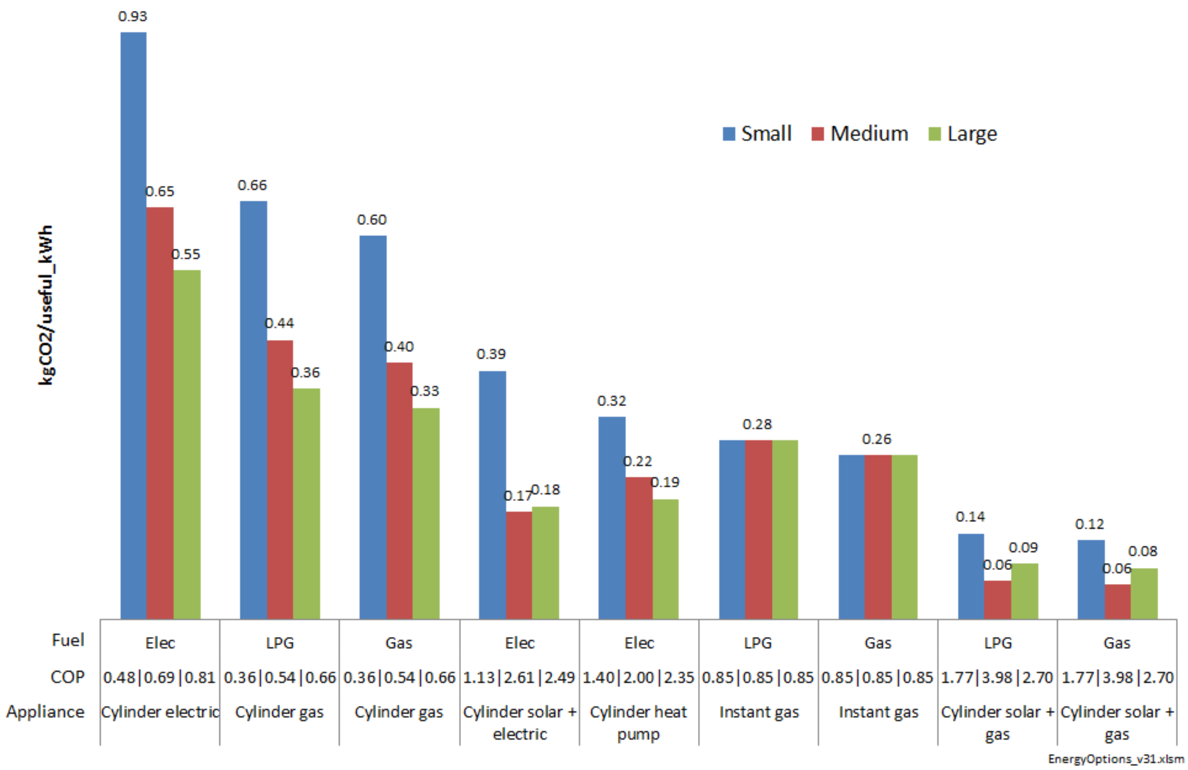
Figure 10: Fuel cost (energy + network) of useful hot water



As can be seen, <u>purely on a $/kWh variable fuel cost basis</u> (i.e. ignoring capital and maintenance costs), solar and heat pump water heaters are the cheapest options, even though electricity is one of the most expensive fuels.

Similarly, the different appliance coefficients of performance can have a major bearing on the effective CO_2 emissions profiles of the different water heating options as shown in Figure 11 below.

Figure 11: CO_2 emissions intensity of water heating options ($kgCO_2$/*useful*_kWh), assuming a central electricity emissions intensity scenario for small, medium, and large domestic water heating loads



Source: Concept analysis. Note: The heat pump COP chosen is for a Wellington location.

Overall, purely from an emissions perspective, instant gas heating options appear broadly equivalent with electric heat pump options, superior to electric resistance heating options, but inferior to solar heating options.

The analysis in Appendix B and Appendix C also highlighted that there didn't appear to be significant dislocations between the effective cost of water heating from a 'private' consumer perspective versus a 'public' whole-of-New Zealand perspective. In large part this is due to the relatively 'flat' profile of water heating across the year, and the fact that the emissions intensity of instant gas water heating and heat pumps is relatively similar.

2.2 Water heating results

The purpose of this analysis is to inform consumers facing a water heating decision which option is likely to be best. There are two principal types of consideration for this decision:

- Which option(s) are likely to deliver hot water at least cost?
- Which option(s) are likely to deliver the best non-price 'quality' benefits that may be of value to consumers?

To the extent that the best option from a cost perspective is not the best option from a quality perspective, consumers will need to make trade-offs.

2.2.1 Determination of least cost water heating options

The most useful metric to reveal which option delivers hot water at least cost is the *lifetime* cost per kWh of useful hot water delivered. There are two key factors to consider in calculating this value:

- The treatment of up-front capital costs and fixed costs
- The avoidability of different costs.

Treatment of up-front capital costs and fixed costs

Capital costs

Some water heaters such as solar water heaters and heat pumps have very high coefficients of performance resulting in very low fuel consumption costs. However, typically such heaters also cost a lot more to purchase and install.

From a lifetime cost of water heating perspective it is therefore necessary to weigh up the benefit of a lifetime of lower fuel bills against the higher up-front costs. For consumers with a large water heating load this fuel-saving benefit may outweigh the higher cost, whereas for smaller heat-load consumers the reverse may be true. This trade-off is exactly the same in purchasing a car and explains why taxi-drivers appear more willing to pay the higher capital costs to purchase fuel-efficient hybrid electric vehicles, whereas drivers who travel much less generally chose lower capital cost but less fuel efficient cars.

In order to calculate the contribution of capital costs to the per kWh cost of heating water it is first necessary to amortise, or 'spread', this up-front cost over an appropriate lifetime. For the purposes of this analysis it is considered that a ten year period is appropriate for a consumer's perspective. i.e. it is considered unlikely that consumers would value savings over longer than a ten year period given the uncertainty as to whether they will be staying in the property for that length of time, and uncertainty as to whether their water consumption requirements may change (e.g. due to evolving family circumstances).

To spread the capital costs over a ten year period it is not appropriate to simply divide the capital costs by ten. Instead, it is necessary to amortise such costs using a discount rate in order to take account of the time value of money (i.e. $1 given to someone now is worth more in present value terms than giving them $1 in ten years' time). An 8% discount rate was used for this analysis.

For example, a $5,000 up-front capital cost represents a $745/year annual capital cost contribution to the lifetime cost of water heating when spread over a ten year period using an 8% discount rate.

This annual capital cost contribution can then be divided by the annual kWh of useful hot water to work out the capital contribution to the per kWh cost of hot water. Continuing with the above example, for an annual useful hot water load of 2,000kWh, this would result in a per kWh of hot water cost of:

$$\$745 \div 2{,}000\text{kWh} = 0.37\ \$/\text{kWh}$$

Fixed costs

Some water heaters will incur other annual costs which don't vary with the kWh of hot water delivered. For example, daily fixed charges for gas supply, and annual appliance maintenance costs.

These annual costs are divided by the annual kWh of useful hot water to work out their contribution to the per kWh cost of hot water.

Avoidability of different costs

In considering which options are likely to be least cost at delivering hot water, it is necessary to only consider those costs which are *avoidable* based on the consumers' decision. There are two types of cost which may be considered unavoidable for this evaluation.

Firstly, in situations where a consumer has an existing workable water heater and is considering whether to switch to another water heating option, they should only consider the variable and annual fixed costs of the existing water heater, whereas they should also include the capital costs for the new water heater. This is because the capital costs of the existing heater are sunk and cannot be avoided, but the capital costs of the new heater could be avoided.

Secondly, the daily fixed charges for fuel delivery should not be considered in the evaluation if the consumer is going to have that fuel delivered anyway for a purpose other than water heating. For example, the daily fixed charge for electricity supply is not considered for electric water heaters, because consumers will want to have electricity anyway to run lights, appliances etc. However, a consumer could avoid any fixed daily charges for *gas* supply if they chose not to have gas at all. Accordingly, for the purposes of this evaluation, the fixed daily charges for gas supply are added to the cost of useful hot water from gas-fired water heaters[10].

The avoidability of some costs is also different when they are considered from a whole-of-New Zealand perspective. Thus:

- Some electricity and gas network costs which are charged to consumers on a variable basis may be unavoidable from a whole of New Zealand perspective because they are for the capital recovery of sunk assets; and
- Conversely, other electricity and gas costs which are charged on a fixed basis to consumers (i.e. charged on a $/day basis), may be avoidable from a whole of New Zealand perspective;

Appendix B details the analysis in relation to this potential public versus private benefit disconnect.

Overall calculation of lifetime cost of hot water

Equation 4 below shows how the over cost per kWh of useful hot water is calculated.

$$\mathbf{Cost_{useful}} = \frac{\mathbf{Var_{delivered}}}{\mathbf{COP}} + \frac{((\mathbf{DailyFix} \times 365) + \mathbf{Capex_{New}} + \mathbf{Opex})}{\mathbf{Load_{useful}}} \qquad \textbf{Equation 4}$$

Where

$Cost_{useful}$ = The effective $/kWh cost of useful hot water

$Var_{delivered}$ = The $/kWh variable cost of delivered fuel (including energy, network and CO_2 costs[11])

COP = The coefficient of performance of the appliance (effectively synonymous with the 'efficiency' of the appliance

[10] For sensitivity purposes, the analysis also looks at the impact of excluding gas fixed charges to simulate situations where a consumer is committed to having gas anyway (e.g. for space heating or cooking).

[11] For a consumer these energy, network and CO_2 costs are generally bundled into a single $/kWh tariff from their electricity or gas supplier. However, for the purposes of this analysis such costs have been disaggregated to enable:

- consideration of the different levels of avoidability from a whole-of-New Zealand perspective for such costs;
- projections of movements in these cost elements at different rates; and
- better identify the environmental costs of the different fuel + technology options.

DailyFix = Any <u>avoidable</u> $/day daily fixed fuel charges (including energy, network and retail charges)

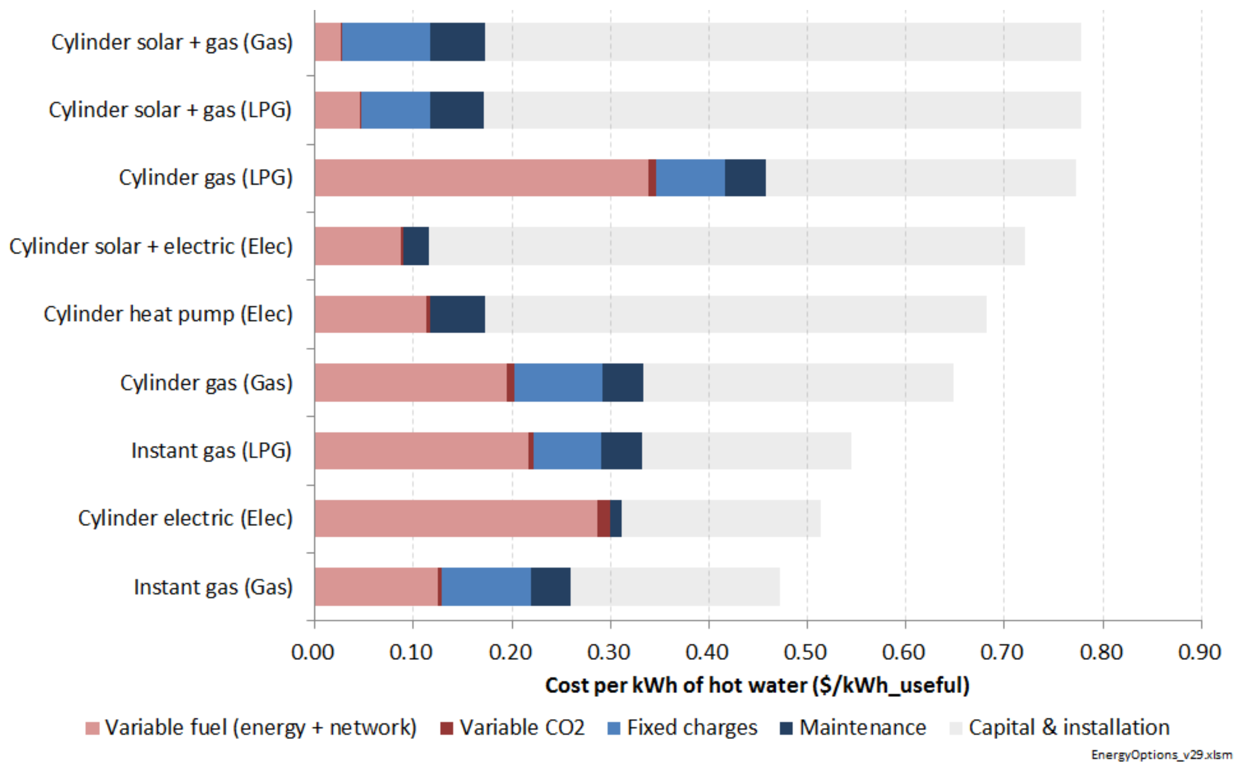
$Capex_{New}$ = The amortised capital + installation cost of any new appliance

Opex = The annual maintenance cost of the appliance

$Load_{useful}$ = The annual kWh useful heat load

Figure 12 below shows the overall result of this analysis for different water heating options for a medium-sized water heating load.

Figure 12: Lifetime cost of hot water for medium-sized Wellington households



There are a number of important conclusions to draw from this graph:

- In almost all cases the variable fuel & CO_2 costs of an option is smaller than the fixed and capital costs. This highlights the importance of considering such costs in determining the most cost-effective option. For example, looking at Figure 12 above, solar + gas is the cheapest option on a variable cost basis. However, when the capital and fixed costs are taken into account it becomes the most expensive option.
- Consumers with an existing water heating appliance should only switch to the cheapest new appliance if the cost of the new appliance *including* capital costs is less than the cost of the existing appliance *excluding* capital costs. In the above situation, the cost per kWh of hot water for an existing hot water cylinder is approximately 0.31 $/kWh, whereas the lifetime cost of the cheapest alternative option – instant gas – is 0.47 $/kWh. Thus, in this case – and indeed in all the cases for Figure 12 above – it would not be cost-effective to switch-away from the existing appliance.

The results shown in Figure 12 above are only for one consumer situation. As was highlighted previously, there can be significant variations in consumer situations, particularly relating to the size of the hot water load.

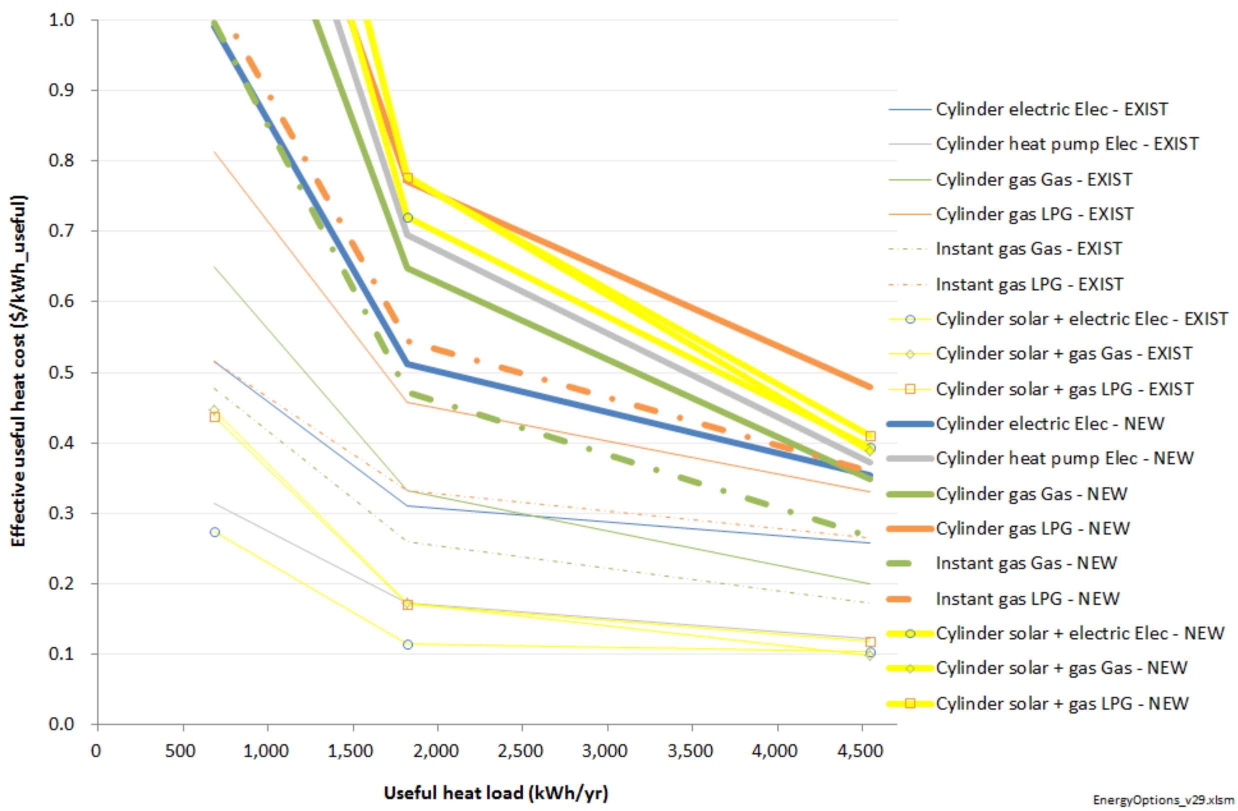
There are two terms in Equation 4 above which mean that the cost per kWh of useful heat is likely to vary with the size of the heat load.

Firstly, as set out previously, the larger the heat load, the smaller will be the effective cost per kWh of useful heat for the recovery of capital and fixed costs.

Secondly, as also set out previously, the coefficient of performance for cylinder-based options will generally increase with heat load due to standing losses becoming a proportionately smaller amount. As the COP increases, the variable cost of fuel per kWh of useful heat falls.

This variation in the lifetime per kWh cost of hot water with changing hot water load size is illustrated in Figure 13 below, which shows the total effective per kWh useful water heating costs for different appliances and consumer situations. The thick lines are for new appliances (and thus include capital costs), whereas the thin lines are for existing appliances (and thus exclude capital costs).

Figure 13: Effective per kWh useful water heating costs for different appliances and consumer situations including gas and LPG daily fixed charges



Source: Concept analysis

Based on this analysis the following general conclusions can be drawn:

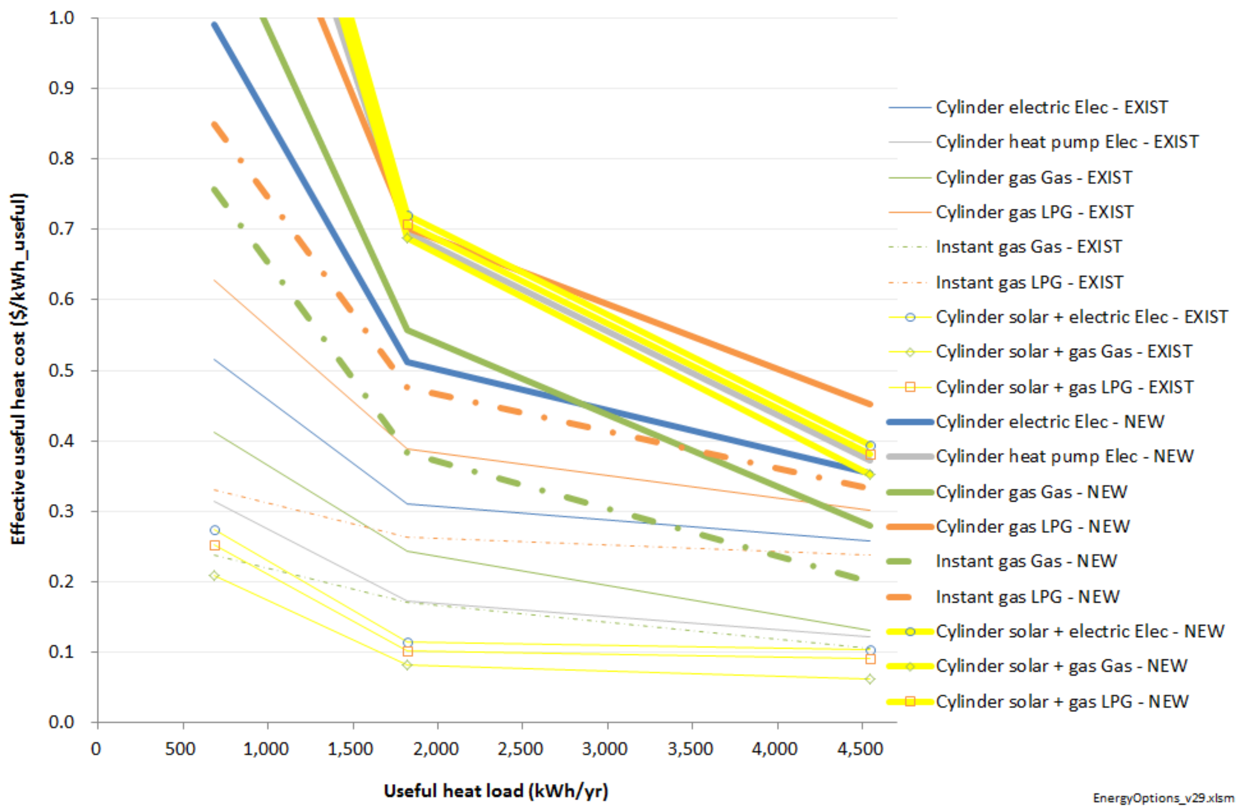
- For new-build situations, the most cost-effective option is generally instant gas water heating. This is because the low capital cost of instant gas outweighs the relatively higher running costs compared with hot water heat pumps or solar water heating. For small heat loads there is little difference between the cost of installing an instant gas heater and a standard electric cylinder. However, as set out in section 2.2.2 below, instant gas water heating offers the additional benefits of never running out of hot water, and not taking up interior house space.

- The high capital cost of heat pumps and solar water heaters means they would only be cost effective for heat loads materially greater than the large heat load scenario considered in this report. However, even in these situations they may be limited in their ability to deliver such hot water due to limitations on cylinder size.
- For someone with an existing functional hot water system (of whatever type), it is not cost-effective to incur the capital costs involved in switching to a new system, as this will outweigh any potential benefit from reduced running costs – although for users with large hot water loads the difference in cost is relatively small. This can be inferred because all the thin lines in Figure 13 above are lower than all the thick lines for the three heat loads considered[12]. However, as set out in section 2.2.2 below, if people value the non-price 'quality' aspects of instant gas hot water (particularly never running out of hot water) then the extra amount they may need to pay may be considered small if they are a large user of hot water. (Approximately 0.02 $/kWh of useful hot water based on the above analysis).

If the fixed daily charges of gas and LPG options are not considered (i.e. in instances where the consumer is committed to having gas anyway for cooking or space heating), then the relative economics of such options improves even further, as illustrated in Figure 14 below. The main difference in outcome appears to be that for large heat loads it now appears to be cost-effective to switch away from an existing electric cylinder to a new instant gas water heater.

[12] The apparent benefit for consumers with an existing LPG-fired water heater switching to a new instant gas water heater is likely to be in most cases not practicable, because consumers with LPG for heating will likely be located in a part of the country where reticulated gas is not available (i.e. the South Island and some more rural parts of the North Island).

Figure 14: Effective useful water heating costs for different appliances and consumer situations excluding gas and LPG daily fixed charges



Source: Concept analysis

2.2.2 Consideration of the different 'quality' aspects of water heating options

For many products and services, cost is not the only determinant of the best option for a consumer. The other key determinants are non-price 'quality' attributes. For products and services such as stereos, cars, cell-phones, and internet provision, such quality attributes are additional key factors in determining which product or service is 'best'.

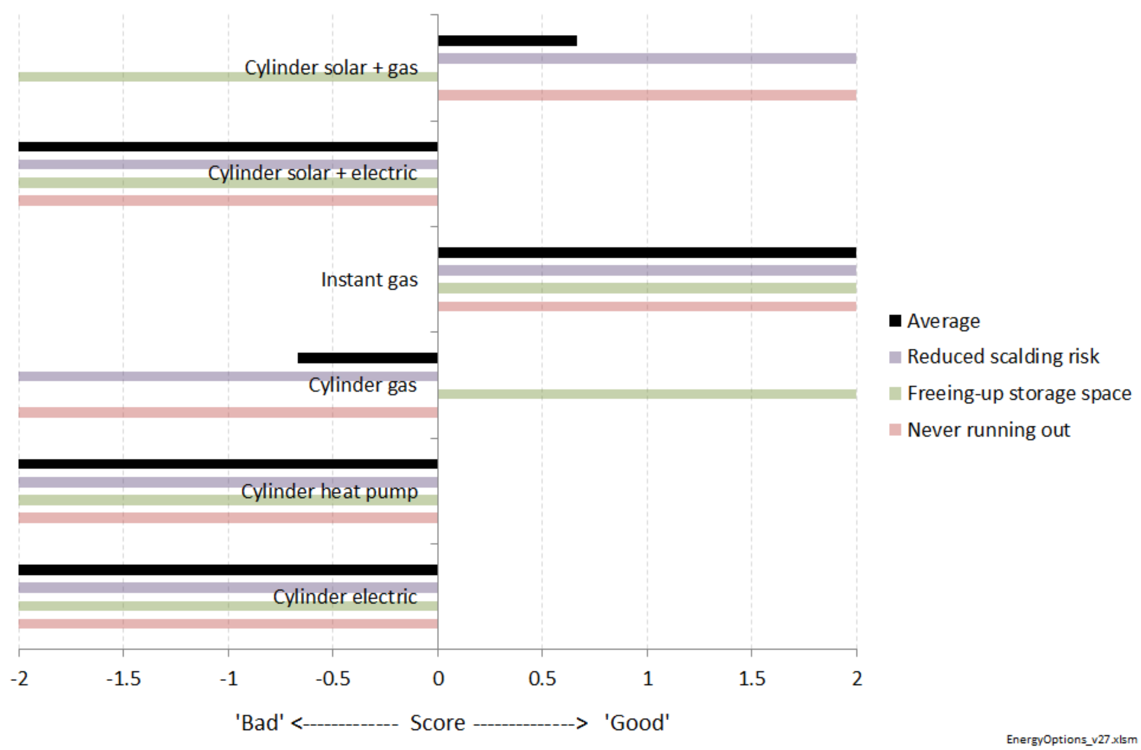
It is no different for water heating because, in addition to having different cost characteristics, the different appliances also have different quality attributes. These are set out in the following table.

Table 2: Quality aspects of different water heating appliances

Quality aspect	Appliances affected
Never running out of hot water	Good for instant gas, and solar + instant gas boost. Bad for cylinder-based options – particularly those with a long recovery time (e.g. some heat pumps)
Not taking up interior house space	Bad for cylinder options. Good for instant gas.
Health risk from scalding water	Worse for cylinder options as they have been observed to have increased likelihood of incorrectly set, or faulty, thermostats or tempering values.
Noise from operation	Sometimes an issue with heat pump systems[13].

In order to try and represent how the different appliances rate on quality overall, a 'score' was assigned to each appliance for each quality aspect. This score rated from -2 ('bad') through to +2 ('good'). A simple arithmetic average was also calculated across all quality aspects. The results of this exercise are shown in the following figure:

Figure 15: Simple scoring of water heating appliances for quality characteristics



Source: Concept estimates

[13] To address this, some units have a timer functionality which prevents operation during particularly noise-sensitive times and if they are located in a particularly noise-sensitive position (e.g. outside a bedroom window). However, this will have a detrimental effect on the availability of hot water at certain times.

It should be appreciated that this is a highly subjective exercise, as the value which different people will place on the different aspects is likely to vary significantly.

However, it shows that instant gas water heating scores very strongly relative to other heating options on all these non-price quality attributes.

3 Space heating

3.1 Key factors affecting the relative benefits of water heating options

As set out in section 1.2 above, there are many different factors relating to the consumer situation and the fuel + technology characteristics which will affect the relative benefits of the different space heating options. These are detailed in the following sub-sections.

3.1.1 Consumer situation factors

Overview of different consumer situations

The appropriate number and kW size of a property's space heaters will be principally driven by the following factors:

- ***The size of the property***: The greater the number of rooms, the more heaters will be required. Similarly, the larger the size of a room, the greater the required heater kW rating.
- ***The rate of heat loss out of the property / room***, driven by:
  - *The geographic location* of the property and the subsequent outside temperature: A property located in Auckland will require heaters with a smaller kW rating than one in Invercargill.
  - *The level of insulation* of the property / room: A well-insulated property will require heaters with a smaller kW rating than a poorly-insulated one. Similarly, a room with three external walls and/or larger windows will require a heater with a larger kW rating than one with only one external wall and/or smaller windows.
  - *The achieved room temperature* of the property: Achieving a steady room temperature of 21^{o}C will require heaters with a greater kW rating than achieving a steady room temperature of 17^{o}C.

The overall heat load of the property – i.e. the total annual kWh of energy required to heat the property – will be driven by all the above factors plus:

- ***The heating regime*** of the property: A property which is heated 24hr a day will have a significantly greater heat load than one which is only heated in the evenings. Similarly, a property where the bedrooms are heated a lot less than the living areas, will have a lower heat load than one where the whole house is heated equally.

The significant variation in the above factors can give rise to a significant variation in the number and size of heaters required, and the overall heat load of the property. Such variation can also give rise to material differences in which heating option is likely to be best for a particular situation.

In order to explore the potential difference in outcome as to which heating solution is best between different heating situations, twenty seven different consumer situations were considered, being the combination of:

- Three different locations (Auckland, Wellington, and Dunedin) which has a major bearing on the space heating load;
- Three different-sized properties ('Compact' = 80m^2, 'Typical' = 150m^2, and 'Spacious' = 250m^2) which has a major bearing on the number and size of heaters' required and on the space heating load; and
- Small, medium, and large heat loads for each of the above situations. This reflects differences in the desired heating regimes of different consumers (e.g. how hot to heat the house (e.g. 17^{o}C versus 21^{o}C)

and for how long (e.g. evening only, or all day)) and differences in the energy efficiency of the different properties.

The combination of different consumer situations is intended to capture a broad range of heating situations, and in particular the different cost-benefit outcomes that are likely to arise between heating options with different levels of capital intensity. Thus, an option with a high efficiency but high capital cost is likely to be best for situations with high heat loads, whereas situations with relatively low heat loads may not get sufficient running cost benefit from a high efficiency option to justify the higher capital cost.

Overall, it is considered that the heating situations considered span the full range of likely heating requirements experienced by the vast majority of New Zealand households.

Determining representative values for the overall space heating load

The analysis used the national average figures presented in the HEEP analysis as a basis[14], and factored them to the different locations such that the useful heating requirements for the upper North Island was materially less than in the lower South Island based on analysis Concept has done for EECA[15]. The heat loads for the different sized properties (compact, typical, and spacious) were scaled proportionately to the size of the property, and the values for the small to large heat loads were based on the distribution of observed heat loads from the HEEP study.

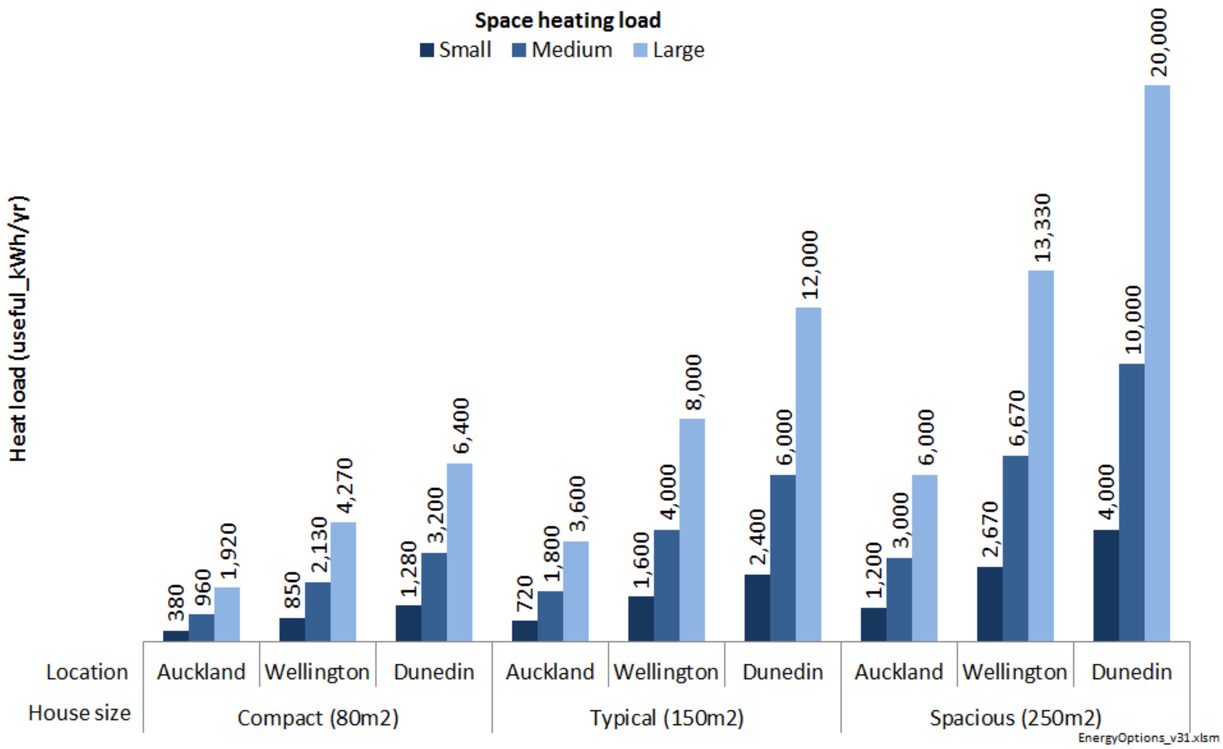
The resulting range of useful[16] heat loads is shown in Figure 16 below.

[14] Table 4 of HEEP 10 indicated that the average total household energy consumption across houses in the HEEP study was 11,410 kWh/yr, of which 34% was for space heating (as per Figure 14 of HEEP 10). Using information provided about the breakdown of the heat among appliance types and assumed efficiencies this results in an average useful heat load of ≈ 3,200 kWh/yr. The HEEP data set was more heavily skewed to properties north of Wellington. (i.e. consistent with the distribution of households in NZ). Taking this into account, and the house sizes in the survey, it was felt that 4,000 kWh/yr was a reasonable estimate for a medium useful heating load for a Typical-sized Wellington property.

[15] This analysis used output from EECA's ACCURATE model which it uses to model the heat loads for different property situations in different parts of the country.

[16] This report distinguishes between *useful* energy and *consumed* (a.k.a. 'delivered') energy. For example, if a consumer has a requirement for 1000kWh of useful heat, but an appliance which is only 85% efficient, then they must consume 1,000 ÷ 85% = 1,175 kWh of fuel.

Figure 16: Space heating load situations considered in the study



Source: Concept estimates

As can be seen, there is a huge variation in the quantity of heat energy desired by different consumers. This is consistent with the observations made in the HEEP study. This study observed that the 5th and 95th percentiles for *total* energy consumption (as distinct to just space heating) were approximately 4,000 kWh/yr and 24,000 kWh/yr, respectively.

Determining representative values for the 'shape' of load

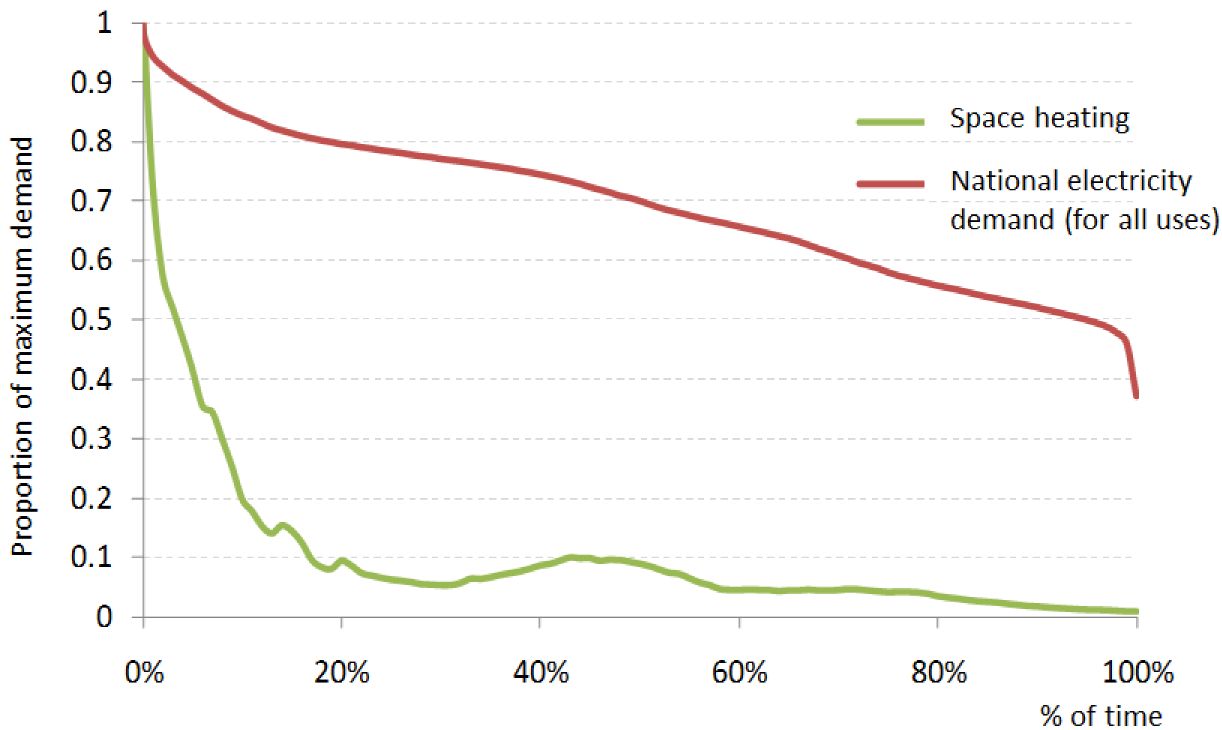
The 'shape' of demand – i.e. how much demand varies on a within-day and within-year basis – can have a material impact on electricity and gas price outcomes due to factors such as peaking wholesale costs, network costs, and emissions factors.

In order to determine appropriate representative values for the 'shape' of space heating load a bespoke model was developed.

This model took historic hourly temperature data readings from NIWA for the whole of 2008 for the representative locations, then apportioned the annual total kWh heating load proportionately to the difference in the external ambient temperature and desired internal temperature for each of the 8,760 hours where the temperature difference exceeded an x˚C threshold (where the value of x ranged from 8˚C in Auckland to 10˚C in Dunedin) . This was done for the four most common heating regimes identified in the HEEP study (1. Evening only, whole house; 2. Morning and evening, living room only; 3. Morning, day, evening, living room; and 4. 24-hour, living room + evening bedroom), and a weighted average heating load shape determined.

This load shape was grouped into 9 different time slots: Three within-day periods (Day, Night and Peak), for three seasonal periods (Summer, Winter, and Shoulder) for use in the analysis framework. A load duration curve shape was also developed through comparing the hourly heating load from the model with the actual hourly total national demand for the identical time periods. This is shown in Figure 17 below.

Figure 17: Comparison of the load duration curve (LDC) for national demand, and the derived coincident curve for space heating



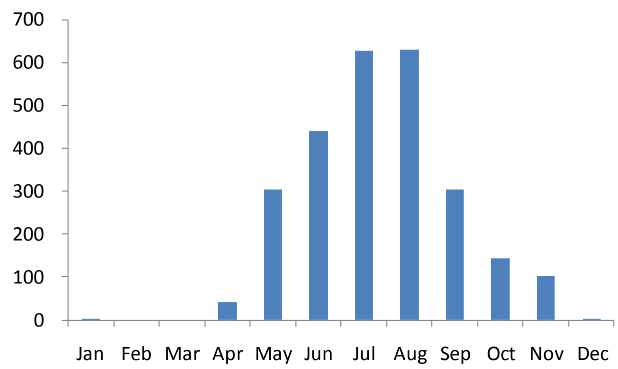
Source: Concept analysis

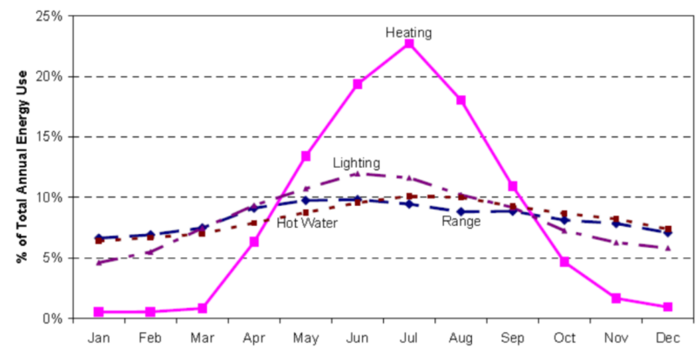
In order to cross-check the performance of this model, the monthly heat load output from the model was compared with the monthly heating profile produced in the HEEP analysis. This is illustrated in Figure 18 below.

Figure 18: Comparison of the Concept-modelled monthly space heating profile, and the HEEP-observed monthly space heating profile

Concept modelled monthly kWh heat load distribution for a medium Wellington heating load

HEEP analysis of energy use by end-use and month (Figure 17 of HEEP 10 report)





Determining values for the number and kW size of heaters for different situations

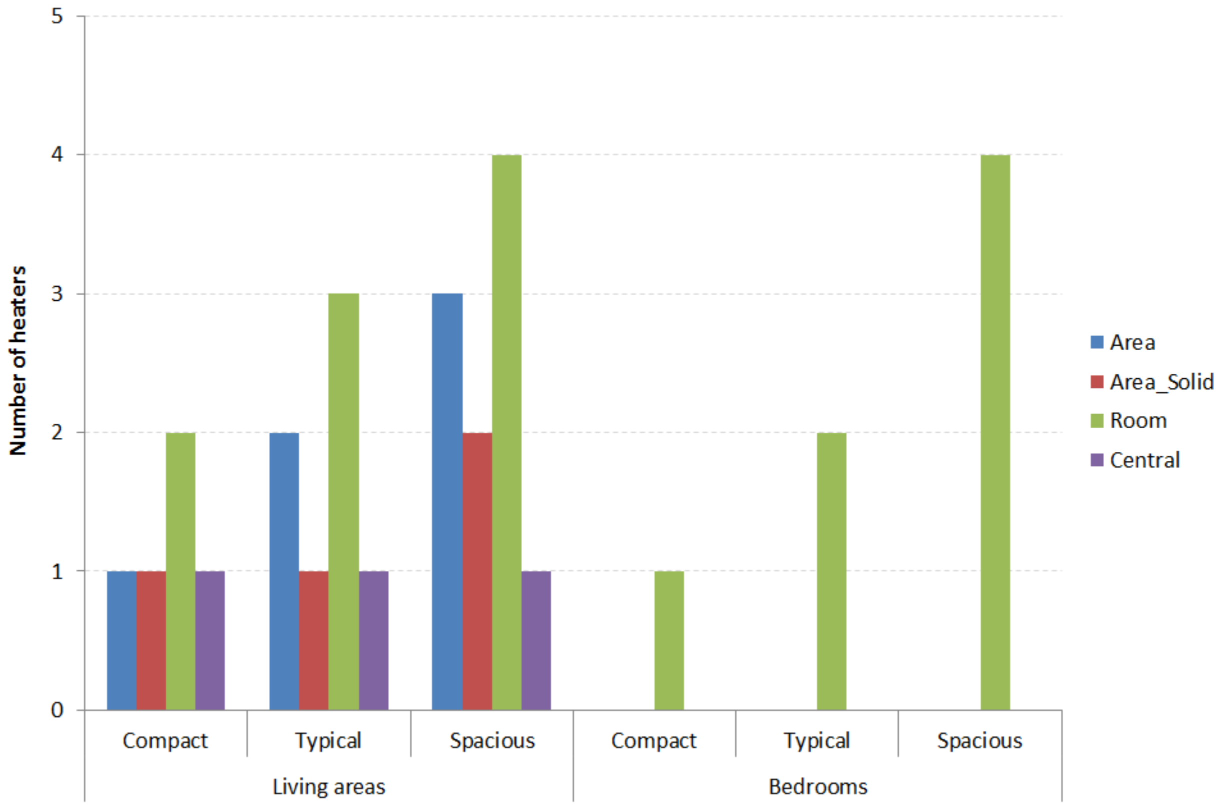
The model distinguished between the different types of heating approaches for the different technologies:

- 'Room' heating approaches consist of a smaller-sized heater in every room. This is typically the approach for electric resistance options.
- 'Area' heating approaches consist of a smaller number of larger-sized heaters located in strategic points around the house (typically main living areas and hallways outside bedrooms) which heat a larger area consisting of several rooms. This is typically the approach for heat pumps, solid-fuel heaters, and flued-gas heating solutions[17];
- 'Central' heating approaches consist of a single large heater, generally located on the outside of the property, with the heat ducted to the individual rooms.

Figure 19 below shows the assumptions used for each of these approaches.

[17] Note: For solid-fuel area heating options, it is assumed that there will be a smaller number of heaters, but with some room-to-room heat transfer ducting for the larger-sized properties.

Figure 19: Number of heaters assumed for the different heating approaches and house situations



Source: Concept estimates

The kW size of each individual heater is a function of:

- The size of the property and heating approach (Area, Room or Central);
- The size of the heat load

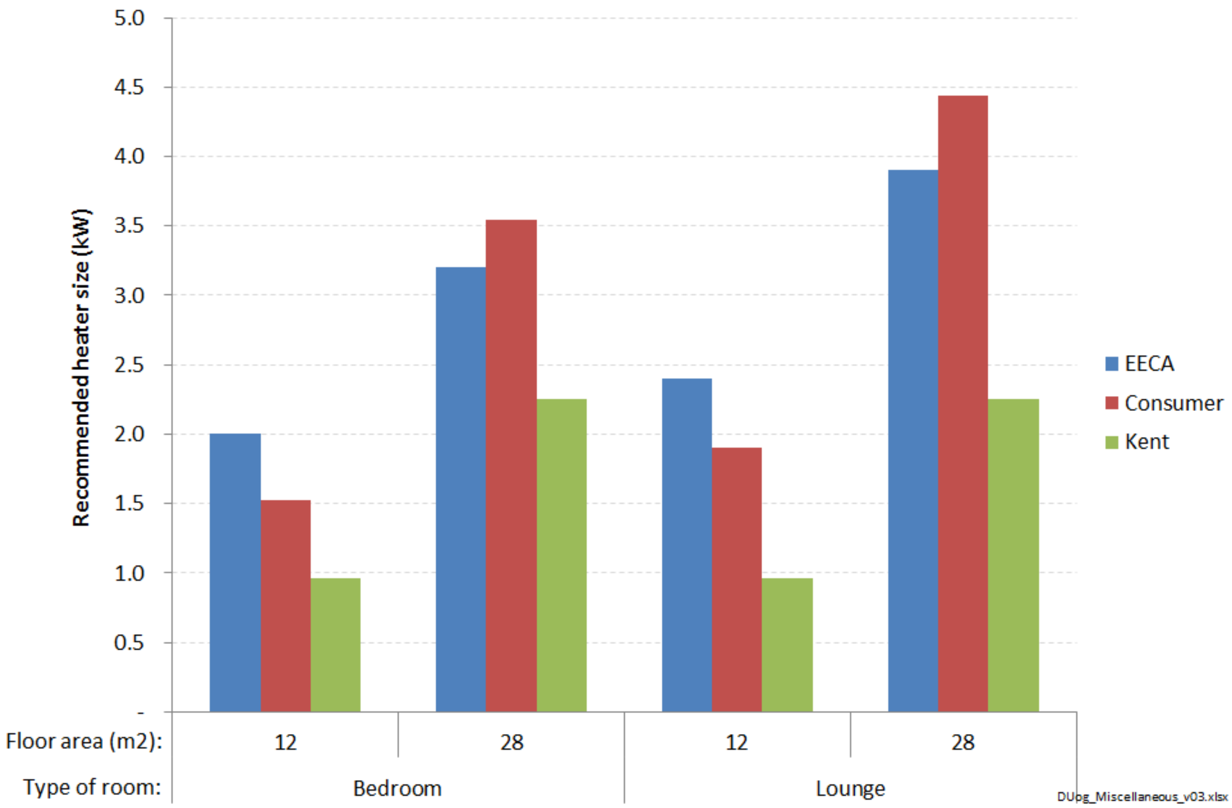
There appears to be a significant difference in views between different parties as to the appropriate size heater for a particular situation. For example, the following compares the recommended heater size for different room situations from three different New Zealand-based organisations / companies: EECA[18], Consumer[19], and Kent (a heater manufacturer)[20].

[18] http://www.energywise.govt.nz/how-to-be-energy-efficient/your-house/heater-sizing-calculator. The variables selected were: Wellington, Ceiling and/or Floor insulation, Two external walls, and Medium window size

[19] http://www.consumer.org.nz/reports/choosing-a-heater/choosing-a-heater#

[20] http://www.kent.co.nz/edit/ftpuploads/10751193_Heater%20Sizing%20Chart.pdf

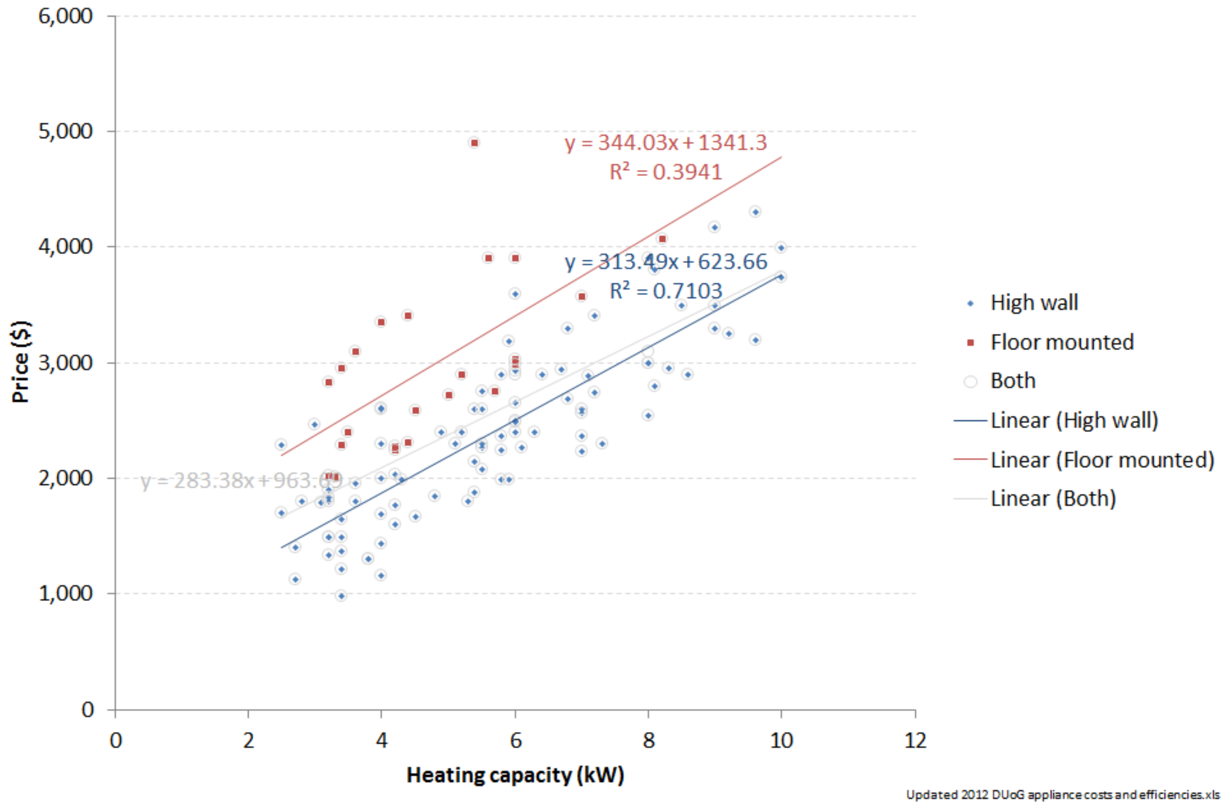
Figure 20: Comparison of recommended heater size from different organisations



As can be seen, there is not only variance in the size of heater recommended for different room situations, but the rate of increase in the required heater size with room size varies between organisation. Thus, Consumer and Kent have the required heater size increasing in direct proportion to the room size, whereas EECA has the required heater size increasing at 70% of this rate. It is not known what is driving these significant differences between these different organisations.

These differences will matter to a certain extent, as larger sized heaters will have a higher capital cost, as illustrated in the figure below showing the relationship between heater size and price for heat pumps.

Figure 21: Relationship between heat pump kW capacity and price



Source: Concept analysis using data from Consumer "Heat pumps" survey, 23 April 2012

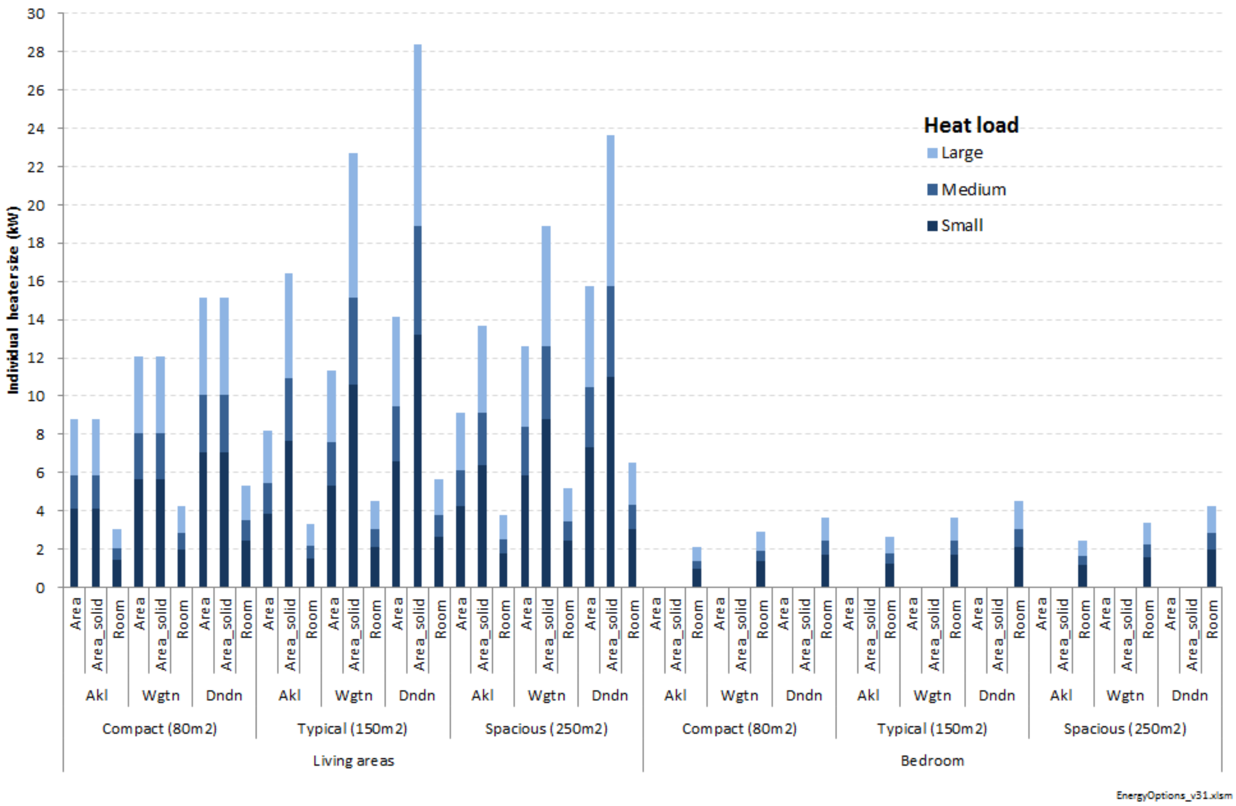
However, it is not considered that these differences will have a major impact on the overall results in terms of comparison between heat pumps and gas heating because:

- They will not alter the results relating to the *running* costs of the different heating options. This is because the analysis considers the running costs for given heat load situations, and the efficiency of the heaters is not considered to vary materially with heater size.
- The difference in capital and installation costs between heat pumps and flued gas heaters is not great. Thus, variation in the appropriate kW size for a particular heating situation as illustrated in Figure 20 is unlikely to alter the *relative* costs of heat pumps and flued gas situations.

However, such differences may alter the relative benefit between relatively high capital cost solutions (such as flued gas, heat pumps, and central heating), and low capital cost solutions such as standalone electric heaters and LPG cabinet heaters.

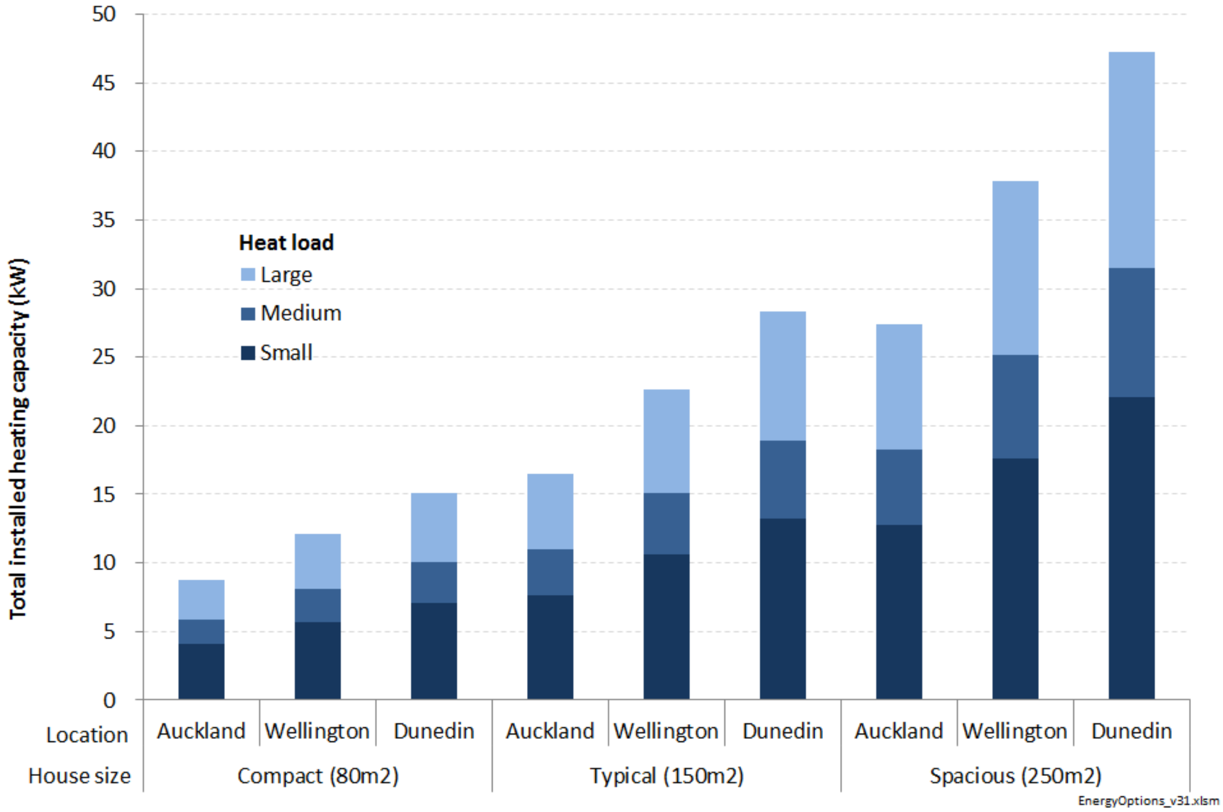
Figure 22 and Figure 23 show the values chosen for the heater sizes for the different heating situations and approaches.

Figure 22: Assumed individual heater sizes for different heating situations



Source: Concept estimate

Figure 23: Assumed overall installed heating capacity required for different heating situations



Source: Concept estimates

3.1.2 Fuel + space heater appliance technology characteristics

This section describes the various cost and performance characteristics of the different space heating appliances.

The analysis focused on a wide variety of different fuels and appliances. However, as with the water heating analysis, it was limited to those appliances which were considered sufficiently mature to be practicable options for consumers. Accordingly it did not consider a number of emerging technologies such as ground source heat pumps, and micro cogeneration.

Capital and on-going maintenance costs

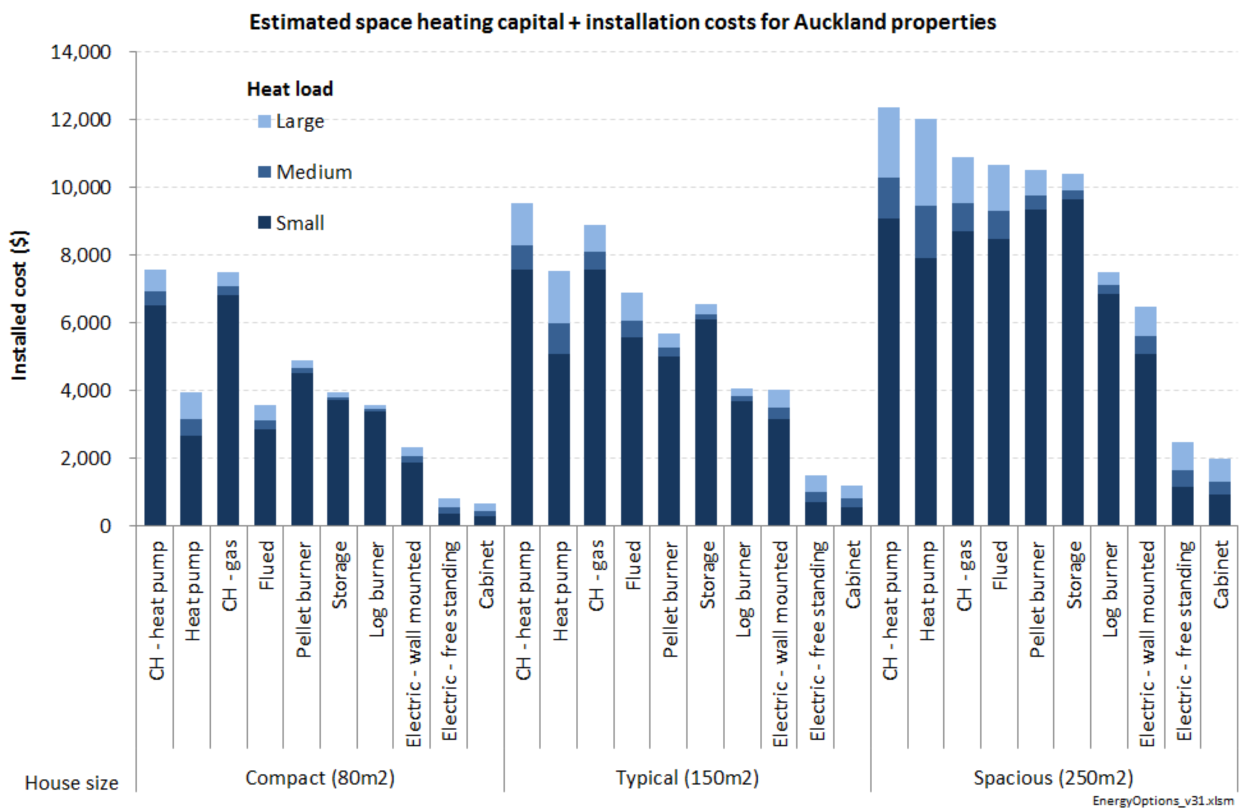
In order to estimate the capital costs of the different options, individual relationships were developed which simulated how such costs would vary with heater size, number of heaters, and house size for each of the different appliances. This is because:

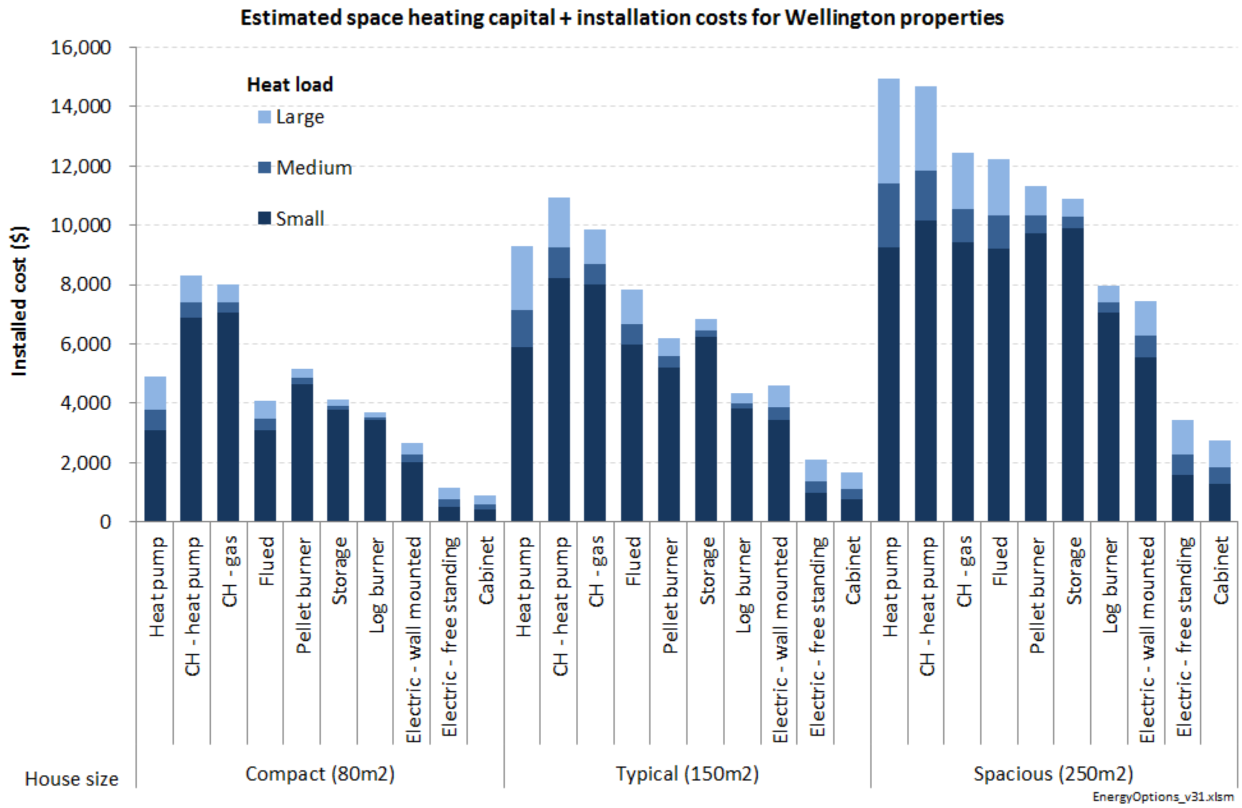
- All such factors can impact materially on both the capital and installation costs of space heaters; and
- The rate of increase of such costs for each of the above factors will be different for each appliance. For example, central heating options start with a relatively high fixed cost, but then increase with house size at a lower proportional rate than those options which consist of individual room heaters.

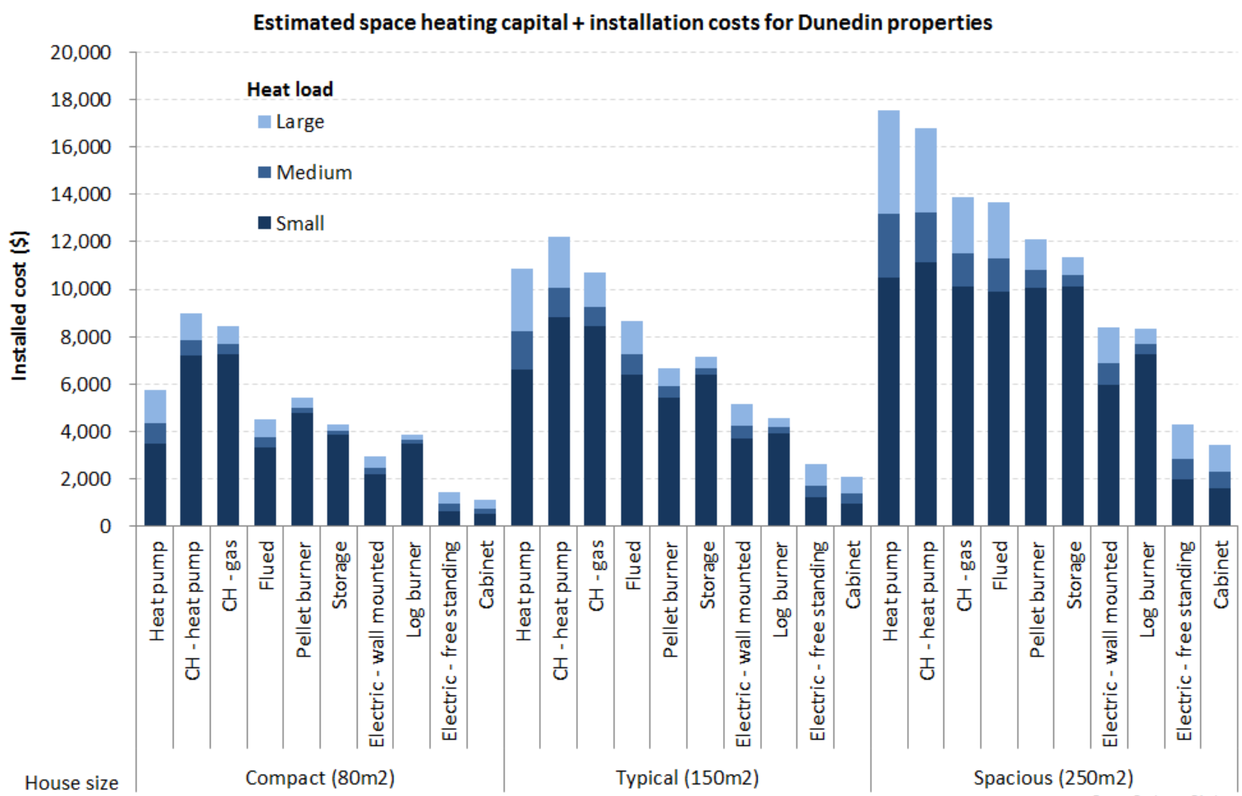
A further complication is that for a given technology there is often significant variation in the purchase and installation costs for a given type of appliance across different brands, retailers and fitters. The values used in the analysis have been chosen as representative median values based on data sourced from a variety of retail websites and discussions with representatives from companies which install such appliances.

Figure 24 below shows the capital and installation costs used for the study.

Figure 24: Estimated space heating capital + installation costs for different locations







Source: Concept estimates based on a variety of different sources

Another complication is that the expected useful life of appliances (i.e. the time they are expected to last before they will need replacing) varies between appliances. Thus, relatively complex appliances which have a lot of moving parts, and/or those which are located outside, generally require replacement much earlier than those which are relatively simple and/or are located inside.

This has been addressed within the analysis by applying different end-of-life factors to the up-front-costs of the different appliances to reflect the time-discounted replacement costs that will likely be incurred in the future. Simple appliances such as log-burners are assumed to have much longer useful lives than more complex (and exterior located) appliances such as heat pumps.

The end-of-life factors assumed for the analysis are set out in Table 3 below. An 8% discount factor was used. Such end-of-life factors were applied to the capital & installation costs shown in Figure 24 above.

Table 3: Assumed end-of-life factors to apply to the initial capital and installation costs of space heating appliances

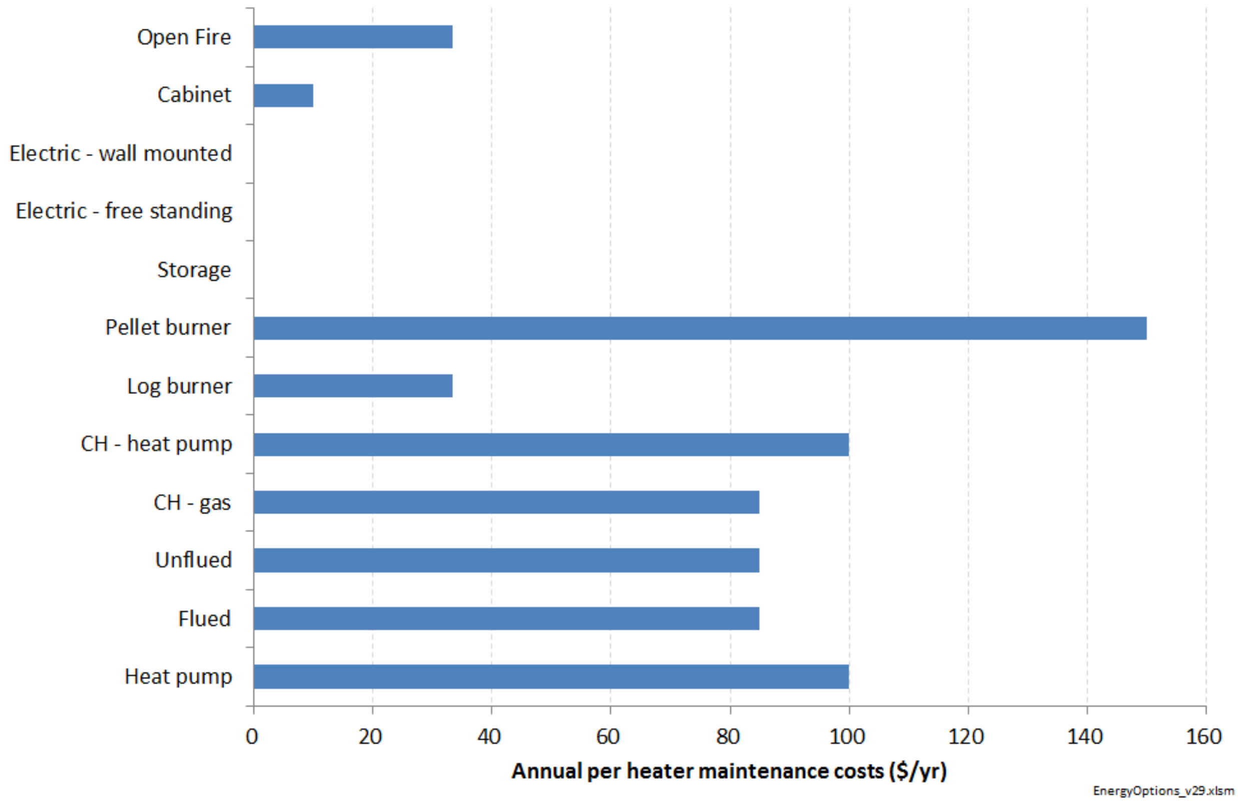
Appliance	End of life (years)	Proportion of costs requiring replacing	Resultant end of life factor[21]
Heat pump	12	70%	28%
Flued	22	90%	17%
CH - gas	18	60%	15%
CH - heat pump	12	60%	24%
Log burner	30	90%	9%
Pellet burner	25	90%	13%
Storage	30	100%	10%
Electric - free standing	25	100%	15%
Electric - wall mounted	30	100%	10%
Cabinet	25	100%	15%
Open Fire	100	100%	0%

Source: Concept estimates

The model also considered the annual maintenance costs associated with the different types of heaters in terms of getting heaters serviced, chimneys cleaned, and the like. These are shown in Figure 25 below.

[21] This is the percentage of the initial capital and installation costs which added to calculate an appropriate 'whole-of-life' capital and installation cost estimate.

Figure 25: Assumed annual maintenance costs of the different space heating options



Source: Concept estimates

It was assumed that in situations where a property was assumed to have multiple heaters, there would be between a 10-15% discount on the maintenance cost of subsequent heaters.

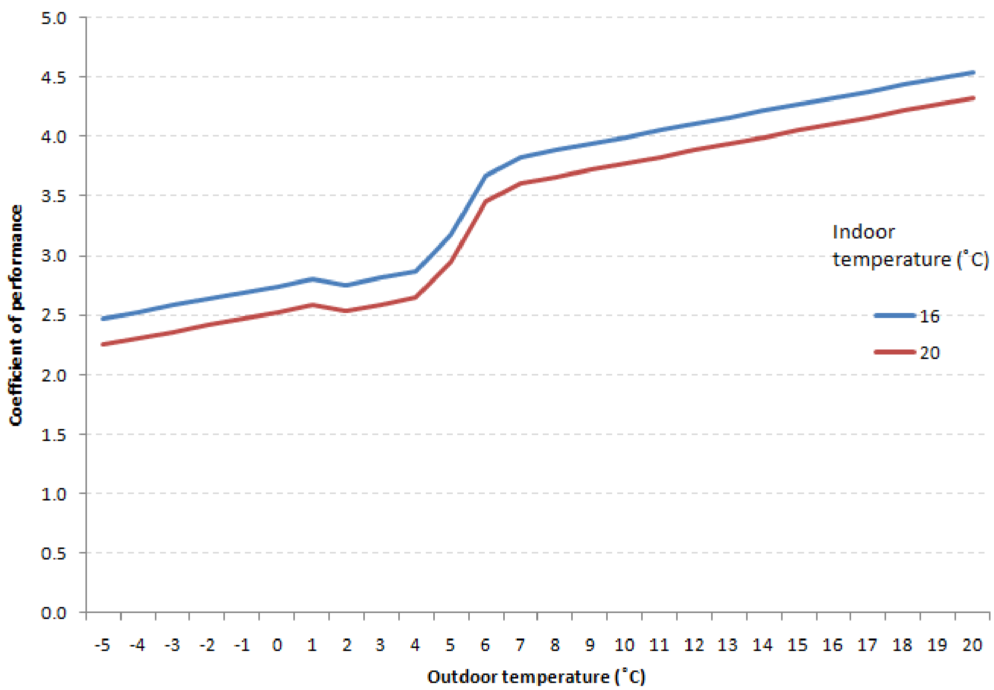
Heater efficiencies

For most appliances, the efficiency is relatively straightforward to determine. Thus, electric resistance heaters are 100% efficient, whereas the likes of a gas heater will be about 85% efficient. However, the efficiency of heat pumps depends on the ambient outside air temperature, and hence will vary according to geographic location.

The coefficient of performance (COP) of a heat pump is a function of the desired indoor temperature and the ambient outdoor temperature, and deteriorates as the temperature range increases. Different models of heat pump exhibit different levels of performance at different temperatures. In particular, different models suffer different degrees of degradation in performance due to freezing around the 'dew point' of air (in the 0˚C to 5˚C range).

For the analysis, an algorithm was developed which represented the typical COP of a heat pump as a function of indoor and outdoor temperature. The representative COP curve for two indoor temperatures is shown in Figure 26 below. In developing this curve the baseline COP at 7˚C / 20˚C (ambient / indoor) was derived from the average of all EnergyStar rated heat pumps published by EECA.

Figure 26: Heat pump coefficient of performance curves

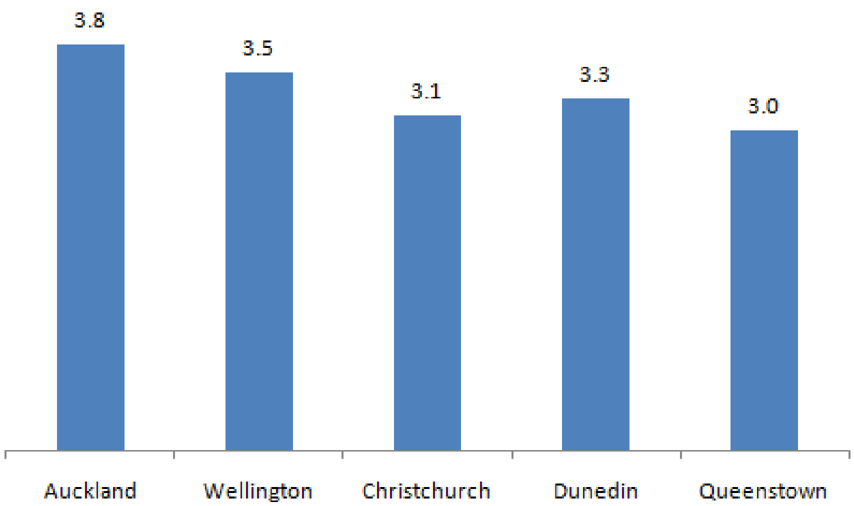


It should be noted that some of the most modern heat pumps have COP curves which are superior to the one shown above, in particular with minimal COP drop-off around the dew point, but equally some also have COPs which are inferior.

Given that different locations will have different ambient temperatures, the average COP of a heat pump will be different for these different locations. Accordingly, in order to determine a load weighted average coefficient of performance for heat pumps for each location, and heating load, the bespoke model described in Section 0 was used, using actual hourly ambient air temperature recordings for 2008.

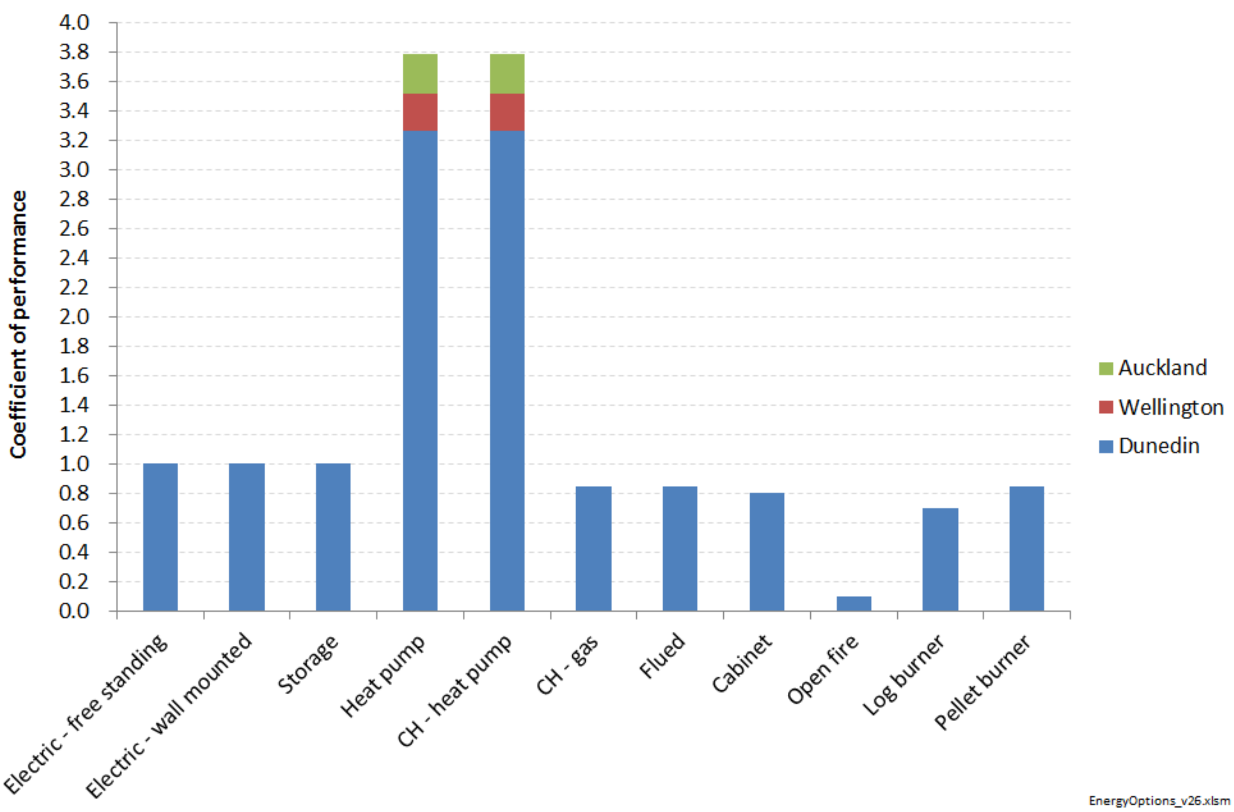
This was undertaken for five different locations (Auckland, Wellington, Christchurch, Dunedin, and Queenstown), with the results shown in Figure 27 below.

Figure 27: Weighted average COPs for five different locations for an 18 degree indoor temperature using 2008 hourly NIWA temperature data



The resulting assumptions for space heating appliance efficiencies are illustrated in Figure 28 below.

Figure 28: Space heating appliance efficiencies modelled within study



Source: Concept estimates

Fuel & CO_2 costs

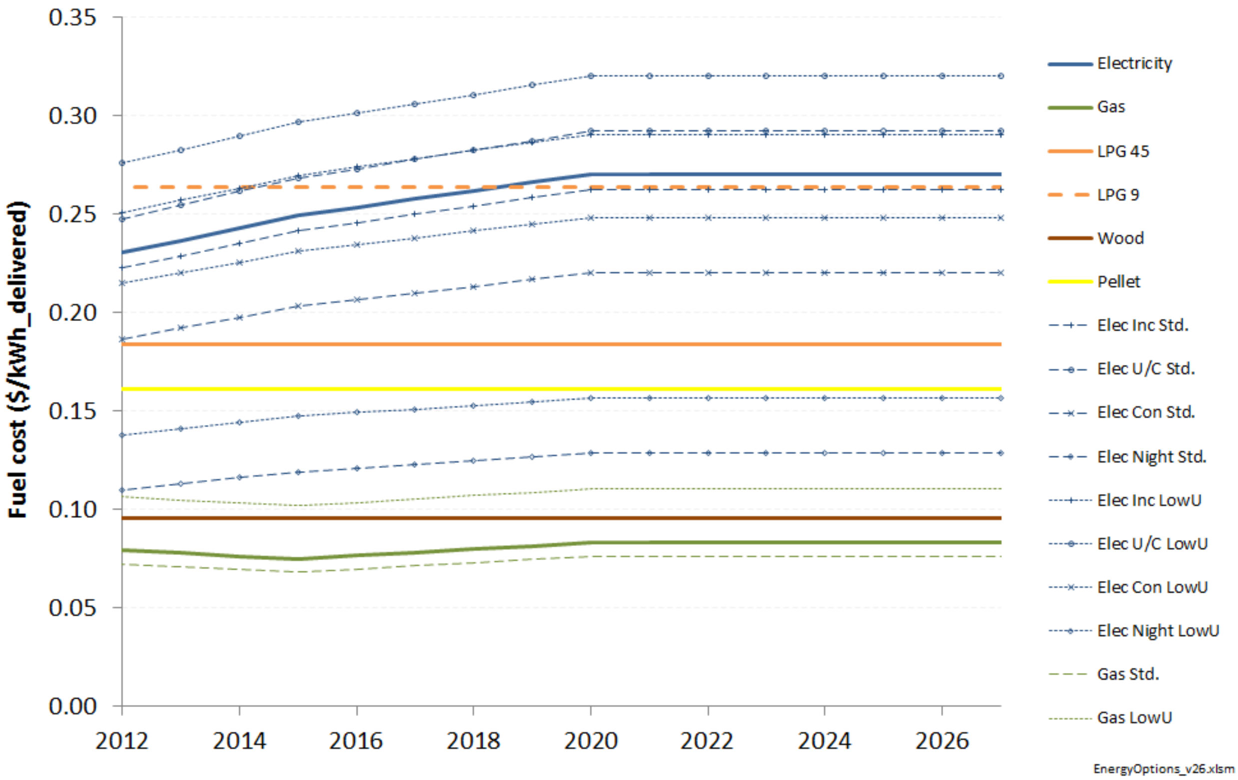
Appendix B and Appendix C set out the assumptions and analysis in relation to fuel and CO_2 costs.

As is detailed in the appendices, consideration of such factors is non-trivial due to:

- Variations in the cost structures between the different fuels including factors such as:
  - fixed versus variable charges
  - different rates for different types of electricity control tariffs
  - low-user versus standard user variants for electricity and gas tariffs
  - different costs at different times of the day and year for electricity and gas
  - the extent to which the split between fixed and variable costs may differ between the prices charged to consumers, and the underlying resource costs faced by New Zealand
- The likelihood that some fuels are likely to see prices move in the future by a greater amount than other fuels
- The fact that different types of electricity generation are likely to operate to meet different types of load, and thus result in different CO_2 emissions intensities. (i.e. an increase in electricity demand which only occurs in winter is likely to result in a different change in generating patterns (and hence emissions) than an increase in electricity demand which occurs at all times of the day and year).

Figure 9 below illustrates the variation in variable fuel prices between the different fuels.

Figure 29: Delivered consumer fuel price projections used within the study (incl. GST)[22]



Source: Concept estimates

As can be seen, on an input fuel basis, gas and wood are relatively cheap compared to electricity and LPG.

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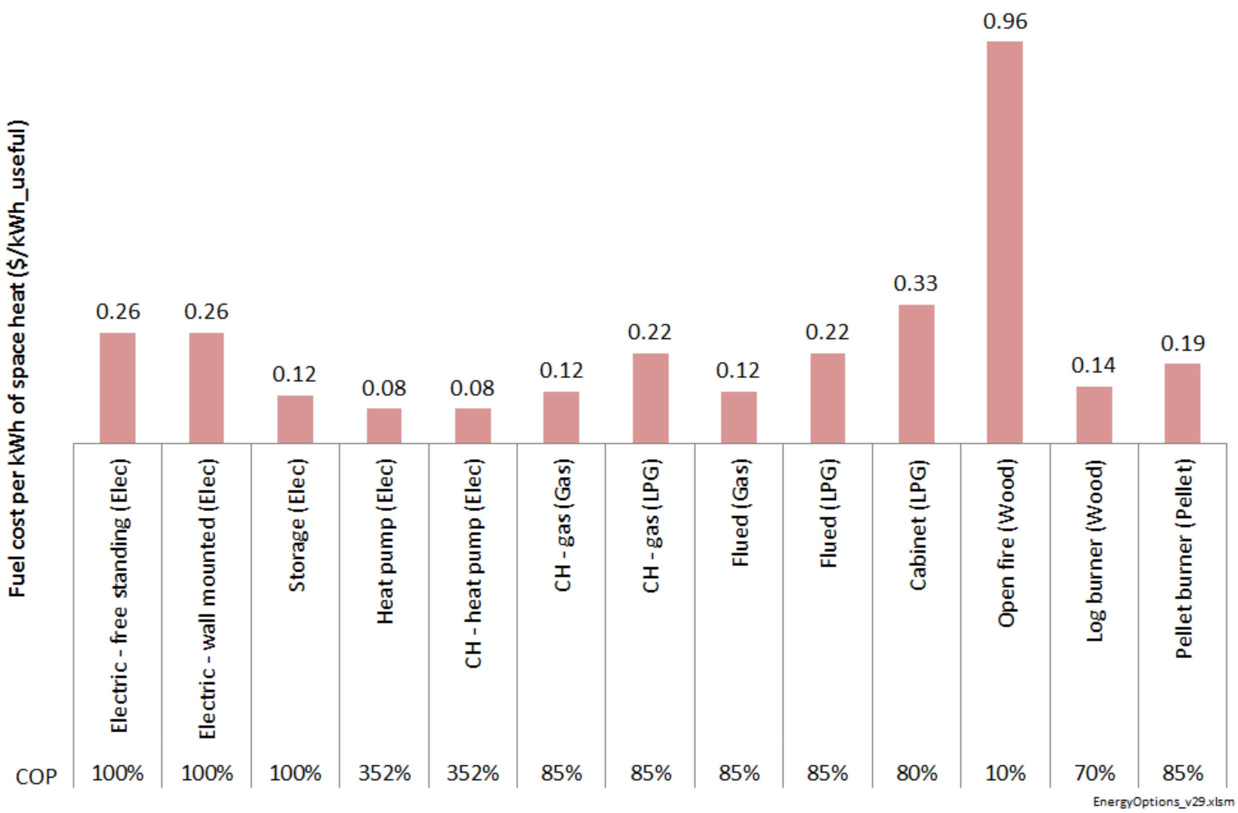
[22] For electricity and gas, the heavy solid lines represent the average price across the range of different tariffs, while the light dotted line represent the specific different prices for the different options. "Std" and "LowU" distinguish between standard and low-user options. For electricity the control types are defined as: "U/C" = uncontrolled, "Inc" = Inclusive control (i.e. for a single meter which has a mixture of controlled and uncontrolled load beneath it), "Con" = Controlled (i.e. all load beneath the meter is controlled), and "Night" = Night-only consumption. "LPG45" and "LPG9" refer to the price of 45kg and 9kg cylinders, respective. (With 9kg only being used for cabinet heaters).

However, once the coefficient of performance of the difference appliances is taken into account, the relative running costs of the different options can be very different, as is shown in Figure 30 below.

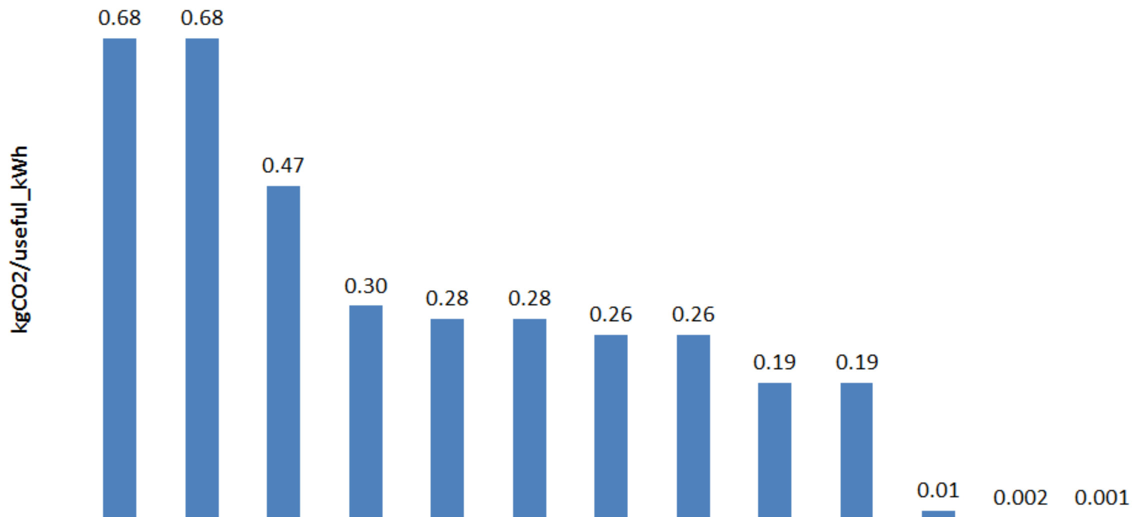
Figure 30: Fuel cost (energy + network) of useful space heat for a Wellington property



As can be seen, purely on a $/kWh variable fuel cost basis (i.e. ignoring capital and maintenance costs), heat pumps are the cheapest options, even though electricity is one of the most expensive fuels. Open fires are so expensive to heat a property because they are only 10% efficient.

Similarly, the different appliance coefficients of performance can have a major bearing on the effective CO_2 emissions profiles of the different space heating options as shown in Figure 11 below.

Figure 31: CO_2 emissions intensity of space heating options (kgCO_2/*useful*_kWh), assuming a central electricity emissions intensity scenario



Fuel	Elec	Elec	Elec	LPG	LPG	LPG	Gas	Gas	Elec	Elec	Wood	Wood	Pellet
COP	100%	100%	100%	80%	85%	85%	85%	85%	352%	352%	10%	70%	85%
Appliance	Electric - wall mounted	Electric - free standing	Storage	Cabinet	Flued	CH - gas	Flued	CH - gas	CH - heat pump	Heat pump	Open fire	Log burner	Pellet burner

Source: Concept analysis. Note: The heat pump COP chosen is for a Wellington location.

Overall, gas heating options appear to have similar (although slightly more) emissions as heat pumps, much less than electric resistance heating options, but more than wood and pellet-fired options.

3.2 Space heating results

The purpose of this analysis is to inform consumers facing a space heating decision which option is likely to be best. There are two principal types of consideration for this decision:

- Which option(s) are likely to deliver space heat at least cost?
- Which option(s) are likely to deliver the best non-price 'quality' benefits that may be of value to consumers?

To the extent that the best option from a cost perspective is not the best option from a quality perspective, consumers will need to make trade-offs.

3.2.1 Determination of least cost water heating options

The most useful metric to reveal which option delivers space heat at least cost is the *lifetime* cost per kWh of useful space heat delivered.

As is set out in detail in section 2.2.1 on page 23 relating to the hot water analysis, there are two key factors to consider in calculating this value:

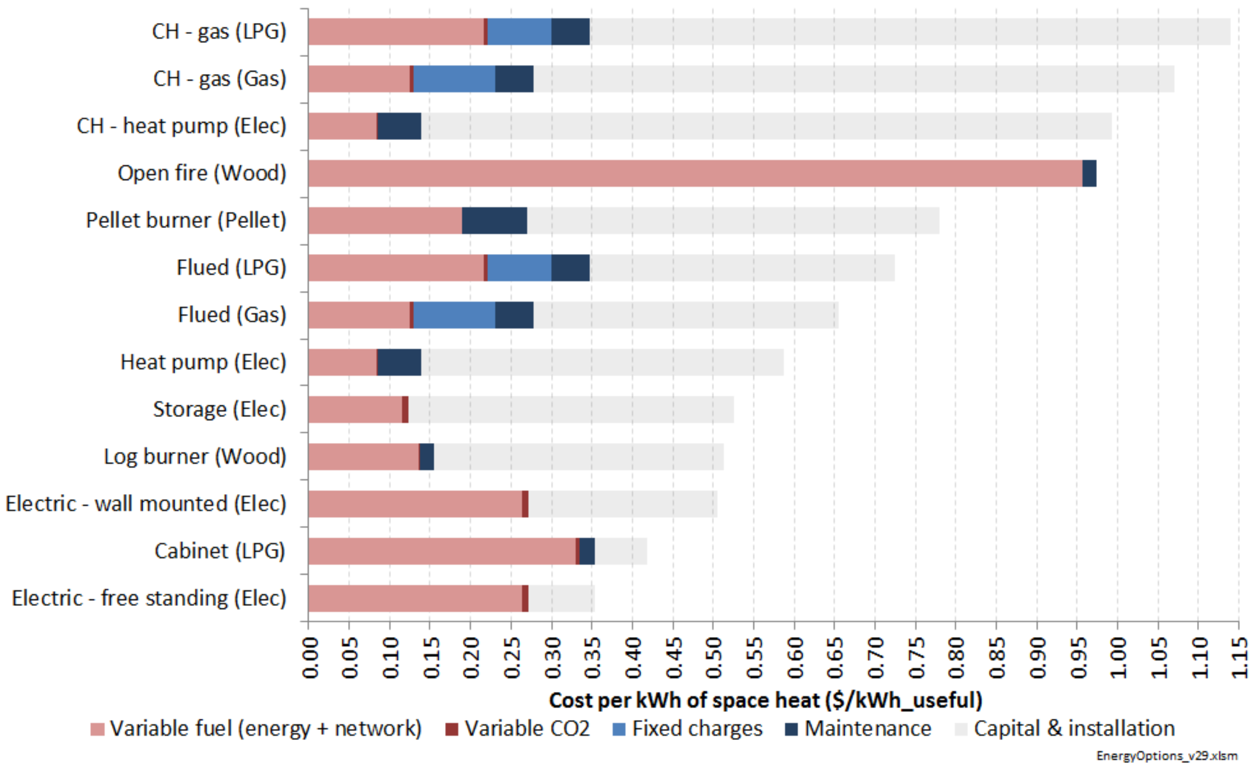
- The treatment of up-front capital costs and fixed costs
- The avoidability of different costs

The same fundamental approach to address these factors for space heating was adopted as for water heating:

- Up-front capital & installation costs were amortised over a ten year period, and this amortised number was divided by the annual kWh of useful space heat to determine the contribution of up-front capital & installation costs to the per kWh cost of useful space heat;
- Similarly any annual fixed costs (i.e. fixed gas / LPG supply charges and appliance maintenance costs) were divided by the annual kWh of useful space heat to determine their contribution to the cost of space heating; and
- Only those costs which are avoidable are included in the calculation:
  - electricity fixed charges are not considered in any evaluation of electricity space heating appliances, as a consumer will have electricity anyway;
  - gas or LPG fixed charges will be included, as a consumer can elect not to have any gas appliances. However, the framework allows such charges to be excluded to allow consideration of situations where the consumer will have gas anyway (e.g. for water heating or cooking); and
  - capital & installation costs are not included for situations where a consumer has an existing workable space heating appliance and is considering switching to a new appliance. (Although the capital & installation costs are included for the new appliance).

Figure 32 below shows the overall result of this analysis for different space heating options for a compact-sized property in Wellington with a medium-sized heat load.

Figure 32: Lifetime cost of space heat a compact-sized property in Wellington with a medium heat load (1,600 kWh/yr)



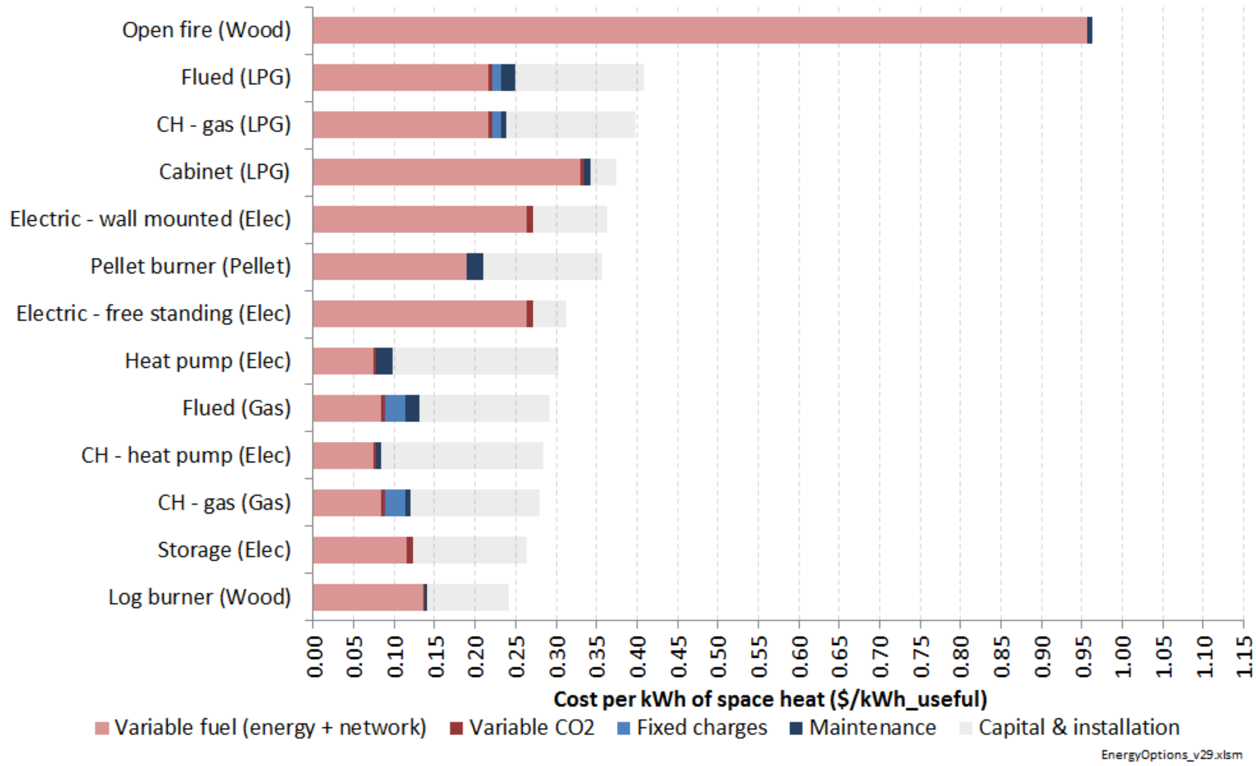
There are several important conclusions to draw from the above analysis.

- Firstly, capital & installation costs dominate the economics for this type of consumer with a relatively small heat load. This makes free-standing electric heaters the cheapest from a lifetime cost perspective, even though their running costs are almost double that of a heat pump;
- Secondly, gas fixed charges make just as big a contribution to overall costs as gas variable charges for small consumers – even though such consumers are assumed to be on the low-fixed charge tariff option;
- It is generally not economic for relatively small heat-load consumers with an existing space heating appliance to switch to the cheapest new appliance[23]. The main exception relates to open fires, and the other (very marginal) exception relates to LPG-fuelled heaters.

However, as the size of the heat load increases, the impact of capital costs and fixed charges on the per kWh of useful space heat falls. This can be seen in Figure 33 below

[23] For such a switch to be cost-effective, the solid red and blue bars for the existing appliance (but excluding the grey bar representing capital & installation costs) would need to be greater than the cheapest appliance including all costs (i.e. including the grey bar).

Figure 33: Lifetime cost of space heat a spacious-sized property in Wellington with a large heat load (12,500 kWh/yr)



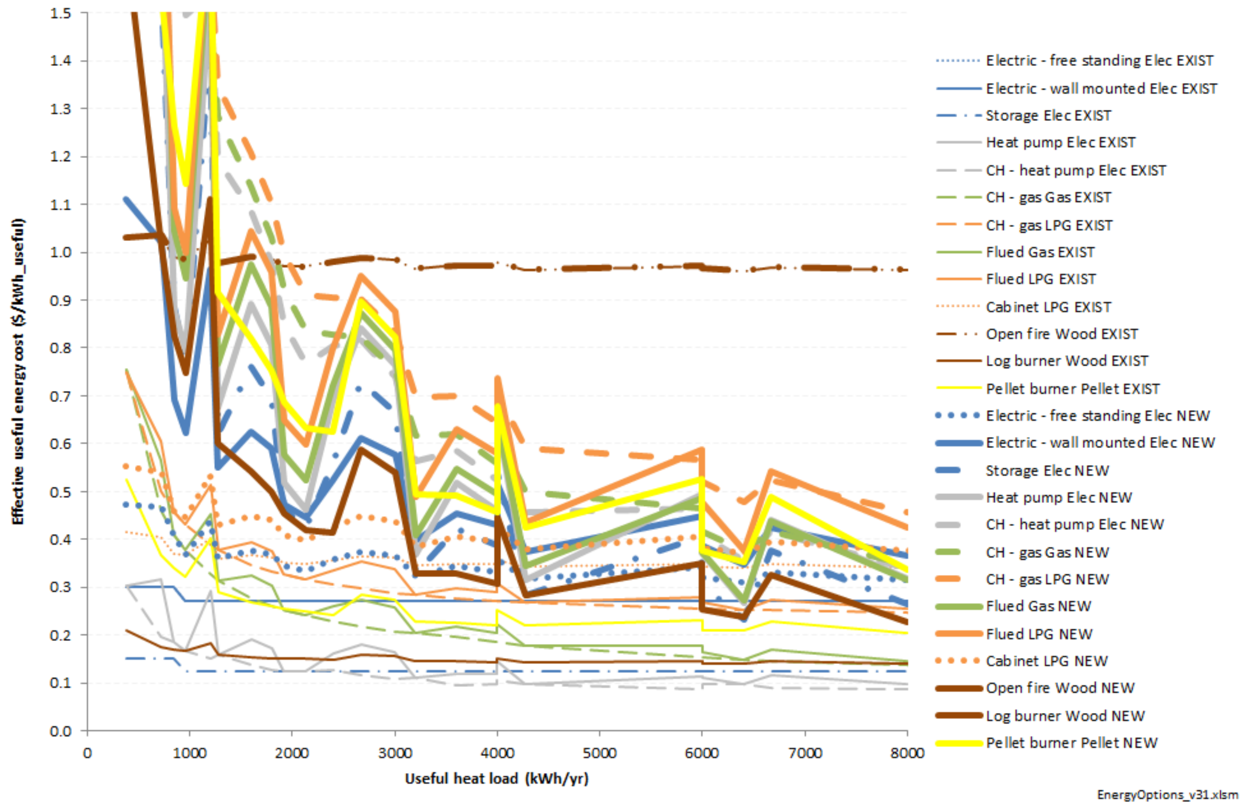
As can be seen, although the variable fuel & CO_2 costs are identical to the small heat load situation represented in Figure 32, the effective contribution of capital and fixed costs is much lower. This makes lower running cost but high capital cost options such as log burners, gas-fired heaters and heat pumps more cost-effective.

That said, if you have an existing space heating appliance it is still generally not economic to switch to the cheapest new appliance. The main exception relates to open fires, and the other (more marginal) exceptions relates to LPG-fuelled heaters and electric resistance heaters.

Although the per kWh contribution of capital & fixed costs has fallen for this larger heat load situation, it is important to note that such costs are still material. This is because the main driver for the capital & installation costs of space heating is the physical size of the house. Thus, although the heat load increases proportionately with the size of the house, so do the capital & installation costs (albeit at different proportionate rates for different heater types). Accordingly, compared with water heating, the contribution of capital and fixed costs does not fall by much if an increase in heat load is due to an increase in house size.

The relative cost of the different options for the consumer situation represented by Figure 33 has changed considerably compared with the consumer situation represented by Figure 32. And given the many different combinations of consumer situation (house size, insulation levels, heating regime, and geographic location) it is likely that the relative costs will change materially again for these different situations. Rather than produce individual bar graphs for each of the dozens of different consumer situations, Figure 34 below shows the *total* per kWh costs for all the different consumer situations and appliance options. The thick lines are for new-build situations (where capital & installation costs are included), the fine lines are for situations where the consumer is assumed to have an existing space heater (and thus capital & installation costs are excluded).

Figure 34: Effective useful space heating costs for different appliances and consumer situations including gas and LPG daily fixed charges[24]



Source: Concept analysis

This graph highlights the fact that the most cost-effective energy option is very situation specific by the fact that:

- Many of the lines cross-over as heat load increases – and thus the 'cheapest' option (being the lowest line) will similarly alter.
- The lines are very 'jagged'. This is due to similar-sized heat loads being considered for different property situations. (e.g. A large heat load for a compact (80m^2) Auckland property is very similar to a small heat load for a spacious (250m^2) Wellington property, yet the capital cost requirements for installing heaters in the different properties will be very different).
- There is a significant difference between the effective cost for existing heating appliances (where the capital costs are not included) and new-build situations.

Nonetheless, it is possible to draw some broad general conclusions:

- For a new-build requirement for medium to large heat loads, log burners are often the most cost-effective, followed by heat pumps and flued gas heating. However, the relative lack of controllability of

[24] 'CH' = Central heating

log burners (as outlined further in section 3.2.2 below), will likely mean this is not a valid comparison[25]. Accordingly, on a realistic like-for-like basis log burners' performance will be worse than this.

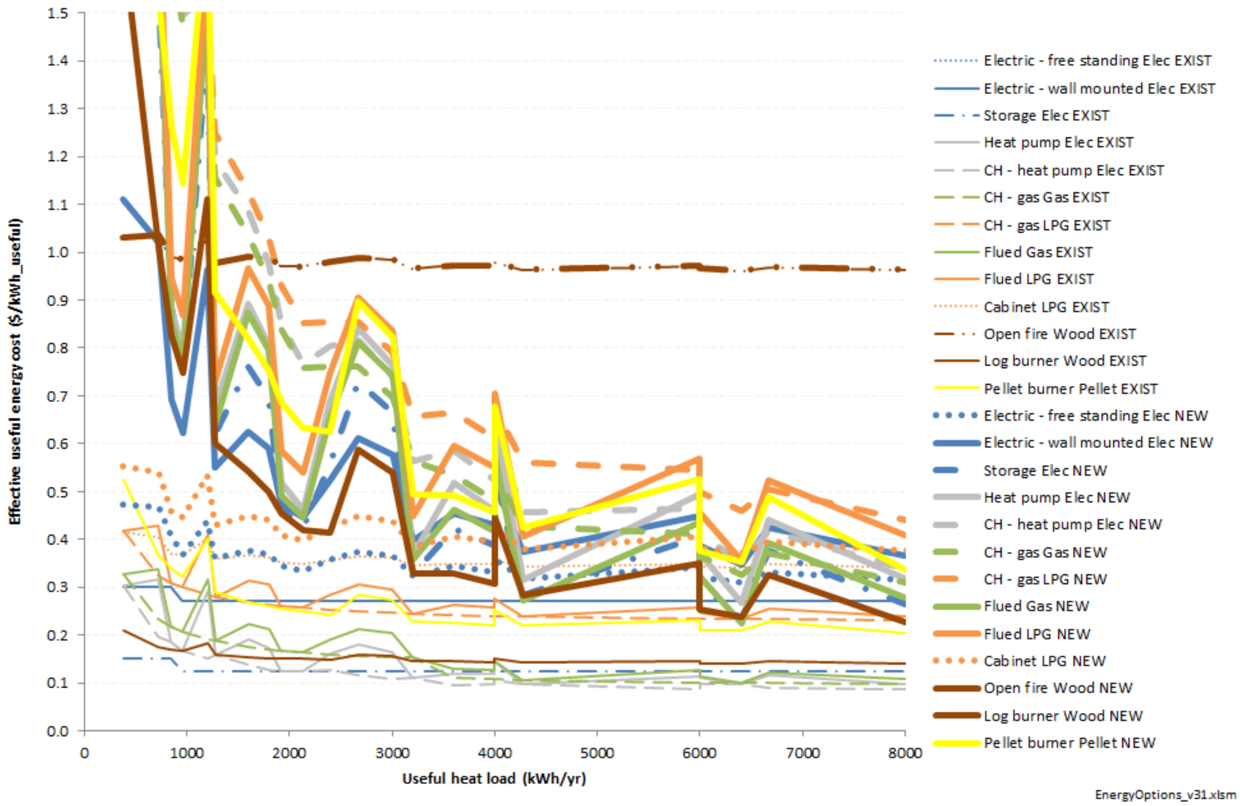
- For new-build requirements for small heat loads, free-standing resistance electric heaters (e.g. fan or oil column heaters), or LPG cabinet heaters are most cost effective as their very low capital cost more than outweighs their higher running costs. However, as noted in section 3.2.2 below, the un-flued nature of LPG cabinet heaters may mean they will be inappropriate for people with respiratory health issues.
- For someone with an existing functional space heating system, it is generally not cost-effective to incur the capital costs involved in switching to a new system as this will outweigh any potential benefit from reduced running costs[26]. The exception to this is for large heating loads for people with resistance electric heaters or LPG-fired heaters, where the relatively high running costs of such systems can make it cost-effective to switch away.

If a consumer is has gas connected for other purposes (e.g. water heating), then the daily fixed charges of gas supply should be excluded from an evaluation of the different space heating options. In such cases gas heating options become cheaper than the equivalent heat pump option for new-build situations. This is illustrated in Figure 35 below.

[25] It is inherently hard to control a log-burner so that it keeps a room at a constant temperature. Thus, typically rooms will be heated to greater or lesser amounts than desired.

[26] This is interpreted from the graph through looking at the effective cost for an existing appliance for a given heat load, and seeing whether there are any new appliance effective costs for the same heat load which are lower. Only for large heat loads for existing electric free standing / wall mounted or LPG heaters (the fine blue and orange lines, respectively) do the effective costs of such heaters rise above the cheapest new-build options (log burners, heat pumps and flued gas heaters to varying extents).

Figure 35: Effective useful space heating costs for different appliances and consumer situations <u>excluding</u> gas and LPG daily fixed charges



Source: Concept analysis

3.2.2 Consideration of the different 'quality' aspects of space heating options

Although the analysis in the previous sub-section has highlighted which appliances are likely to deliver heat at least cost, there are other non-price 'quality' factors associated with the different options that could be of value to different consumers and which will influence which option is best for their situation.

Table 4 below sets out the different quality aspects associated with space heating and which appliances fare better or worse against each measure.

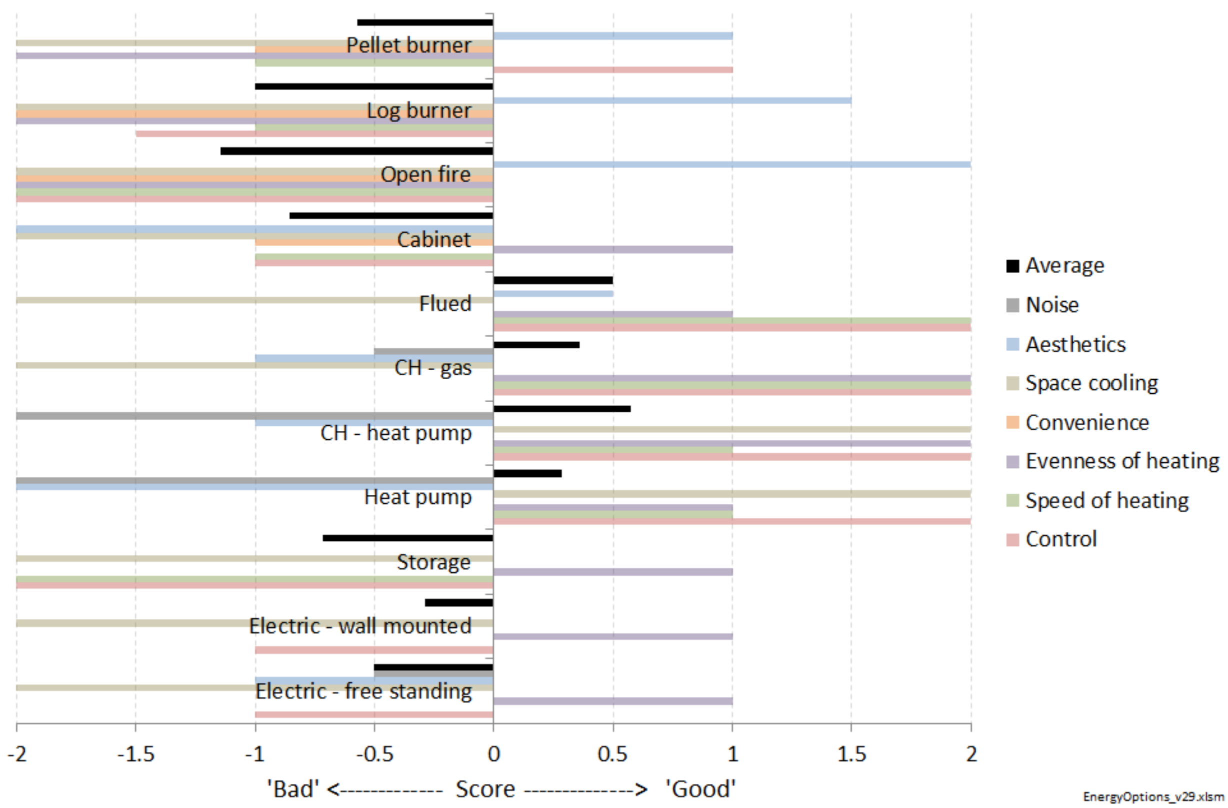
Table 4: Quality aspects of different space heating appliances

Quality aspect	Appliances affected
Evenly heating the whole home	Good for central heating. Worse for heating approaches relying on one or two large interior heaters, particularly log or pellet burners but also, heat pumps, or large flued gas heaters.
Delivering space cooling	Good for heat pumps
Speed of heating	Good for gas heating.
Controllability of heating / delivering heat when wanted	Not so good for log burners, night storage heaters, and some stand-alone electric heaters. All other options are capable of

	control via the use of thermostats and timers (of varying degrees of sophistication)
Aesthetics of a 'real fire'	Very good for open fires. Good for log-burners and flame gas fires
Visual aesthetics for house exterior	Worse for heat pump options requiring multiple exterior units (i.e. for larger houses).
Noise	A problem for some heat pumps.
Ease of use	Not so good for log-burners (requires fuel storage, and carrying sometimes heavy fuel). Similar for pellet burners
Respiratory health and dampness issues	Bad for un-flued gas and LPG options (including cabinet heaters).

In order to try and represent how the different appliances rate on quality overall, a 'score' was assigned to each appliance for each quality aspect. This score rated from -2 ('bad') through to +2 ('good'). A simple arithmetic average was also calculated across all quality aspects. The results of this exercise are shown in the following figures:

Figure 36: Simple scoring of space heating appliances for quality characteristics



Source: Concept estimates

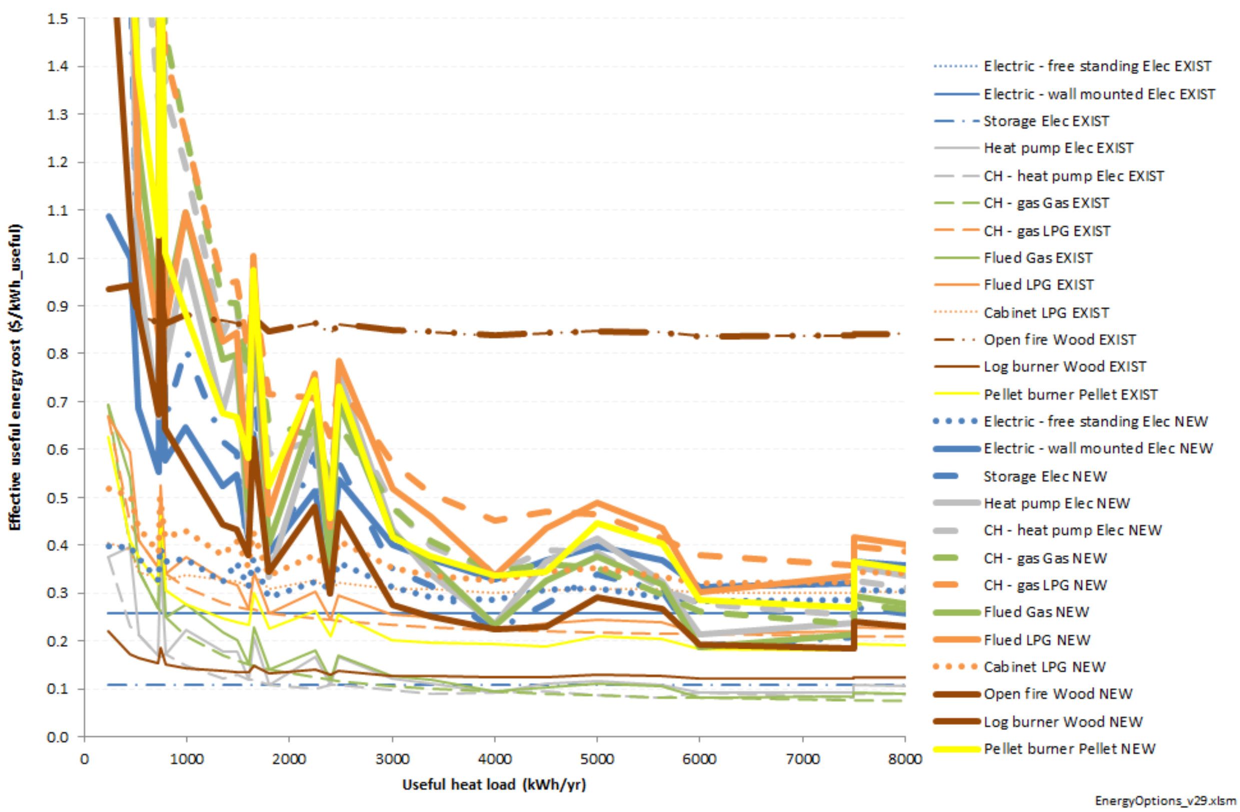
Although this exercise is highly subjective, and doesn't take into consideration that different people are likely to place different weights on the different attributes, it nonetheless suggests that gas and heat pump heating options overall score highest on these quality considerations.

3.3 Public versus private benefit outcomes

As set out in Appendix B, one of the main potential sources of distortion between public and private benefit outcomes relate to resource costs for electricity and gas provision having strong time-based drivers, whereas most mass-market consumers face prices which do not vary across the time of day and year.

However, it doesn't appear to materially affect the relativities of the different energy options such that materially 'wrong' choices will be made between heating types. This is illustrated in Figure 37 below which shows the effective useful space heating costs for different appliances and consumer situations based on the underlying resource costs to New Zealand. As can be seen, this is very similar in terms of the relative position of the different appliance cost lines to the analysis from the perspective of consumers as shown in Figure 35 above.

Figure 37: Effective useful space heating costs for different appliances and consumer situations based on underlying resource costs to New Zealand



Source: Concept analysis

That said, as set out in Appendix B, the distortion to prices will adversely affect consumers' incentives to implement energy efficiency measures relating to space heating.

As initiatives to improve the structure of the prices for electricity and gas networks are implemented, coupled with increased roll-out of time-of-use metering and tariffs, this distortion should progressively be corrected.

The other main distortion considered relates to the current measures under the New Zealand Emissions Trading Scheme which effectively halves the price of CO_2 faced by NZ participants, and caps it at NZ$12.5/t$CO_2$. While such measures are in place, this will distort the economics towards more CO_2 intensive options. However, the scale of distortion is relatively small given that CO_2 costs comprise a relatively small proportion of the overall effective costs of different appliance options, and the emissions intensity of heat pumps and gas heaters are relatively similar. Further, while international CO_2 prices are at their current very low level, the distortion is even smaller still.

4 Industrial / commercial boilers

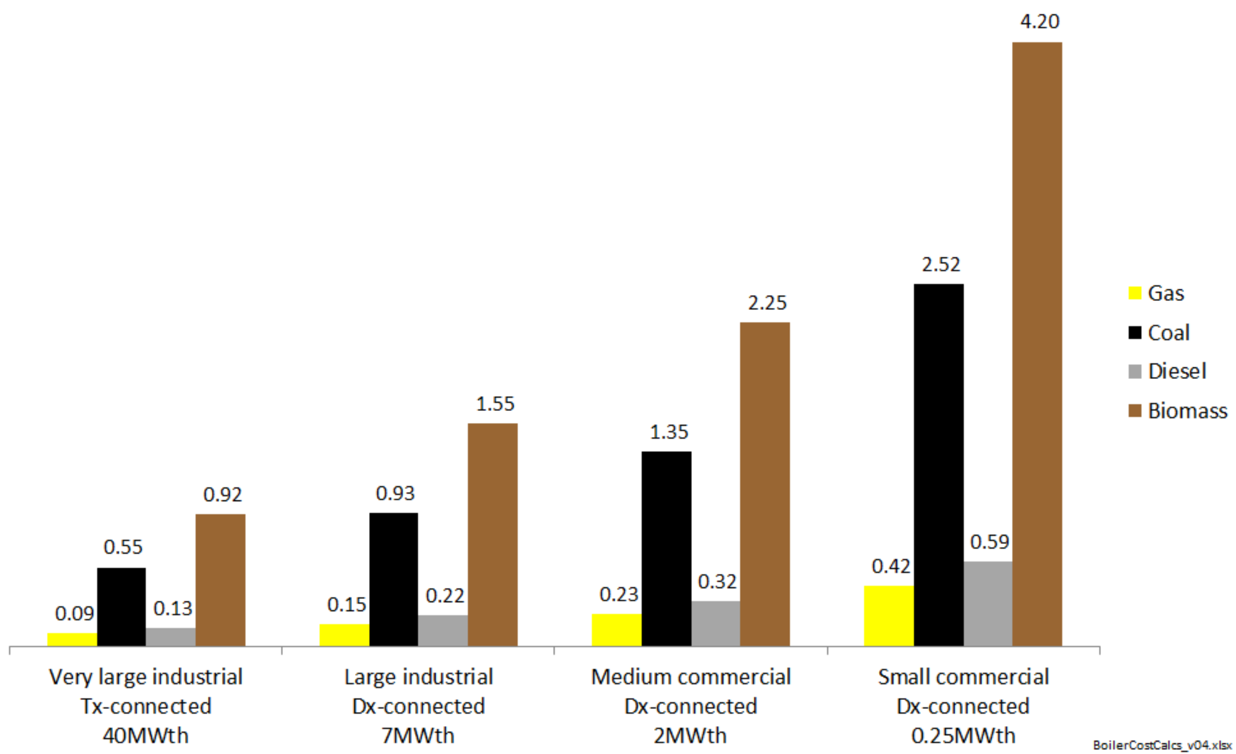
4.1 Approach and assumptions

The original 2009 study only considered the variable fuel & CO_2 costs for intermediate process heat boilers.

For this 2012 study, the capital and operating costs of the different boilers were also considered. In undertaking this analysis, information was sourced from consumer industry representatives who own and operate such boilers, as well as technical experts within EECA who provided information and reviewed assumptions obtained from other sources.

Figure 38 shows the estimates of the capital costs of building new boilers for different fuels and boiler sizes

Figure 38: Estimated boiler capital costs for different sized intermediate process heat boilers ($m/MWth)



Source: Various industry estimates

There are two key conclusions to be drawn from this information:

- Coal and biomass process heat boilers cost significantly more than gas-fired boilers. This is due to their more complex boiler designs required to handle solid fuel, and the need for more costly fuel and ash-disposal management systems.
- There are significant economies of scale associated with process heat boilers.

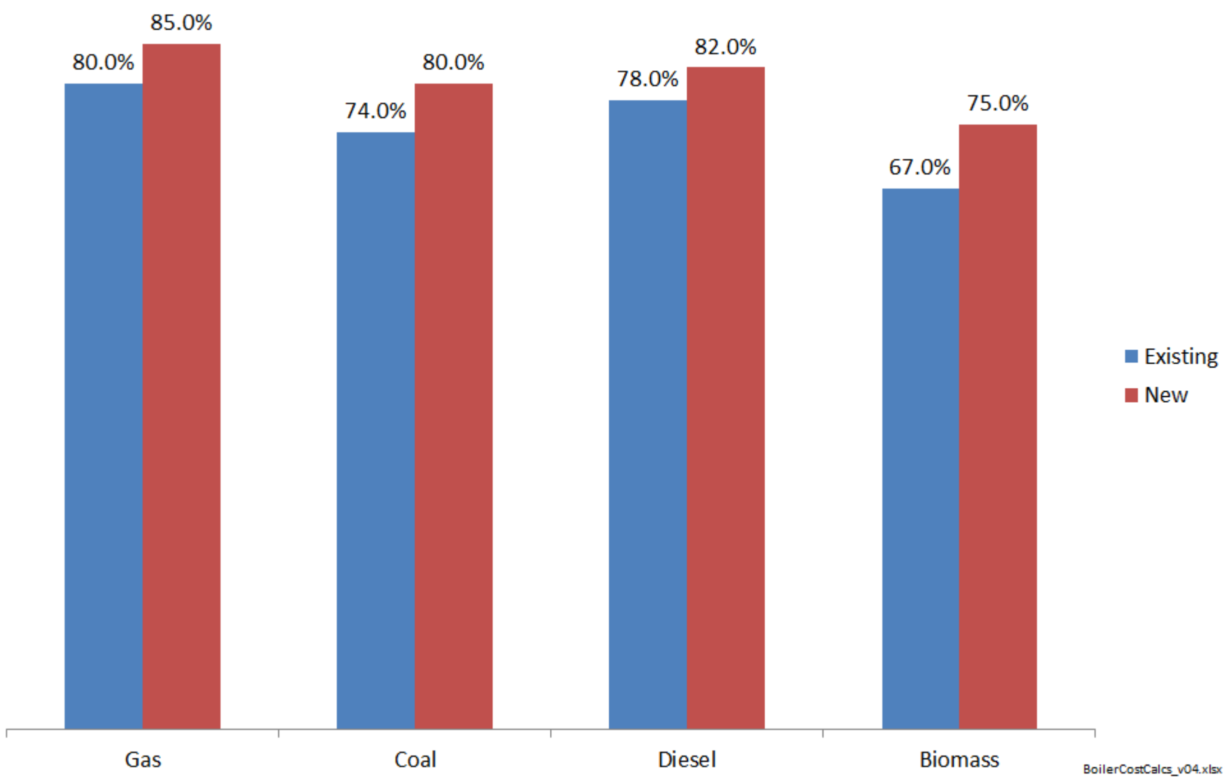
In relation to the annual non-fuel operating costs, an industrial stakeholder who operates many different-sized boilers using a range of fuels suggested that a good rule of thumb for such costs for a new boiler was that they amounted to approximately 2% of the up-front capex.

For existing boilers of a reasonable age (e.g. 15+ years), it was estimated that the operating costs could be three times greater than for a new boiler.

It was also estimated that for a large industrial boiler operating to a reasonably high load factor (60%), approximately 50% of the non-fuel operating costs would be fixed, with the remaining operating costs varying in direct proportion with the number of hours of operation.

With respect to the efficiencies of such boilers, EECA provided updated data which suggested that the original 2009 study used overly generous values with respect to the efficiencies of solid-fuelled plant (i.e. coal and biomass). The new data is presented in Figure 39 below.

Figure 39: Average intermediate process heat boiler efficiencies



Source: EECA estimates

Solid-fuelled boilers suffer a material efficiency impact compared with gas and diesel-fired boilers. This is largely because a gas flame burns much more cleanly and can be more easily controlled compared to the variability and moisture in solid fuel combustion. The effects of fouling from ash and soot also play a part in making solid fuel combustion less efficient than gas.

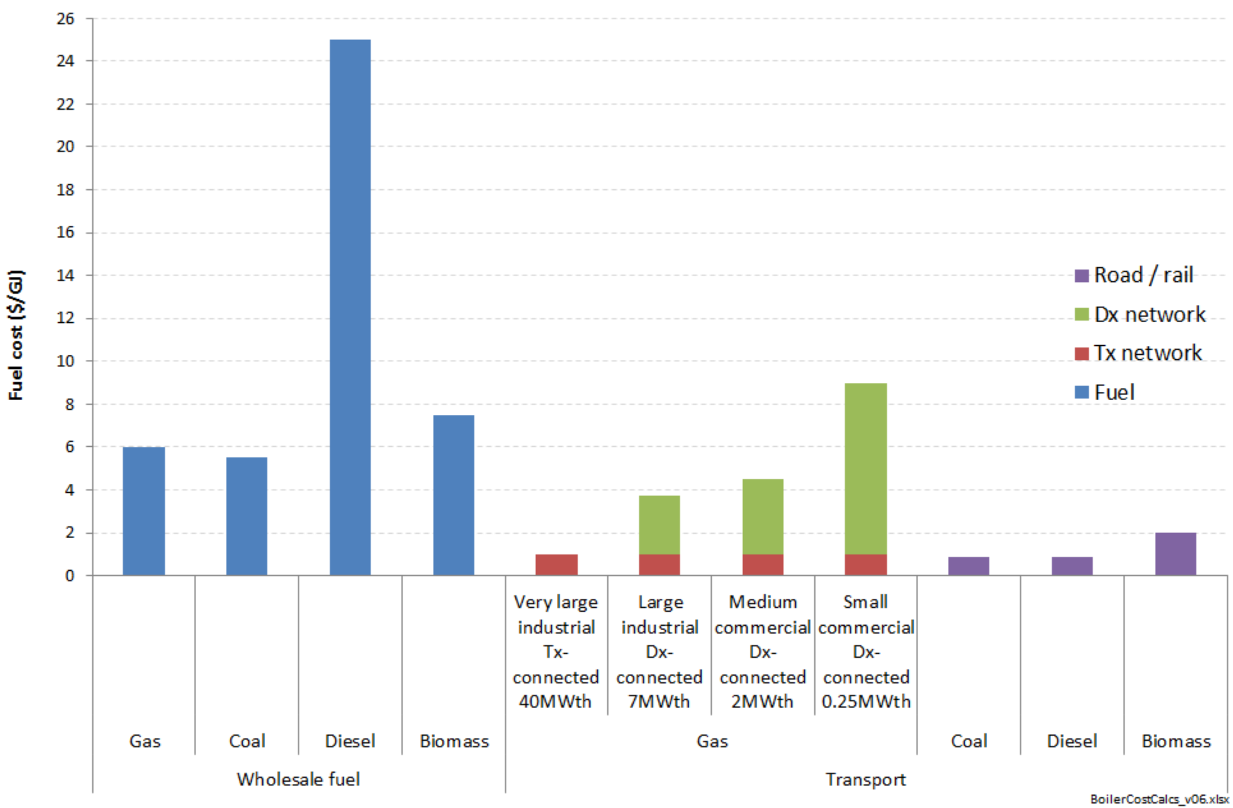
It is also the case that there is often a material difference between the efficiency of a new boiler, and that of an older boiler. This is due to modern boilers having better control systems, and being more likely to be well-maintained.

While the above efficiencies are based on industry averages from a wide variety of different sources, it should also be noted that the specifics of how a boiler is operated and maintained can have a major impact on the efficiency achieved. Thus, a poorly maintained and controlled gas boiler can have a lower efficiency than a well-maintained and controlled coal boiler.

The other main drivers of the relative economics of different process heat boilers relate to fuel costs (wholesale and transport), and CO_2 costs.

Figure 40 below sets out the central assumptions with regards to fuel and transport costs.

Figure 40: Fuel and transport costs for different boiler options



Source: Concept estimates

There are some key take-aways from this data:

- Diesel fuel costs are so high that unless international oil prices move radically (the number shown in Figure 40 relates to an oil price of approximately US$100/bbl), it will not be an economic option relative to the other fuel choices;
- Gas transport costs start to become material for customers connected to the gas distribution network;
- Biomass transport costs are penalised relative to coal transport costs due to the much lower GJ/t energy density of biomass compared with coal.

With respect to CO_2 costs, in addition to the CO_2 price, the emissions intensity of the different fuels needs to be taken into account. These are set out in Table 5 below.

Table 5: Fuel emissions intensities (tCO_2/GJ)

Gas	Coal	Diesel	Biomass
0.0528	0.0912	0.0730	0

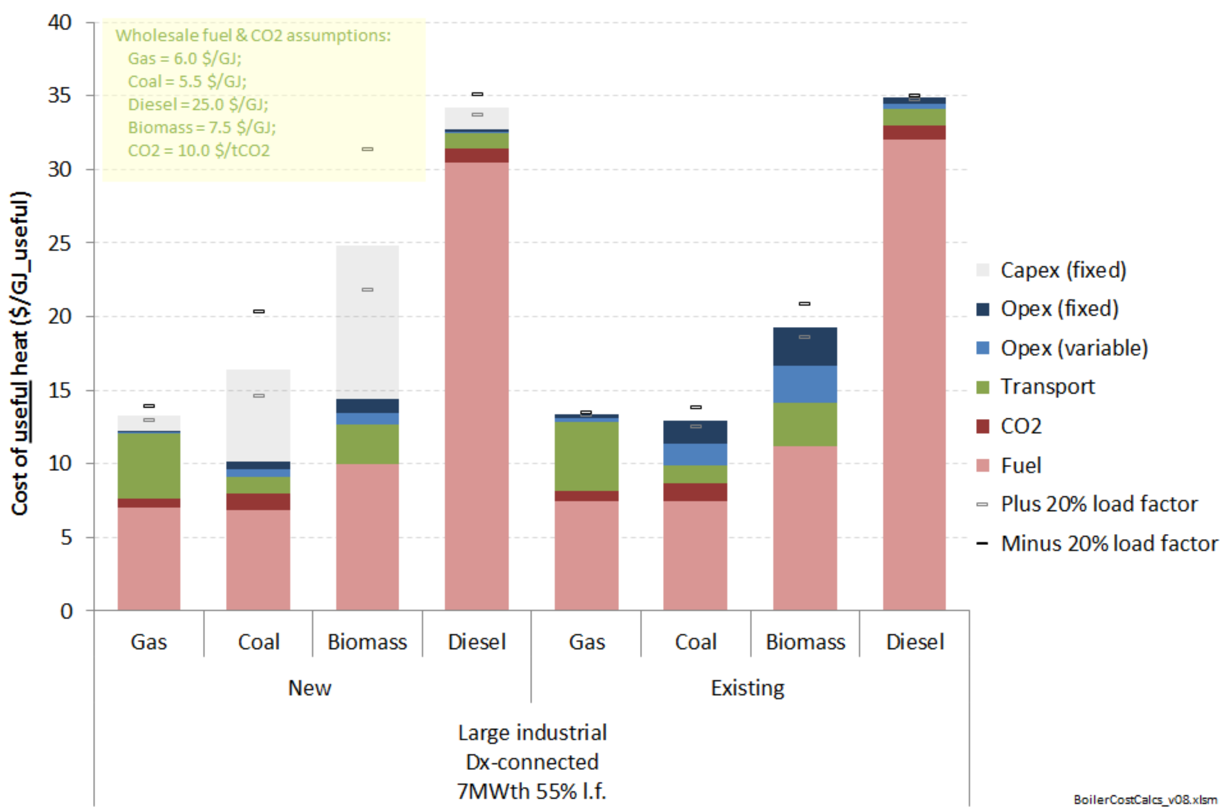
4.2 Industrial process heat results

The analysis combined all the above pieces of information to determine the lifetime $/GJ costs of providing useful[27] intermediate process heat from the different fuel options.

For the fixed operating and capital costs, a $/GJ value was calculated based on the assumed load factor of the boiler. In addition, the up-front capital costs were amortised assuming a 20 year capital recovery period and a discount rate of 10%.

Figure 41 below presents the results of the analysis for large industrial boilers, showing the costs of providing useful heat from the different fuel options for existing and new boilers. In addition to the cumulative bars, the chart also shows sensitivity values (shown as dashes) for how the total costs would vary with load factor varying by plus or minus 20% (and thus varying the GJ over which the fixed operating and capital costs would be spread).

Figure 41: Intermediate process heat costs for large industrial boilers[28]



Source: Concept estimates

The economics of diesel are heavily penalised by high wholesale fuel costs, and for biomass by the high capital & operating costs, and relatively high fuel and transport costs.

In general, it would appear that the main competition in the North Island is between gas and coal. Figure 42 below shows how the relative economics of the two fuels vary across different sized heat requirements and between existing and new boilers.

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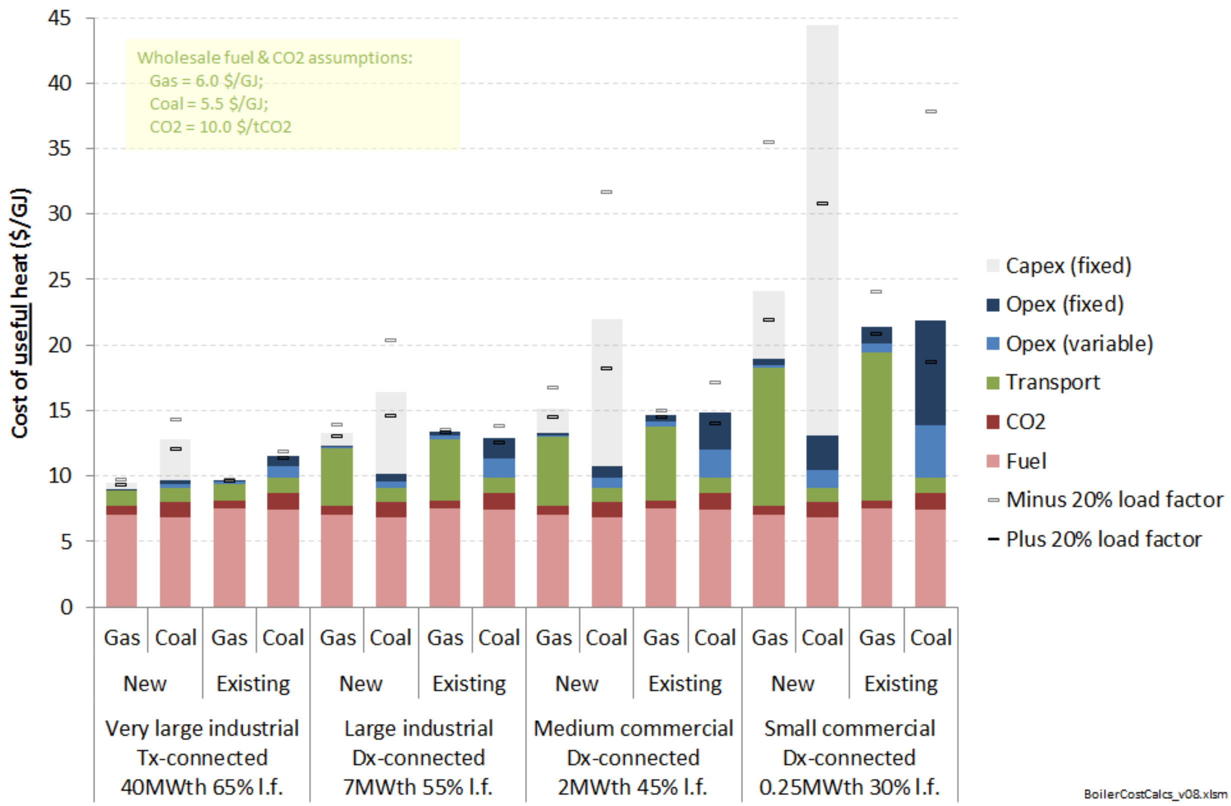
[27] i.e. taking into account of boiler efficiencies.

[28] 'Capex' = Capital costs. 'Opex' = Non-fuel operating costs. 'l.f.' = Load factor

Figure 42: Intermediate process heat costs for varying-sized gas and coal-fired boilers



Source: Concept estimates

In order to understand how sensitive the choice between coal and gas is to varying fuel and CO_2 prices, Figure 43 below shows a series of 'scissor' graphs which show the threshold coal, gas and CO_2 prices for gas and coal options to be of equal cost.

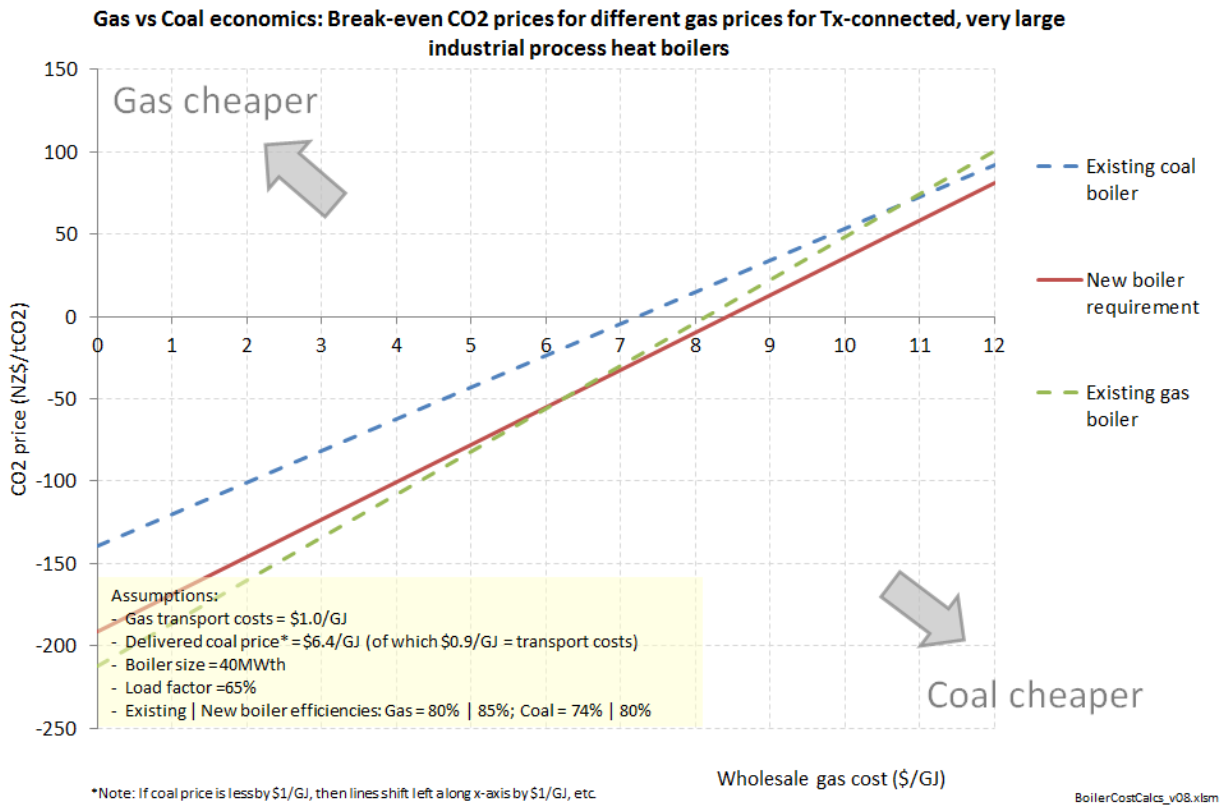
Gas price varies along the x-axis, and CO_2 price along the y-axis, and the thresholds have been calculated for a delivered[29] coal price of $6.40/GJ – considered to be a reasonable estimate of current prices. If coal prices were to be $1/GJ less, then the lines would shift $1/GJ left along the x-axis, etc.).

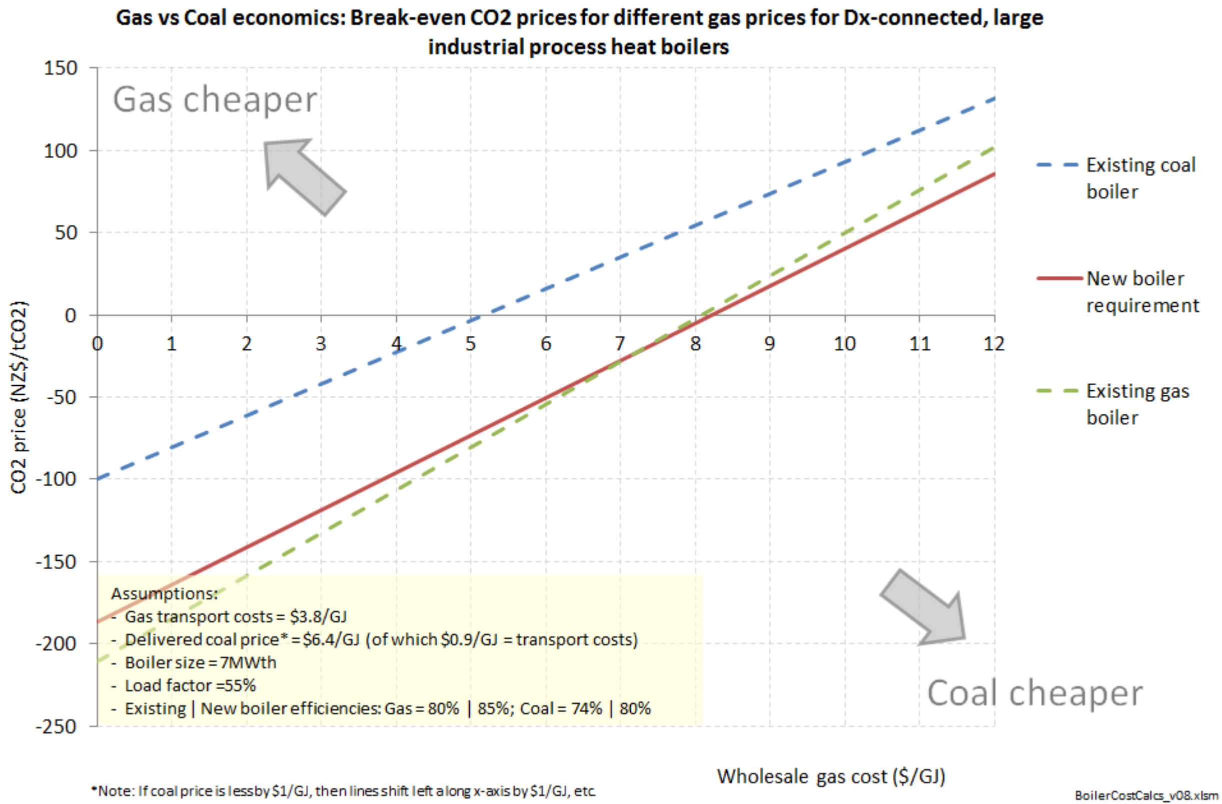
Three situations have been considered:

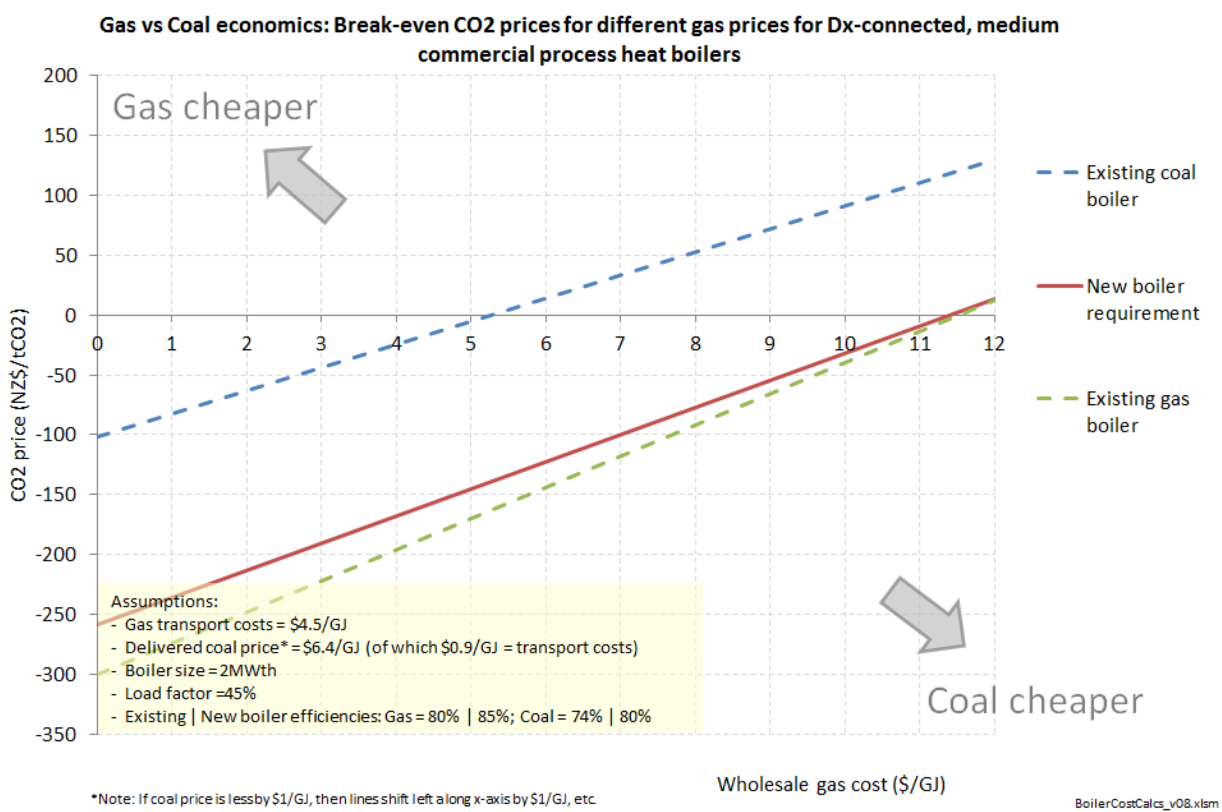
- A new-build requirement;
- Switching away from an existing coal boiler; and
- Switching away from an existing gas boiler.

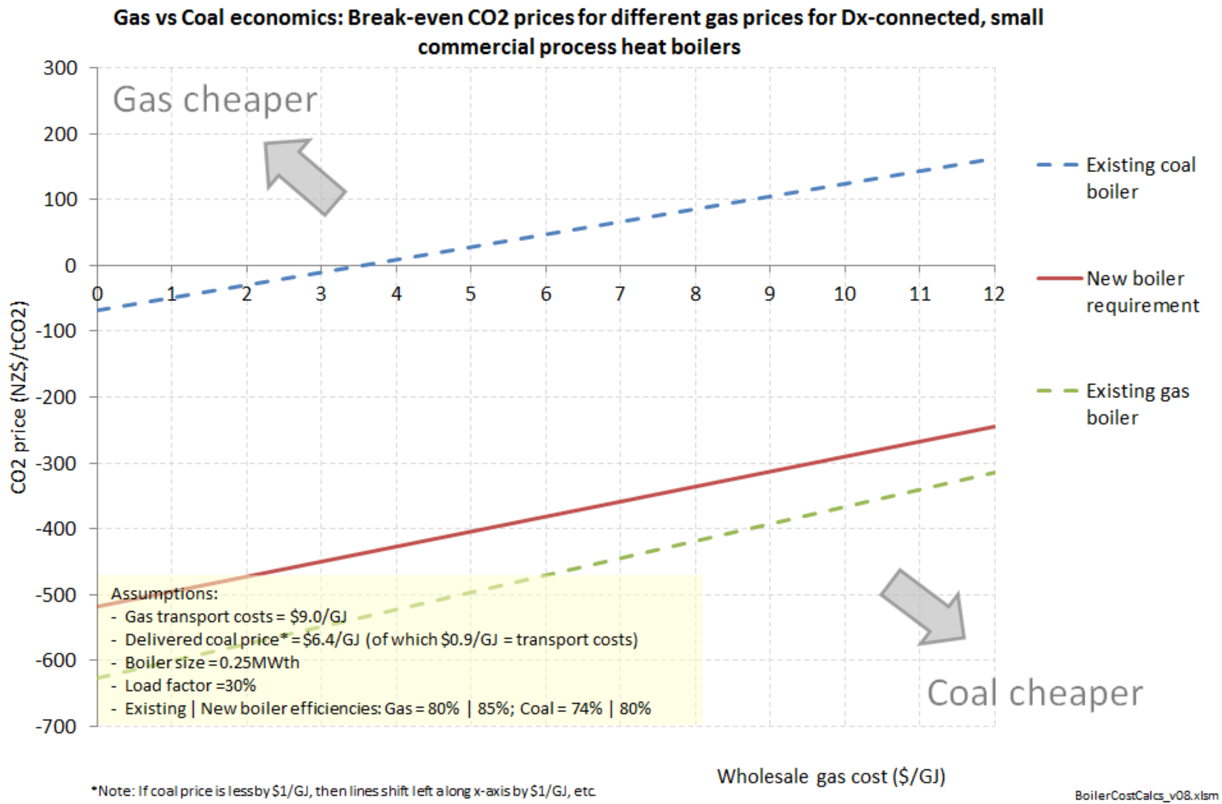
[29] Delivered coal prices include transport costs of approximately $0.9/GJ.

Figure 43: Gas versus coal economics: Break-even CO2 prices for different gas prices for different-sized industrial process heat boilers in different existing versus new-build situations




Gas vs Coal economics: Break-even CO2 prices for different gas prices for Dx-connected, large industrial process heat boilers
Gas cheaper
Coal cheaper
CO2 price (NZ$/tCO2)
150
100
50
0
-50
-100
-150
-200
-250
0
1
2
3
4
5
6
7
8
9
10
11
12
Existing coal boiler
New boiler requirement
Existing gas boiler
Assumptions:
- Gas transport costs = $3.8/GJ
- Delivered coal price* = $6.4/GJ (of which $0.9/GJ = transport costs)
- Boiler size = 7MWth
- Load factor =55%
- Existing | New boiler efficiencies: Gas = 80% | 85%; Coal = 74% | 80%
Wholesale gas cost ($/GJ)
*Note: If coal price is less by $1/GJ, then lines shift left along x-axis by $1/GJ, etc
BoilerCostCalcs_v08.xlsm


Gas vs Coal economics: Break-even CO2 prices for different gas prices for Dx-connected, medium commercial process heat boilers
Gas cheaper
Coal cheaper
CO2 price (NZ$/tCO2)
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
0
1
2
3
4
5
6
7
8
9
10
11
12
Existing coal boiler
New boiler requirement
Existing gas boiler
Assumptions:
- Gas transport costs = $4.5/GJ
- Delivered coal price* = $6.4/GJ (of which $0.9/GJ = transport costs)
- Boiler size = 2MWth
- Load factor =45%
- Existing | New boiler efficiencies: Gas = 80% | 85%; Coal = 74% | 80%
Wholesale gas cost ($/GJ)
*Note: If coal price is less by $1/GJ, then lines shift left along x-axis by $1/GJ, etc
BoilerCostCalcs_v08.xlsm



Anecdotal evidence suggests that the wholesale component of recent gas supply deals for industrial customers is in the $5.50 to $6.50/GJ range, and CO_2 prices faced by New Zealand companies are approximately NZ$5/t$CO_2$.

At such prices, gas is the clear winner. Indeed, for medium and small boiler new investments, gas is the clear winner for almost every conceivable coal, gas and CO_2 price scenario.

For large boilers, gas prices would need to rise above $9/GJ and CO_2 prices remain close to zero for coal to start to become an economic choice for new boiler investments. And for every NZ$25/$CO_2$ increase in CO_2 prices, gas prices would need to be roughly an extra $1/GJ higher before coal would be the most cost-effective new investment.

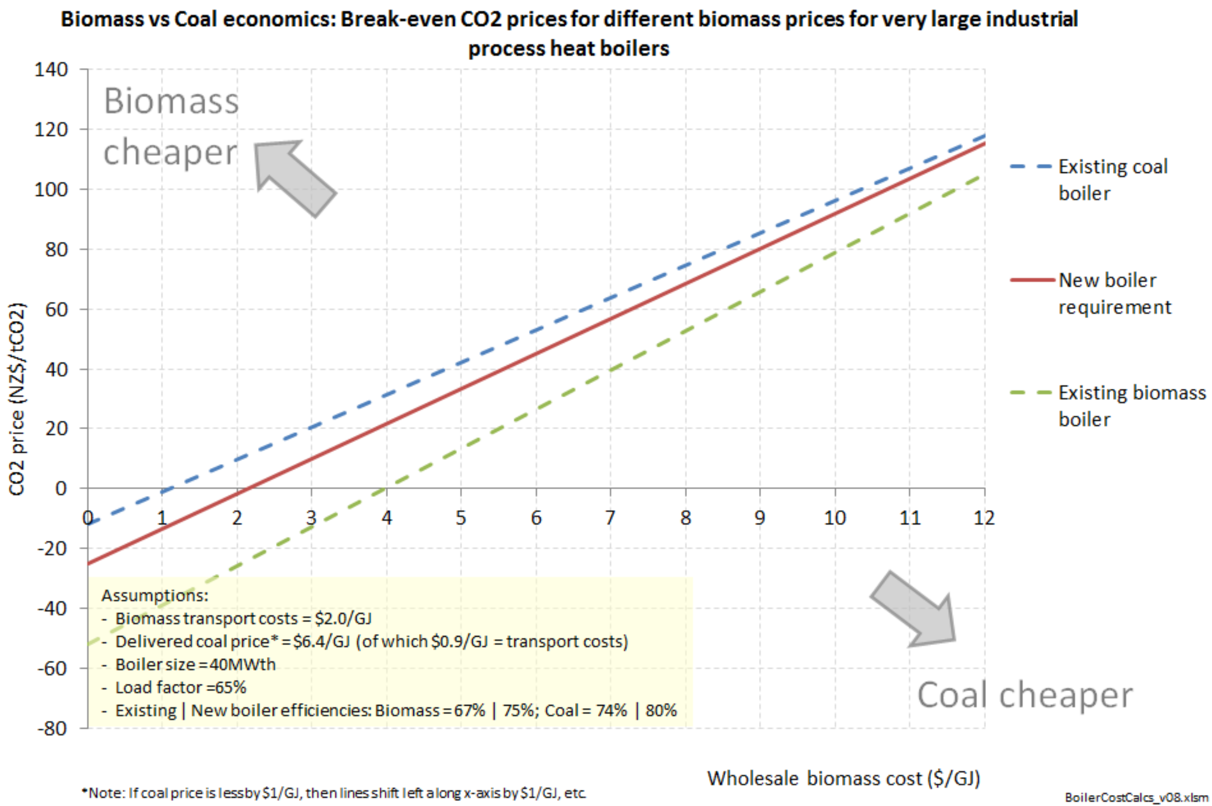
These conclusions also hold for situations where companies have existing gas boilers, even if such boilers have relatively low efficiency.

However, these conclusions may not hold for situations where companies have an existing coal boiler, particularly for small load to medium loads. In such cases the capital cost of a new gas boiler may outweigh any benefit from reduced running costs. That said, for very large heat loads, current fuel and CO_2 prices appear to be at levels where it would be economic to switch from coal to gas.

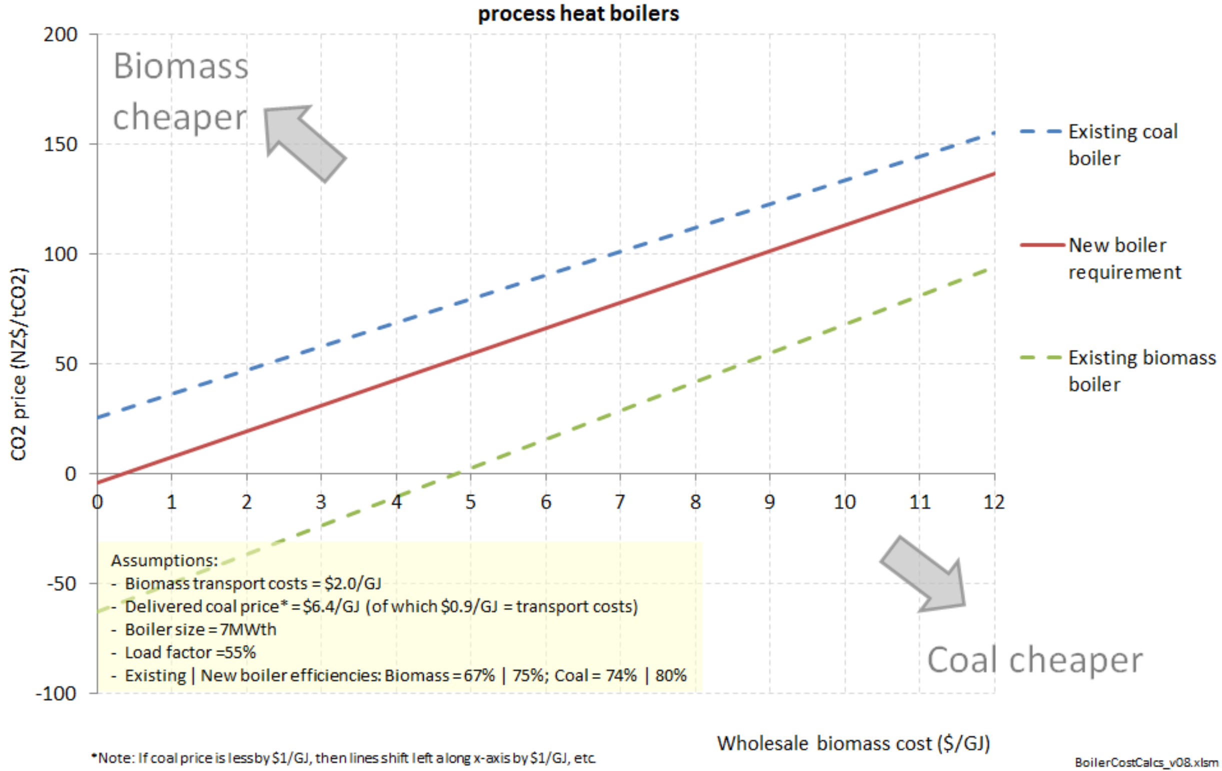
Section 4.3 below discusses the potential for possible movements in fuel and CO_2 prices over the longer term.

In the South Island reticulated gas is not available. Accordingly, Figure 44 presents analysis of the threshold fuel and CO_2 prices for coal versus biomass investment decisions.

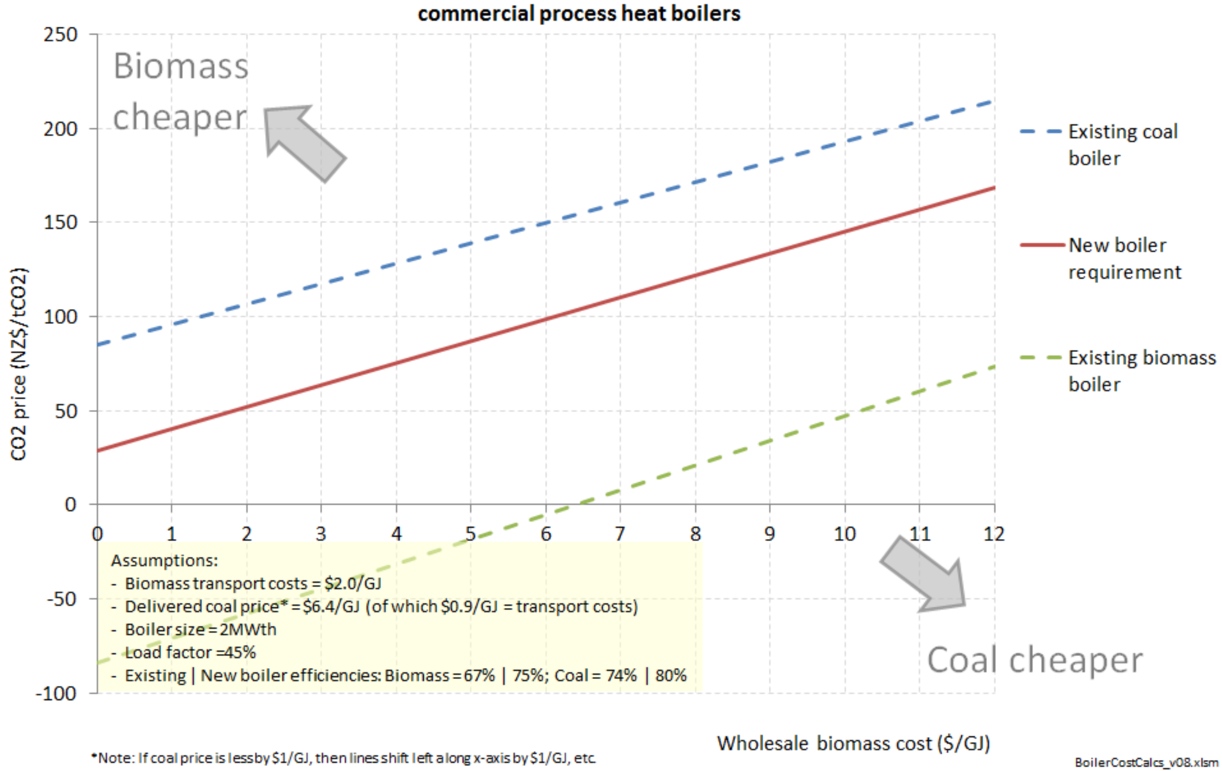
Figure 44: Biomass versus coal economics: Break-even CO2 prices for different biomass prices for different-sized industrial process heat boilers in different existing versus new-build situations

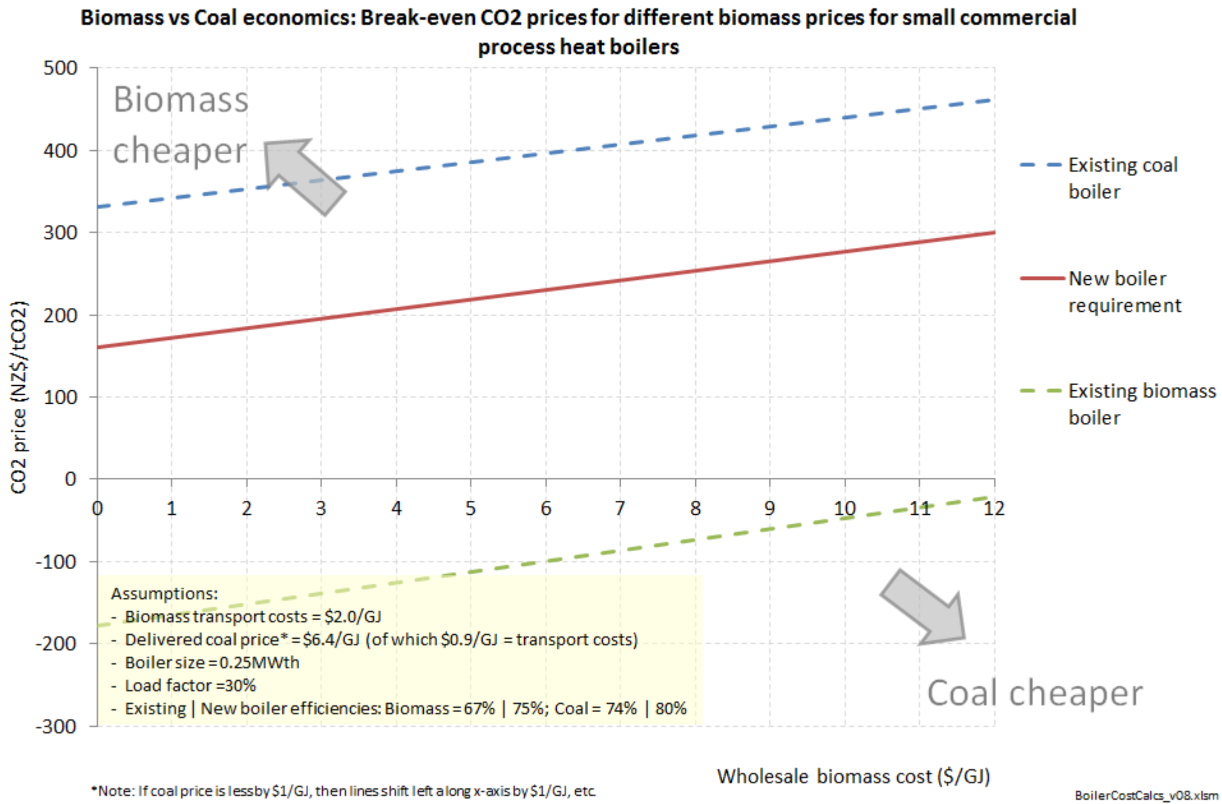


Biomass vs Coal economics: Break-even CO2 prices for different biomass prices for large industrial process heat boilers



Biomass vs Coal economics: Break-even CO2 prices for different biomass prices for medium commercial process heat boilers





This analysis suggests biomass is only likely to be an economic option if its fuel and transport costs are very low. This is certainly the case for situations where biomass fuel is on-site and has low effective fuel costs and zero transport costs, such as for forestry or paper processing plants where biomass material is a 'by-product' of the main industrial process[30].

However, for situations where biomass fuel would need to be specifically purchased and transported to an un-related industrial process, it would appear that coal will generally be the most economic option. This is particularly the case for small-scale boilers where the higher capital and non-fuel operating costs of biomass boilers start to impact on the average $/GJ cost of producing useful heat.

4.3 Possible future fuel and CO_2 prices

4.3.1 Gas prices

The recent gas supply / demand study undertaken for Gas Industry Company indicated that the New Zealand gas sector is in the strongest position it has been in for many years.

Higher oil prices have led to a significant increase in hydrocarbon exploration effort, with the result that New Zealand's gas reserves have improved, and gas demand (especially for methanol production) is increasing. The stronger supply outlook is also reflected in lower wholesale gas prices (currently around $6/GJ compared to over $8/GJ in the mid-2000s in real terms).

While a deterioration in the supply position could occur if there was little or no exploration success going forward, this would probably take around a decade to fully unfold. During such time, some discretionary gas

[30] In such situations, biomass fuel may even have a negative cost as it is a waste product that would otherwise incur disposal costs.

users (e.g. methanol production and power generation) would be likely to scale back, thereby helping ensure that gas reserves would go to the highest value process and space / water heating uses.

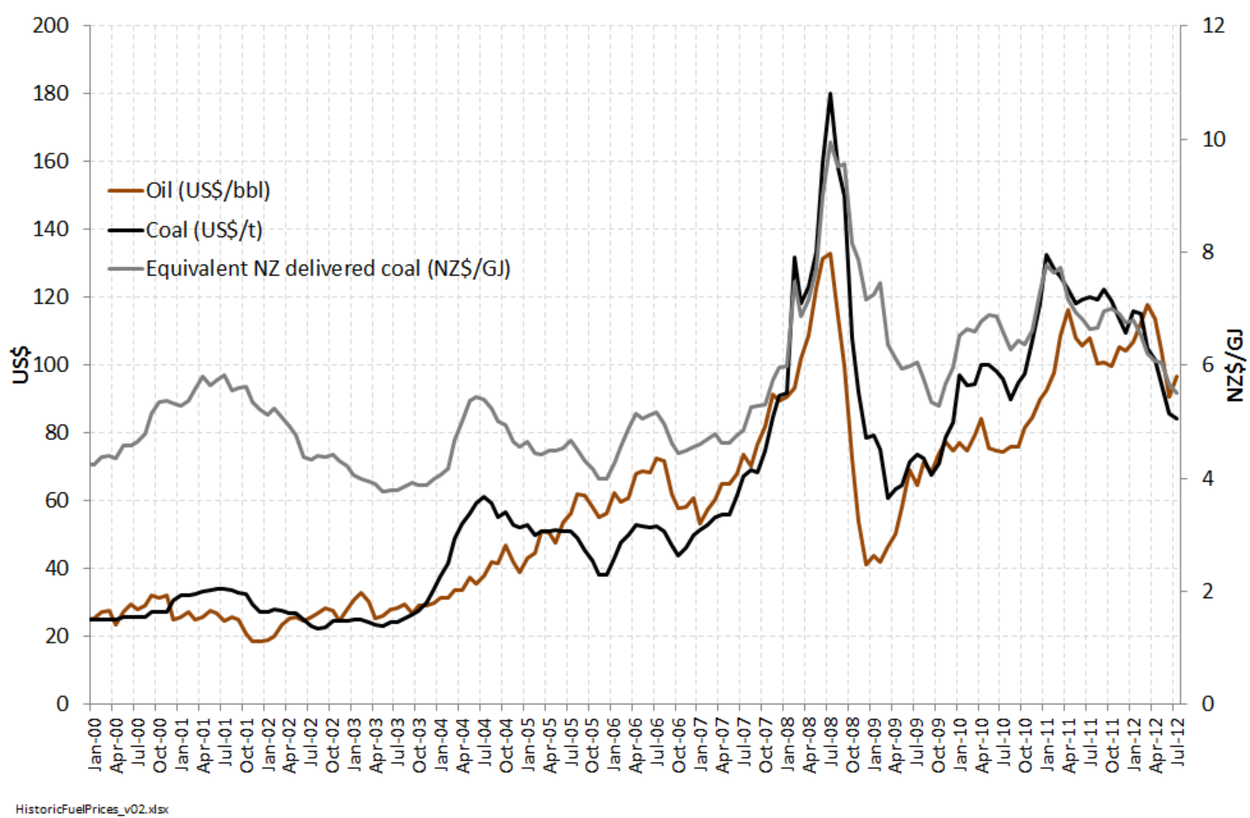
On balance, the study concludes that, provided exploration effort is sustained, gas prices are likely to remain around current levels for the short- to medium-term at least, and may even reduce if the gas reserves position improves further.

Ironically, the one future scenario where higher gas prices could emerge relatively quickly would be if a major new gas field was discovered of a scale which is economic to develop for LNG export, and such a field were located close to the existing gas transmission network[31]. In such a future, New Zealand gas prices would be likely to rise to export parity levels with international LNG prices, which are currently around $12/GJ. This is currently happening in Australia, where the LNG developments in Queensland are progressively pushing up gas prices faced by consumers on the East Coast.

4.3.2 Coal prices

The development of a major import facility at Tauranga means that North Island coal prices are strongly linked to international coal prices. Figure 45 below shows that international coal prices have recently eased off from very high levels, but are still relatively high by historic standards.

Figure 45: Historic international coal and oil prices

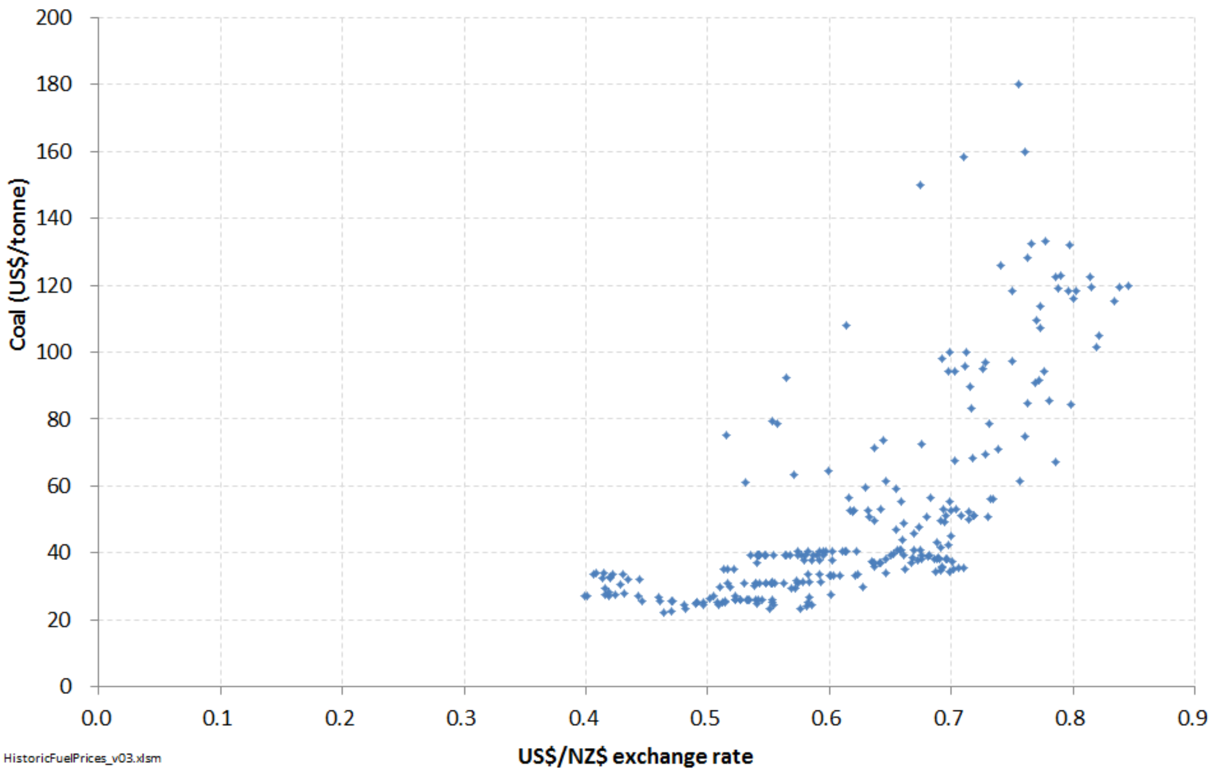


Source: Concept analysis using World Bank and Reserve Bank of New Zealand data Notes: International coal price based on f.o.b. Newcastle, Australia prices. International oil price based on average spot prices of Brent, Dubai and West Texas Intermediate, equally weighed. NZ delivered coal prices include international freight costs to NZ, and within-NZ transport costs to end consumer.

[31] If a major field were discovered in the South Island, it is unlikely that it would be economic to develop gas transmission pipelines to connect it to the existing North Island gas network. As such, it would not affect North Island gas prices.

The chart also shows that the movement in the NZ$ equivalent coal price has been less volatile. This is because, as illustrated in Figure 46 below, the NZ$ exchange rate has also been correlated with international coal prices.

Figure 46: Comparison of US$/NZ$ exchange rate with international coal prices for January 1990 to July 2012



Source: Concept analysis using World Bank and Reserve Bank of New Zealand data

This has had the effect of dampening the movements in the NZ$ equivalent international coal price faced by New Zealand consumers. Thus, when international coal prices have been high, the US$/NZ$ exchange rate has also tended to be high which reduces the NZ$ equivalent coal price, and vice versa.

This correlation with international coal prices is because New Zealand's economy is strongly driven by export commodities (e.g. dairy, oil, wood products, aluminium, methanol, etc.). Thus, when the world economy is experiencing strong growth, international commodity prices tend to be high, with the result that the NZ$ exchange rate also tends to be high, and vice versa. This effect of the world economy driving commodity prices can also be seen in Figure 45 above with the correlation between international oil and coal prices.

4.3.3 CO_2 prices

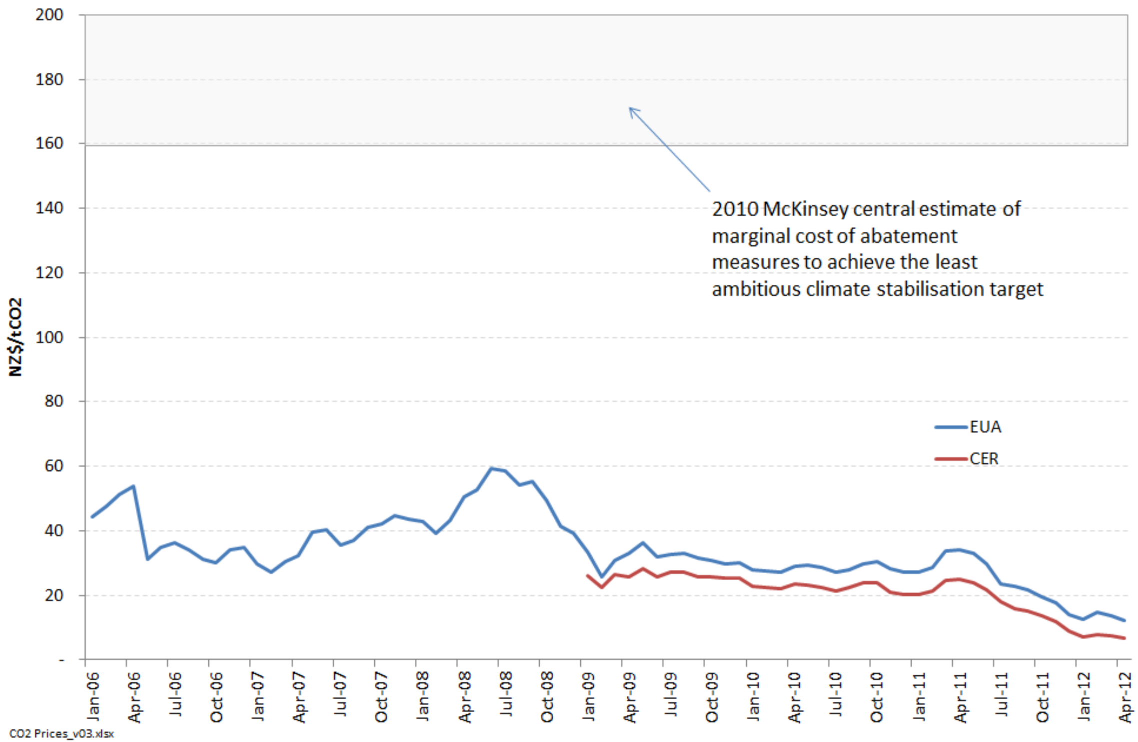
Figure 47 shows that over the past few years the price of CO_2 for the two main international schemes[32] has softened considerably, such that the international price of CO_2 is now approximately NZ$10/t$CO_2$

It is possible that CO_2 prices could continue at such low levels going forward. However, it is also possible that CO_2 prices could rise significantly. For comparison, Figure 47 also shows the range of prices indicated by a

[32] The EUA price is for EU Allowances that can be traded in the EU Emissions Trading Scheme. The CER price is for a Certified Emissions Reduction unit issued by the Clean Development Mechanism (CDM) Executive Board under the rules of the Kyoto Protocol.

2010 McKinsey study that shows the estimated marginal cost of abatement measures to achieve the least ambitious IPCC climate stabilisation target.

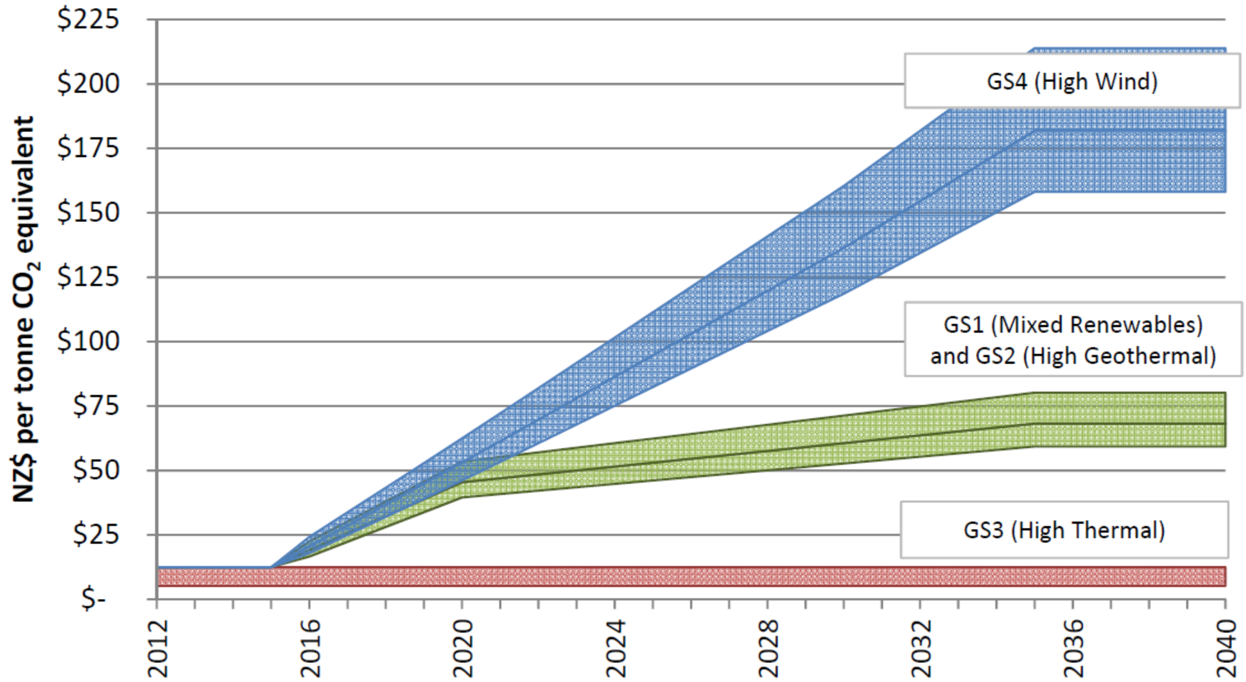
Figure 47: CO_2 prices



Source: Concept analysis using Intercontinental Exchange data

MBIE has also proposed CO_2 price scenarios as inputs into the development of the generation scenarios for the EDGS exercise. Such scenarios were based on the International Energy Agency's *World Energy Outlook*. These scenarios are shown in Figure 48 below.

Figure 48: Proposed carbon price assumptions for MBIE generation scenarios



Source: "*Introducing the Electricity Demand and Generation Scenarios*", July 2012, Ministry of Business, Innovation & Employment

As can be seen, in three out of four scenarios, CO_2 prices rise significantly from current levels.

On balance, it is considered likely that there will be more upward pressure on CO_2 prices than downward pressure.

However, there is the potential for the NZ ETS CO_2 price capping measures to start to result in inefficient choices being made between low and high CO_2 options if international CO_2 prices rise to higher levels. This will particularly be the case for the choice between coal and gas-fired options. However, for South Island gas consumers (where gas is not an option), international CO_2 prices would need to rise to significantly higher lives (approximately NZ$50/t$CO_2$ and above), before the NZ ETS measures would start to materially impact on the choice between coal and biomass options.

Appendix A. Determination of which energy end-use requirements to study

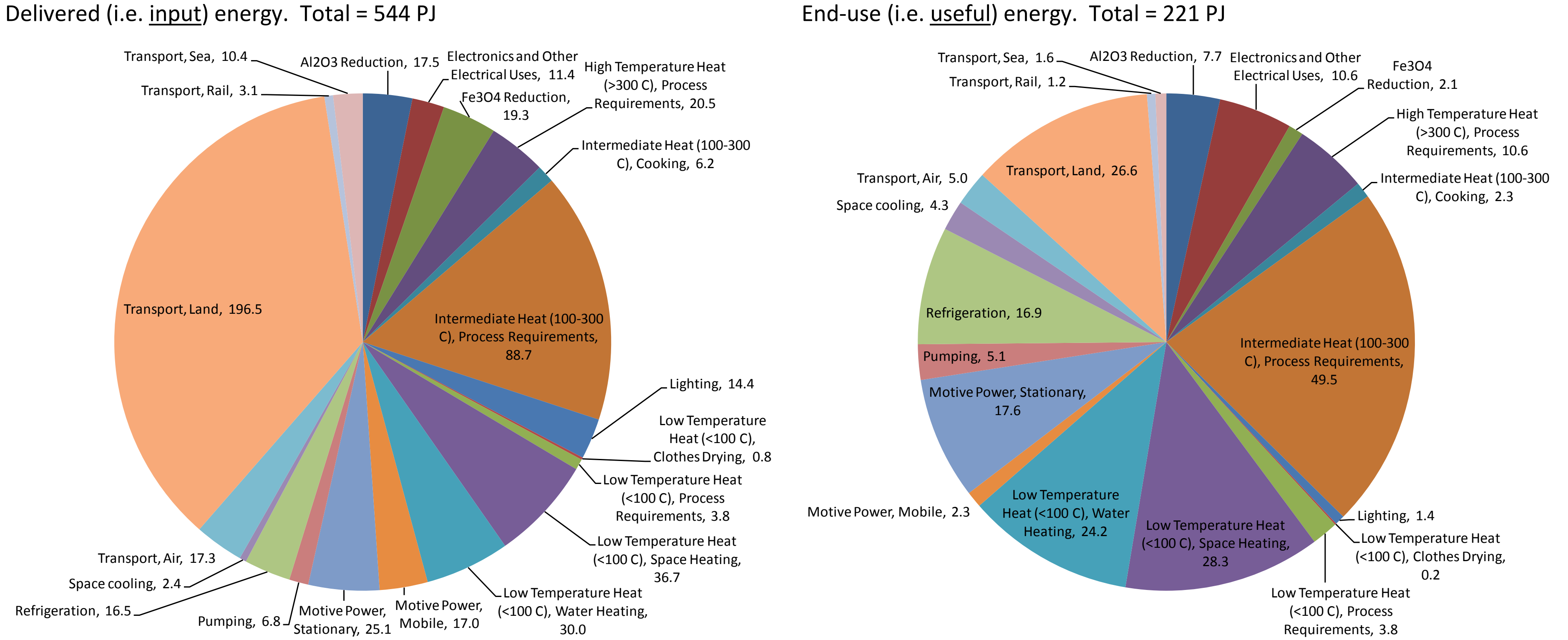
An initial stage of the analysis was to determine which industrial, commercial and residential applications should be analysed in detail. This was achieved through a process of 'filtering' using the following criteria:

- The application should represent a significant proportion of energy end-use (i.e. it would not be worth devoting considerable analytical effort on a relatively minor energy application); **and**
- There should be genuine fuel choices. i.e. Energy requirements whose fuel choices are driven by technical, process-specific factors would not be appropriate to consider.

Figure 49 below presents the split of New Zealand's total end-use energy consumption in 2007 according to the various different types of end-use. Two pie charts are presented. The first being the total input energy, the latter being the amount of useful energy taking account of appliance conversion efficiency[33].

[33] For example, if a domestic gas heater is 75% efficient, then whilst it may consume 1,000 kWh of gas to heat a home in a year, only 750 kWh will be converted into useful heat. Similarly, only a relatively small fraction of the energy within petrol is converted into kinetic energy for transporting people and goods in automotive vehicles.

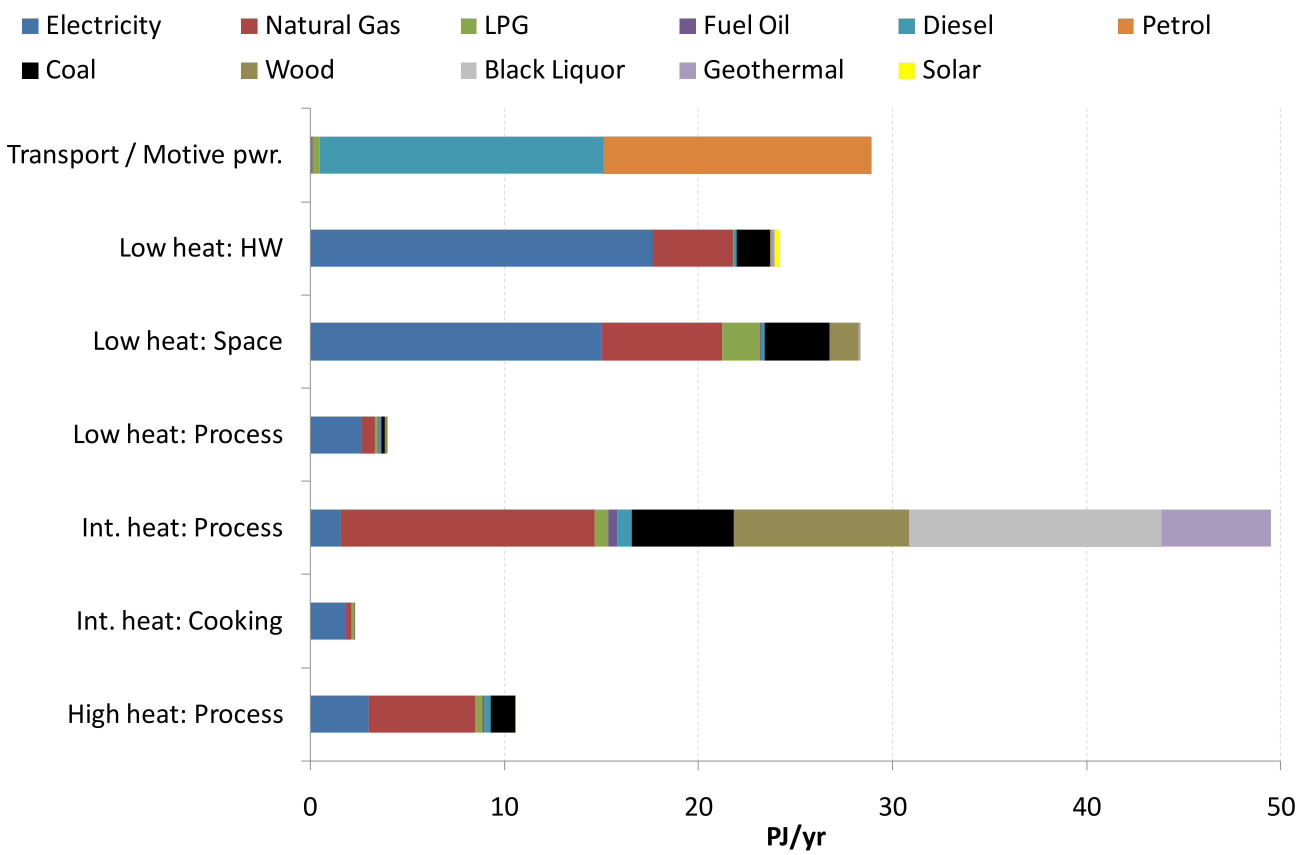
Figure 49: Total energy for the various types of end-use for year ending March 2007 (PJ/yr)



Source: EECA Energy end use database (http://enduse.eeca.govt.nz/), with additional Concept analysis

The next stage of the analysis was to filter out those end-uses where fuel switching is not a practicable option, with the results shown in Figure 50 below.

Figure 50: Split of end use (i.e. useful) energy by fuel for end-use types where fuel switching is a practicable option (PJ/yr)[34]



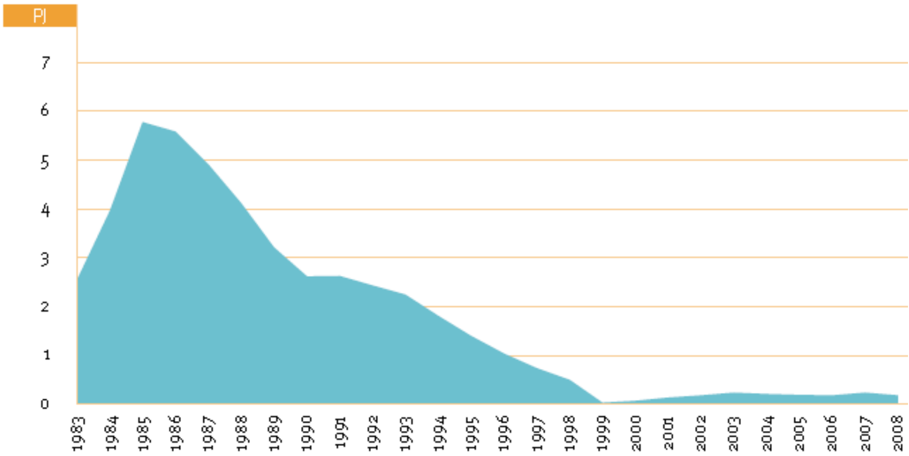
Source: EECA Energy end use database (http://enduse.eeca.govt.nz/), with additional Concept analysis

Whilst transport represents a major energy end-use requirement, consideration of switching from petrol/diesel to compressed natural gas (CNG) for transport requirements was ruled out of scope for this project as it is a major study in its own right that would require consideration of:

- transport technology, including public transport and next generation electric vehicles; and
- the scale and cost of significant new CNG infrastructure given that, as Figure 51 below shows, CNG for use as an automotive fuel has largely disappeared from New Zealand following the removal of government subsidies in 1987.

[34] Low Heat = <100˚C, Intermediate = 100 – 300˚C, High = > 300˚C

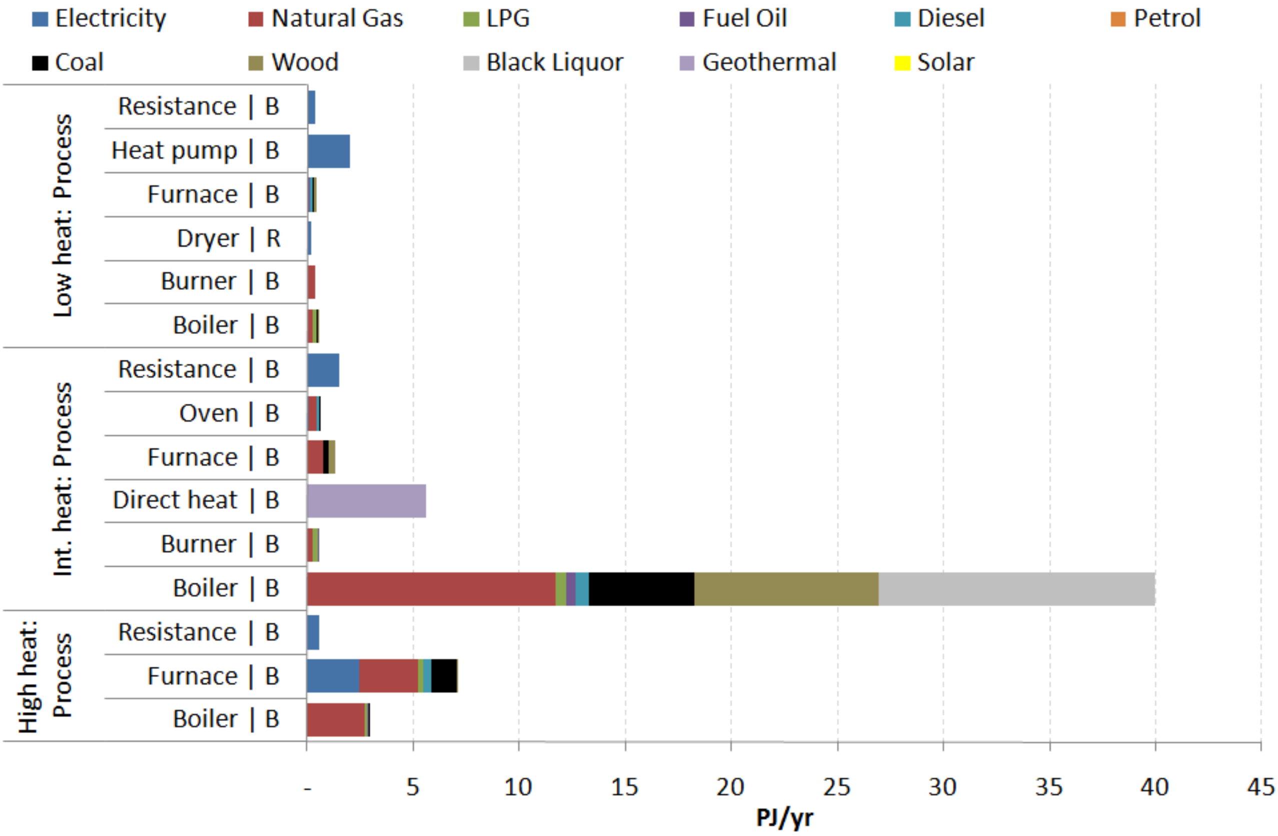
Figure 51: Annual CNG sales



Source: MED 2009 Energy Data File, Figure E.6

Turning to non-transport energy end-uses, it is clear that process heat requirements represent a significant proportion of energy end-use. Figure 52 below presents a more detailed breakdown of the different types of process heat by energy conversion technology.

Figure 52: Split of end use (i.e. useful) energy by fuel, energy conversion technology, and Business / Residential customers for process heat uses (PJ/yr)



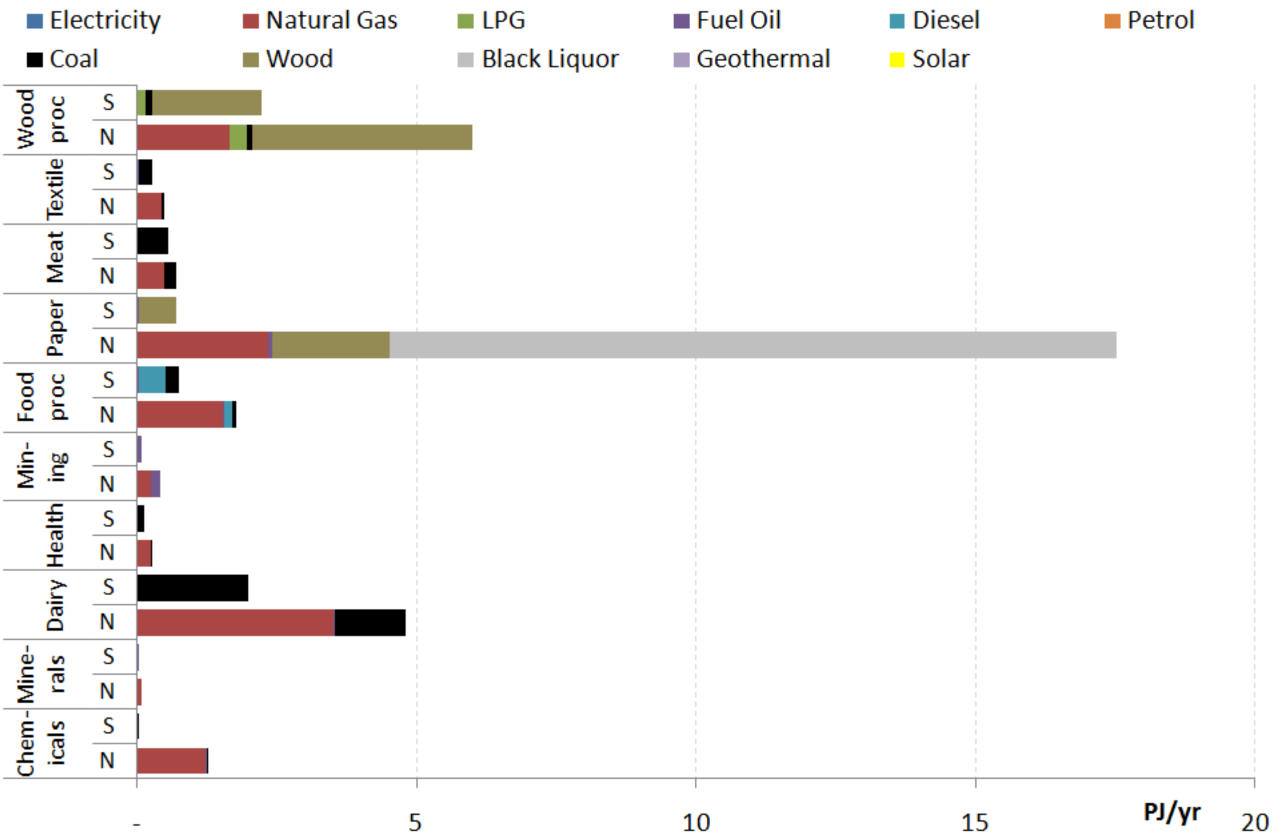
Source: EECA Energy end use database (http://enduse.eeca.govt.nz/), with additional Concept analysis

Based on inspection of Figure 52, it was decided to only consider *one* of the process heat requirements in this analysis – namely boilers used for intermediate process and high process heat. This is because

- boilers dominate the technologies used for the provision of process heat;
- there is a very real ability to fuel switch between gas, coal, and biomass for boilers
- end-uses which use technologies such as furnaces and ovens generally have process-specific requirements which make the fuels less easily substitutable. Thus, consideration of whether the electric furnaces used by the basic metals industries (which dominate this use) could be substituted for gas, would require specialist analysis which was deemed outside the scope of this study.

However, even within the category of process heat boilers, it should be appreciated that the fact that gas is only available in the North Island will reduce the opportunity for fuel switching in the South Island largely between coal and biomass. This is illustrated in Figure 53, below.

Figure 53: Split of end-use (i.e. useful) energy by industrial sector and North / South island for boiler-fired intermediate process heat applications (PJ/yr)

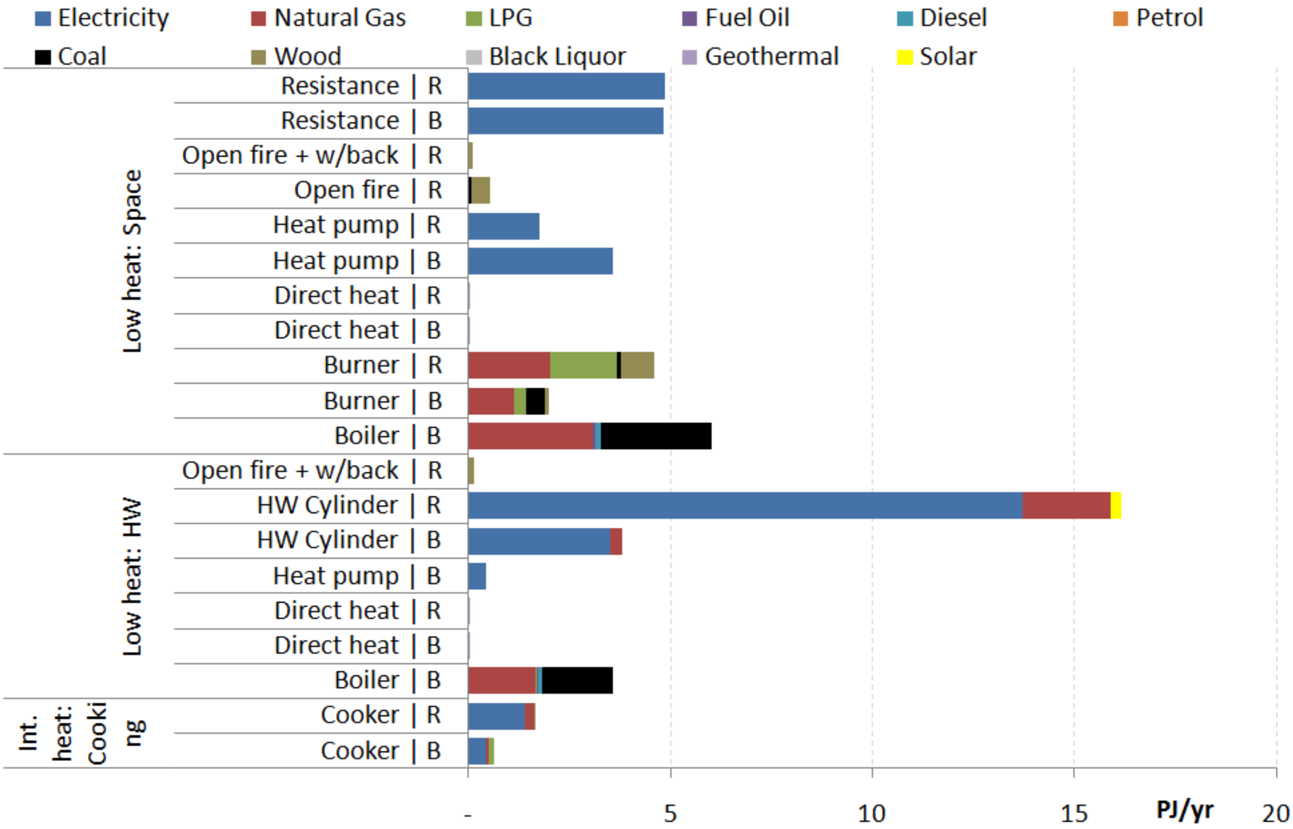


Source: EECA Energy end use database (http://enduse.eeca.govt.nz/), with additional Concept analysis

The majority of coal burned is in the south island where gas is not available. Thus consideration of coal → gas switching is really only an issue for the Dairy and Meat processing sectors, where coal burned in boilers represents end-use energy requirements of 1.3 and 0.2 PJ/yr, respectively. In total, this amount of energy is equivalent to ≈ 1% of total NZ gas consumption.

Turning to the other end-use requirements, Figure 54 below presents a more detailed split by energy conversion technology for space heating, hot water heating, and cooking.

Figure 54: Split of end use (i.e. useful) energy by fuel, energy conversion technology, and Business / Residential customers for space & water heating, and cooking (PJ/yr)



Source: EECA Energy end use database (http://enduse.eeca.govt.nz/), with additional Concept analysis

Based on inspection of Figure 54, cooking has been discarded from this study on the grounds that it represents too small a level of overall end-use consumption to warrant detailed analysis. Further, cooking is an end-use where the *type* of heat delivered (by gas and electric ovens or hobs) is deemed to have quality aspects which are hard to quantify[35], and which people may value more than the relative price of the fuels.

This leaves space and water heating as representing significant energy end-uses, where process-specific considerations are not likely to dominate, and where gas is a practicable alternative. Accordingly, along with coal-fired industrial process heat boilers, these two end-uses have been the focus of the analysis.

Even within space and water heating, the detailed modelling has only considered *residential* use, and has excluded business use. This is because:

- It is unlikely that any 'lessons learned' for residential users would be materially different for business users, and thus the extra cost involved in analysing business tariffs would be unlikely to be justified.
- The opportunities and economics of switching of coal-fired boilers to gas-fired boilers for business space and/or water heating are being covered in the analysis of boilers for intermediate process heat.

[35] For example, some people prefer gas hobs because of the controllability of the heat, whereas electric ovens are preferred by some in terms of giving more of an even cooking heat.

Appendix B. Fuel and CO_2 prices

Fuel prices

Projections of fuel prices

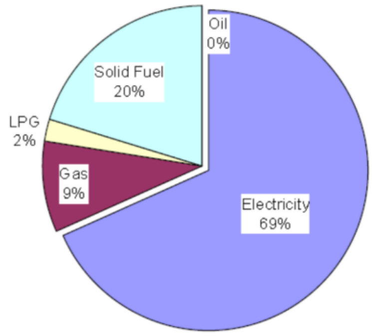
Five different fuels have been considered for the analysis:

- Electricity
- Gas (i.e. reticulated gas)
- LPG (i.e. bottled gas)
- Wood
- Pellet (i.e. wood pellets for use in pellet burners)

Diesel/oil, and coal were not considered because:

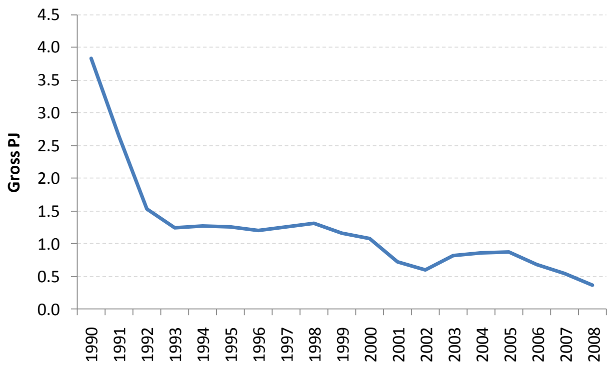
- HEEP identified that oil-fired usage represented a miniscule amount of domestic heating fuel (as shown in Figure 55 to the right); and
- MED statistics illustrate that domestic coal use has dropped significantly (as shown in Figure 56). Figure 54 on page 80 also indicates that there is a very small amount of coal used for residential heating. This decline is likely to continue due to increasing restrictions on emissions from solid fuel fires, plus the impact of a cost of CO_2 being introduced with the ETS.

Figure 55: Total delivered (i.e. input) energy use by fuel



Source: Figure i from HEEP 10 report

Figure 56: Residential coal consumption



Prices are those faced by consumers i.e. they include GST and any transport costs. For electricity and gas, where retailers offer a prompt payment discount (PPD), the prices assume that customers pay on time and thus get the PPD.

For electricity, gas, and LPG, the analysis has separated the prices consumers face into the fixed and variable components, plus separated the price into network, wholesale energy, metering, and retail charges. This separation is necessary because:

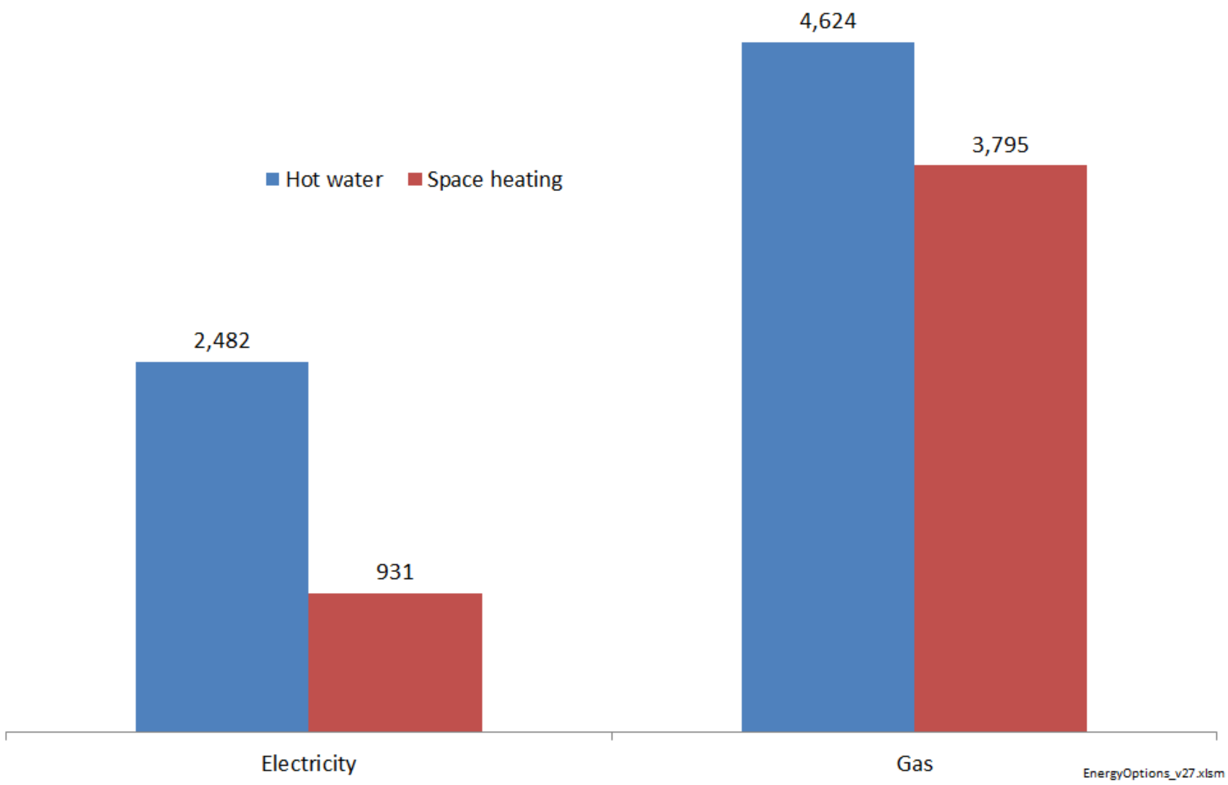
- Fixed charges can have a material impact on the economics of different heating options, particularly for small heat loads
- There are expectations that there will be material movements in the network and wholesale energy components of electricity and gas, and for the relativities of such movements to vary between wholesale energy and network charges, and between electricity and gas. The model has therefore been constructed such that projections of future price changes to these individual components can be transparently made, with the final price to consumers being the combination of these individual component price projections.
- The avoidability of the underlying cost drivers for the different elements (wholesale energy, network, metering and retail) are likely to vary for the perspective of New Zealand versus the

charges faced by consumers. Explicitly identifying the various elements enables specific assumptions to be made about each component in an internally consistent fashion.

For electricity and gas, further differentiation has been undertaken to take account of the different tariffs that may be applicable to the different heating situations:

- For electricity, it is necessary to take account of the different type of controlled tariffs that space and water heating appliances may be on. Thus, space heating may be on a single meter which has hot-water control beneath it, and will thus get the benefit of the 'Inclusive' network tariff discount. Alternatively, space heating may be on an 'Uncontrolled' meter with a more expensive network tariff. Night storage heaters will be on a specific night tariff with both the energy and network component discounted. Water heaters may either be on a dedicated 'Controlled' meter or an 'Inclusive' meter.
- For both electricity and gas it is necessary to take account of the 'Low-user' tariff variants which are available with lower fixed charges, but higher variable charges. Consumption thresholds were determined below which it was assumed it would be appropriate for the consumer to be on the low-user tariff. The thresholds were determined based on analysis of HEEP data and MBIE Electricity Data File data. They are shown in Figure 57 below. It is important to note such Low User variants are only considered for calculating the private benefits of the different options from a consumer perspective. No such Low User variants are appropriate for considering the public benefit from a whole of New Zealand perspective.

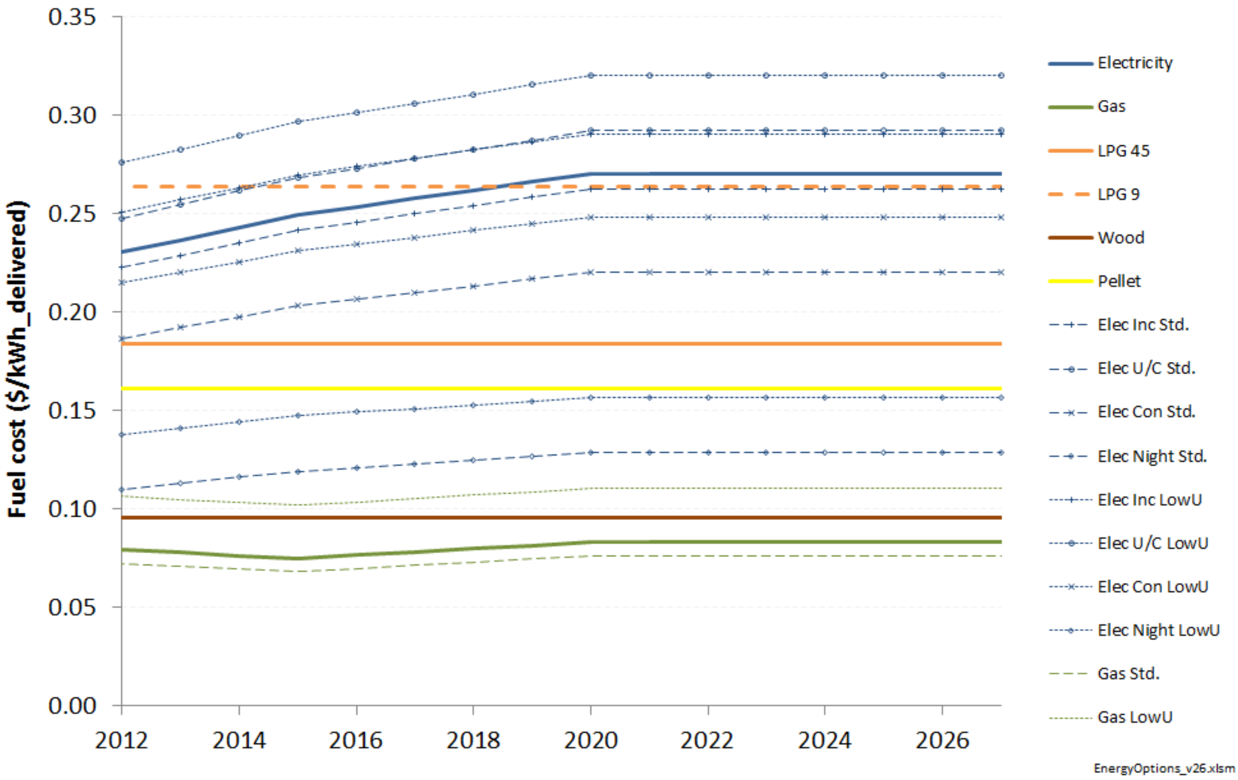
Figure 57: Consumed energy Low User consumption thresholds (kWh/yr)



A further complication relates to the potential for energy and CO_2 prices to change materially over time. This has been addressed within the modelling framework by explicitly projecting fuel, network and CO_2 prices, and discounting back over the period of evaluation to calculate a present value average $/kWh price.

Figure 58 shows the variable fuel price projections (including network / transport) for consumers that have been used within the study.

Figure 58: Delivered consumer fuel price projections used within the study (incl. GST)[36]



Source: Concept estimates

It is important to note that prices are based on typical prices in the main urban centres. In many cases, particularly in more rural areas, consumers can access wood at much cheaper prices which will markedly improve the economics of log burners.

Similarly, electricity and gas prices in many rural networks are often (but not always) materially more expensive than those in the main urban centres.

Potential distortions between 'private' prices faced by consumers and 'public' costs faced by New Zealand

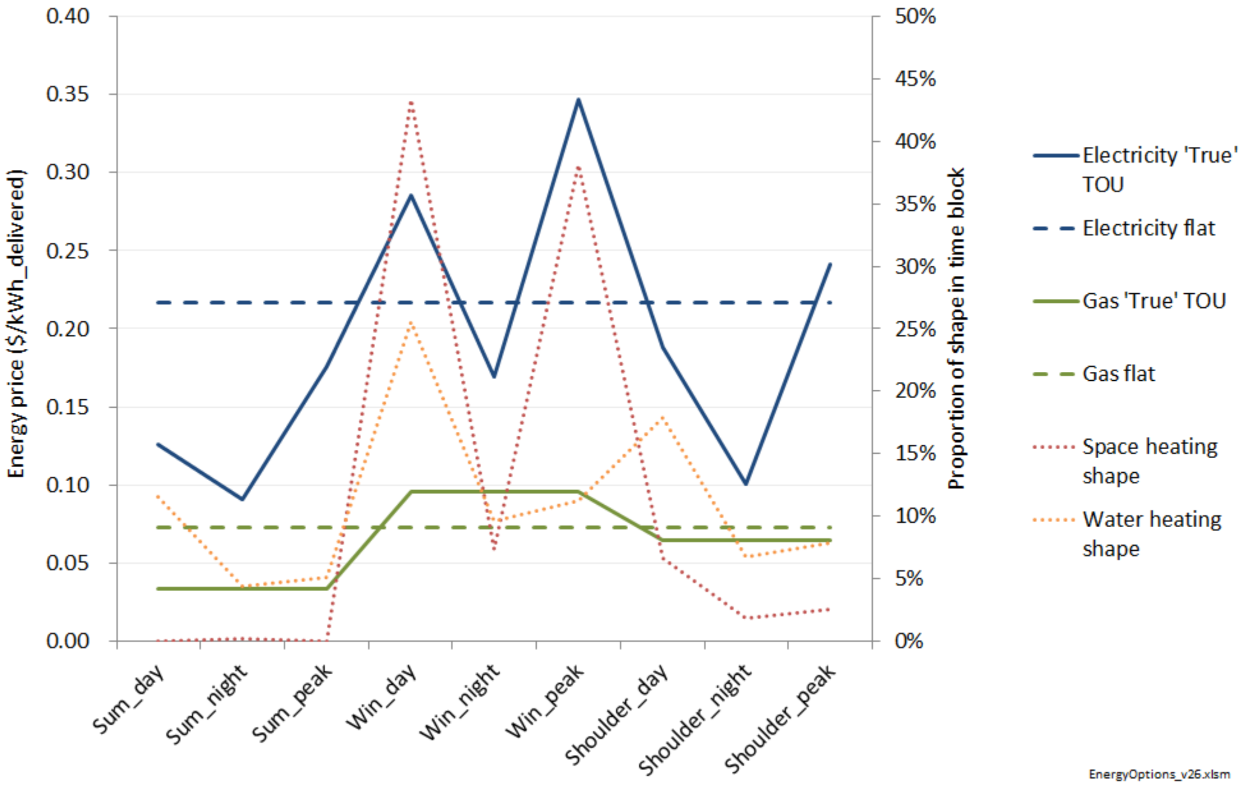
Time-of-use drivers of costs

One of the most significant potential distortions between the private benefits to consumers of different energy options versus their public benefit to New Zealand, relates to electricity and gas costs having strong seasonal and within-day drivers, but most consumers facing a single whole-of-year average price for their space and water heating. This is illustrated in Figure 59 below which shows Concept's simplified estimates of:

[36] For electricity and gas, the heavy solid lines represent the average price across the range of different tariffs, while the light dotted line represent the specific different prices for the different options. "Std" and "LowU" distinguish between standard and low-user options. For electricity the control types are defined as: "U/C" = uncontrolled, "Inc" = Inclusive control (i.e. for a single meter which has a mixture of controlled and uncontrolled load beneath it), "Con" = Controlled (i.e. all load beneath the meter is controlled), and "Night" = Night-only consumption. "LPG45" and "LPG9" refer to the price of 45kg and 9kg cylinders, respective. (With 9kg only being used for cabinet heaters).

- the extent to which the 'true' underlying wholesale plus network cost drivers for the different times of the day and year differ from a flat tariff; and
- the typical shapes for space and water heating across the different times of the day and year.

Figure 59: Estimated variation in electricity and gas wholesale and network costs across different times of the day and year[37]

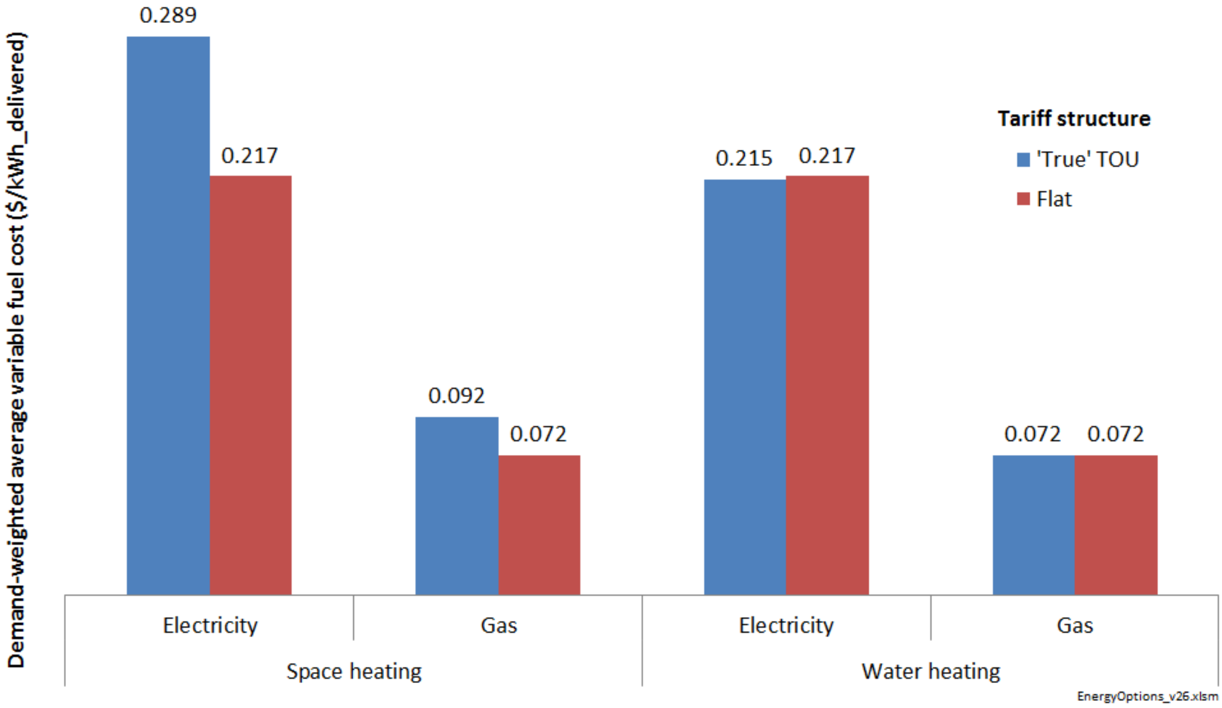


Source: Concept analysis

For space heating in particular, which has a very pronounced seasonal and within-day shape, this can affect the apparent cost for electricity and gas options. This is illustrated in Figure 60 below which shows how, using the data shown in Figure 59 above, the apparent cost to consumers of energy for space heating is significantly reduced relative to the 'true' cost for New Zealand, whereas such distortion is insignificant for water heating.

[37] Estimation of the shape of electricity and gas network costs was based on analysis from various sources including: observed wholesale electricity prices, analysis published by Orion on network cost drivers, Concept analysis of wholesale gas swing costs, and Concept analysis of gas network cost drivers. In some cases, it has been necessary to use simplified assumptions due to lack of data.

Figure 60: Estimation of scale of distortion from electricity and gas consumers not facing 'true' time-of-use tariffs



Source: Concept analysis

Treatment of fixed costs and sunk network assets

For both electricity and gas, consumers are charged a combination of fixed (i.e. $/day) and variable (i.e. $/kWh) charges.

When considering the economics of electricity heating options, the fixed charges of electricity supply were not taken into account because they are unavoidable from both a consumer and New Zealand perspective i.e. a consumer will still use electricity for other uses such as lighting, even if they don't use electricity for heating.

For gas, however, the fixed charges may be avoidable (and thus included in the cost analysis) in scenarios where gas is only going to be used for one purpose at a property (e.g. just space heating, or just water heating). To take account of this, two scenarios for gas fixed costs were considered:

1) where gas is only used for one use (i.e. space or water heating) and thus the gas fixed costs could be considered avoidable; and
2) where gas is used for multiple uses, and thus the gas fixed costs are considered unavoidable – and are thus not considered in the evaluation of the economics of gas-fired appliances.

This treatment of gas fixed costs was used for both the Consumer and New Zealand perspective analyses. However, for scenario 1 above, from a New Zealand perspective only a *fraction* of the fixed costs were considered avoidable:

- 44% of the fixed charge associated with the recovery of retail fixed costs were considered avoidable[38].

[38] 100% of the costs of metering were considered avoidable (i.e. if a consumer doesn't have gas at their property, then New Zealand want incur any resource costs associated with providing a gas meter to that property). Metering costs are assumed to account for 20% of total retail costs.

- The element of the fixed charge to recover the fixed costs of network supply were considered unavoidable.

Additionally, from a New Zealand perspective, part of the variable charge paid by consumers is for the recovery of *sunk* network assets. These are unavoidable and, looking forward, can be thought of as a 'free' asset from a New Zealand perspective. For a cost: benefit analysis therefore, such sunk network costs should be thought of as unavoidable and not considered within the cost: benefit analysis.

However, if due to demand growth there is a need to invest in new network assets, then such network costs should be regarded as avoidable, and included within the cost: benefit analysis.

Clearly, the extent to which there is surplus network capacity or a need to invest in new network capacity will vary considerably across the country and by type of network asset (gas vs. electricity, and transmission vs. distribution).

However, in general it is assumed that the gas network has considerably more surplus capacity than the electricity network. This is based on various analyses published by Transpower, the Electricity Authority, Gas Industry Company and Vector on the need for future electricity and gas network investment.

In order to take account of this treatment of sunk assets in the analysis from a whole of New Zealand perspective 56.3%[39] of the variable component of electricity network costs are assumed to be avoidable, whereas only 2.8% (using a simple factor of 1/20th of electricity) of the variable component of gas network costs are assumed to be avoidable. This is because there is assumed to be much more surplus capacity on gas networks than on electricity networks.

Clearly, there are some major assumptions and generalisations in this approach. Nonetheless, it is believed to be a reasonable 'ball-park' estimate of the avoidability of network costs in relation to demand growth, and the relativities between electricity and gas.

It should also be noted that some electricity appliances (e.g. heat pumps) impose network costs due to poor power factors. Different heat pump brands have different performance in this respect, with the better quality heat pumps imposing much less of a power factor cost than some of the poorer quality brands. In some parts of Australia, it is understood that the rapid uptake of such appliances is causing power factor problems in certain networks at certain times of the year (e.g. when there is a large air conditioning load).

To-date, New Zealand hasn't suffered such problems to the same extent. However, it is understood that as the penetration of these appliances increases in places such as Auckland, it is becoming more of an issue.

At the moment mass-market customers do not have a power factor element to their network charges. However, the analysis has not sought to take into account power factors costs in the analysis because of:

Similarly, many of the back-office retail costs are driven by customer numbers (e.g. some billing costs, CSR staff numbers etc.). If there are fewer gas customers, then New Zealand won't incur so many resource costs associated with providing such back-office functions for gas retail. 30% of the non-metering retail costs are assumed to be avoidable in this way.

[39] This is derived as follows. Distribution costs (which represent ≈ 75% of network costs to consumers) are assumed to be 50% driven by rising MW demand (based on a statement by Orion in their pricing methodology to this effect). Transmission costs are assumed to be 75% driven by the need to meet peak demand. (Based on the fact that transmission infrastructure comprises a lot less customer assets than distribution infrastructure, and a statement by the UK National Grid in the 1990s that 90% of their costs were driven by peak demand). The weighted average of these cost drivers is 56.3%.

- The very location-specific nature of such costs (i.e. it will be more of an issue on some networks than other); and
- The assumption that such costs are relatively second order compared to other network costs.

Treatment of gas connection costs

There will be costs involved in connecting customers who don't currently have a gas connection. This cost will vary significantly according to whether it relates to gas being put in at the time a new sub-division is built or subsequent to such a time and the distance of the property to the nearest gas pipe.

However, a central estimate of $1,000 customer has been used based on discussions with network companies.

When conducting the analysis from a consumer perspective, however, this cost is not included as it is understood that most network companies waive the gas connection cost (if the property is within a typical distance from a gas main) if they are connecting the gas for use in applications such as space or water heating.

CO_2 prices

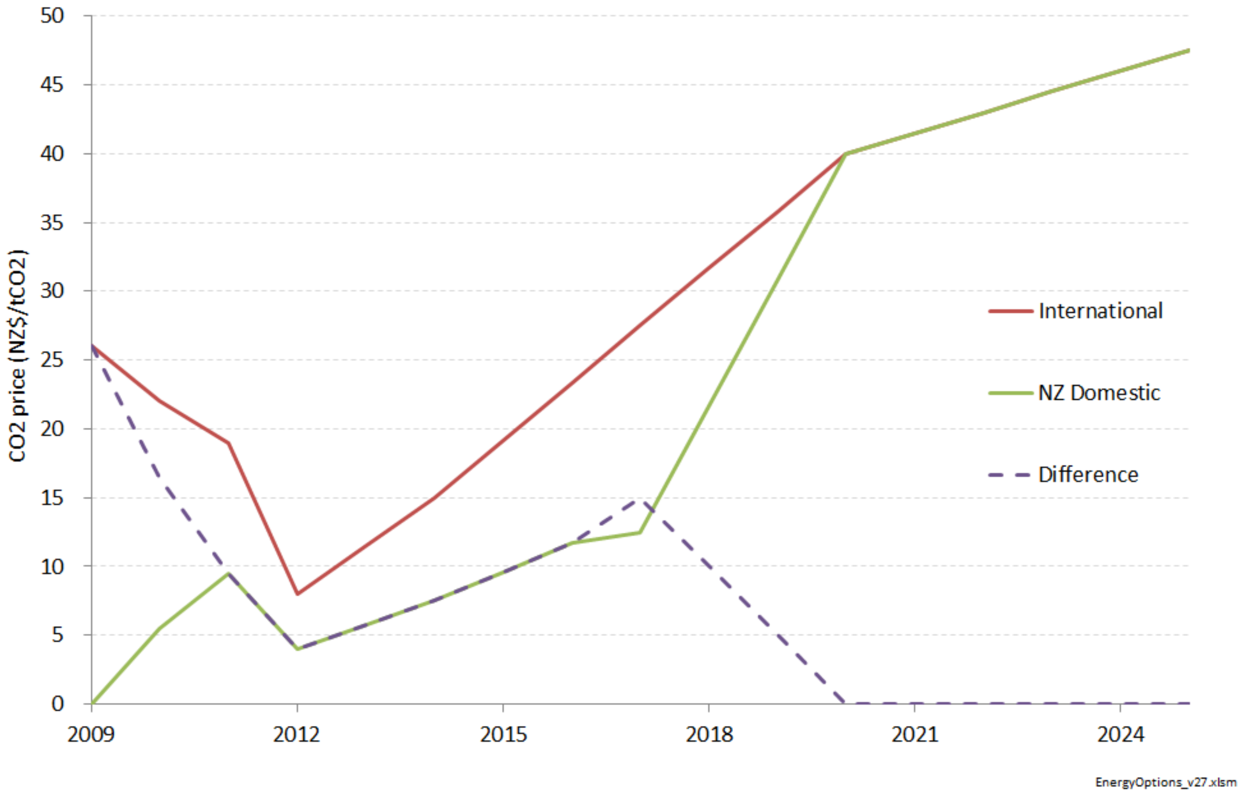
The current New Zealand Emissions Trading Scheme has measures which mean that New Zealand emitters need only provide one New Zealand unit (equivalent to a tonne of CO_2) for every two tonnes of CO_2 emittied, plus there is a cap of NZ$25/t$CO_2$ on the price of CO_2. Taken together this means that the price of CO_2 faced by New Zealand emitters can be no more than NZ$12.5/t$CO_2$.

However, New Zealand's CO_2 liability under its international agreements will be based on the international CO_2 price of the day.

This dislocation between the price faced by consumers under the NZ ETS, and the price faced by New Zealand is explicitly taken into consideration for the different cost-benefit analyses.

Figure 61 shows the central assumption for the international price of carbon faced by New Zealand, the price faced by the energy sector, and the difference between the two.

Figure 61: CO_2 price assumptions



Source: Concept estimates

The second externality relating to CO_2 prices is the fact that CO_2 prices to electricity mass-market consumers will be based on the emissions intensity of an average demand shape, whereas space heating in particular has a much more peaky (and hence emissions intensive) shape. This is set out in Appendix C below.

This difference in apparent emissions intensities is taken into account for the different evaluations from Consumer and New Zealand perspectives.

Appendix C. Determination of the relative carbon intensities of the different fuels

The 2007 CAENZ study[40] undertook an excellent analysis of the carbon emissions for the various different fuels used by consumers taking into account the carbon intensity of the raw fuel, processing losses, transmission & distribution losses, and even emissions associated with road/ship transport for fuels such as wood, pellets and LPG.

Accordingly, the emissions factors developed by the CAENZ study have been used as the basis for this analysis, *except for the derivation of electricity emission factors,* where Concept used its own electricity market simulation models to derive such estimates.

This is because the CAENZ factors were based on a 2003 Concept study which examined the impact of a flat 50MW change in electricity demand, and examination of the consequential impact on the MWh generated from the different types of generator in order to derive a weighted average of the marginal generator and associated emission factor.

However, there have been some material changes to the electricity sector since the 2003 study was undertaken, in particular:

- Relative coal and gas prices have changed;
- Emissions now face a cost of CO_2;
- Unless a major new field is discovered, there is unlikely to be sufficient gas to underpin a new baseload CCGT development, whereas in 2003 a combined-cycle gas turbine (CCGT) was still considered to be the marginal baseload new entrant;
- The relative economics of new renewable projects have changed, in particular the development of significant quantities of relatively low-cost baseload geothermal options and wind options;
- The electricity system is becoming increasingly MW capacity constrained due to demand growth being met by non-hydro generation, in particular from increasing quantities of wind; and
- The decline of Maui and its ability to swing at relatively low cost to meet seasonal variations in demand is having a material impact on the *within-year* shape of gas prices[41]. This is likely to have a material impact on the relative costs of providing low-capacity factor gas-fired generation to meet peaky demand.

Many of these changes are likely to have an impact on the emissions intensity of electricity.

Additionally, the 2003 study considered baseload demand, whereas heating has a very peaky profile. As set out in more detail below, it is likely that the type of generation (and thus the consequent emissions factor) will be materially different for a peaky demand profile compared with a baseload demand profile.

The following sub-section sets out the analysis Concept has undertaken to estimate the likely emissions intensity of electricity used for different space and water heating demand profiles.

[40] *"Understanding the Contribution of Direct Use of Gas to New Zealand's Future Energy Efficiency Objectives"*, New Zealand Centre for Advanced Engineering (CAENZ), November 2007.

[41] This is largely evidenced through Contact's major investment in the Ahuroa gas storage facility whose whole income is derived from providing fuel flexibility services.

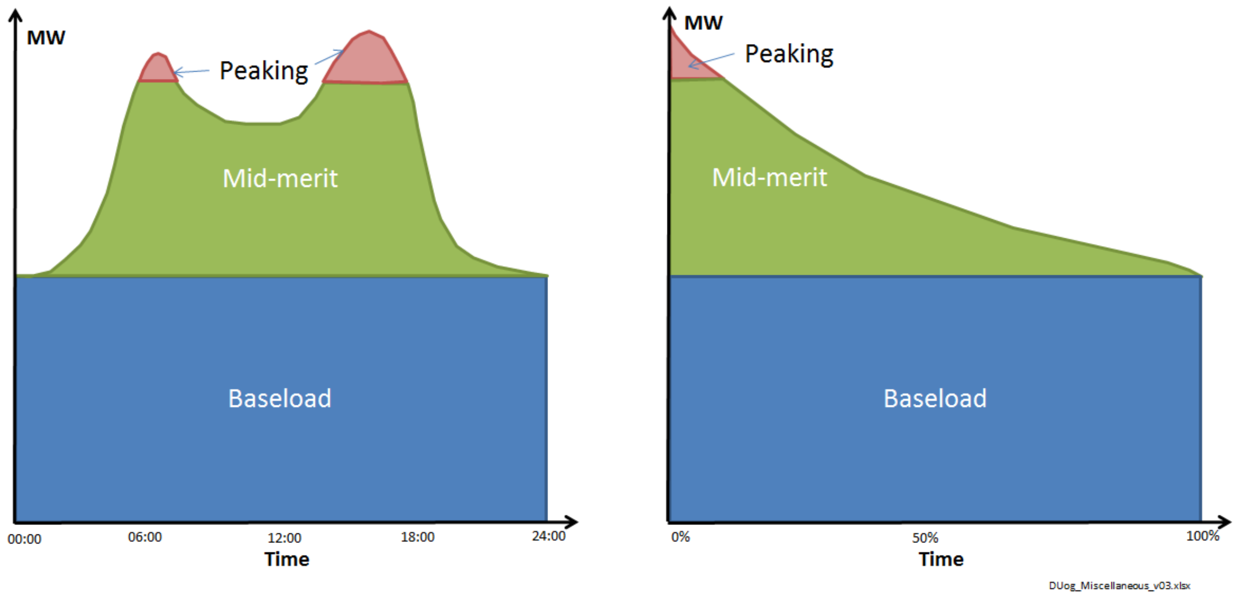
Conceptual framework for considering the carbon intensity of electricity emissions

Electricity is an unusual product in that it cannot be economically stored in large quantities, yet demand varies significantly throughout the day and year, driven by factors such as the weather and consumer working patterns.

This inability to store electricity, combined with significant variation in the demand for electricity, gives rise to a requirement for some plant to be available to operate relatively infrequently during periods of high demand.

Figure 62 below shows a highly stylised representation of this variation in demand, and how this gives rise to a need for some plant which can operate all the time ("Baseload"), some which operates for most of the time ("Mid-merit"), and some which operates very infrequently ("Peaking"). (Note: This discussion initially considers a simple electricity system which doesn't have hydro generation, as hydro introduces another dimension of complexity. The implications of hydro are discussed later in this sub-section after outlining the initial concepts.)

Figure 62: Illustration of the distinction between baseload, mid-merit and peaking generation plant



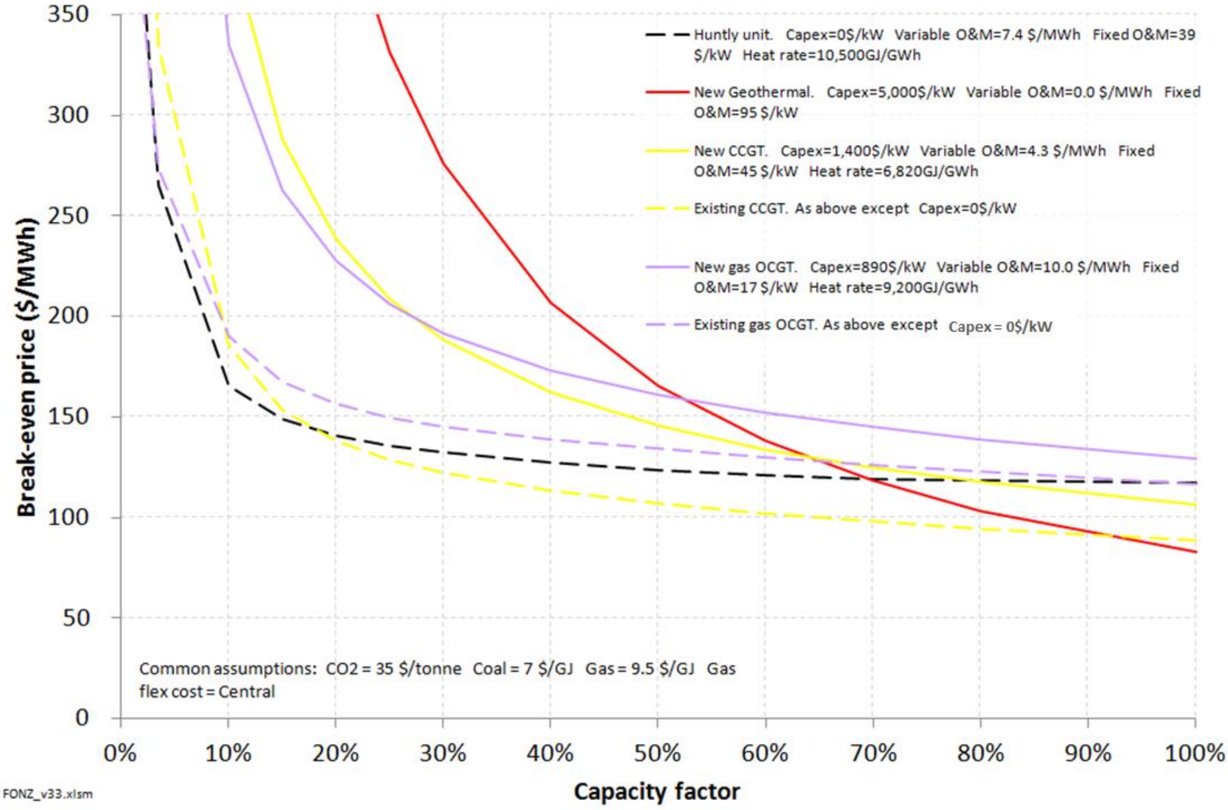
In Figure 62, the diagram on the left shows a chronological representation of how demand varies over time (in this case a single day), and the diagram on the right shows how this demand can be re-ordered in a load duration curve format.

Electricity is also an unusual product in that there are a many different types of production facility that can make the 'product' – i.e. there are many different generation technologies. Thus there are many different types of fossil-fuelled generator as well as many different types of renewable generation technology.

Not only do such generating technologies differ in the variability and controllability of output, but they also have very different cost structures. Thus, renewable technologies tend to be very capital intensive, but have very low operating costs. Conversely, fossil fuel generators (also known as 'thermal' generators) have proportionately lower capital costs, but much higher fuel costs. Within the class of thermal generators there is also variation between those options with a relatively high efficiency but high capital costs (e.g. a CCGT), and those with a lower efficiency and lower capital costs (e.g. an OCGT).

This means that while a renewable generator may be the least-cost option for providing baseload power, they become progressively more expensive as options to provide mid-merit and peaking power. This is because the very high capital costs get spread over proportionately fewer kWh, making the lifetime average $/kWh cost of producing peaking power from a renewable generator very expensive. This is illustrated in Figure 63 below, which also shows that the lower capital cost of an open cycle gas turbine (OCGT) means it is likely to be more cost effective than a CCGT for low capacity factor duties.

Figure 63: Generator cost curves



Source: Concept analysis

Using the above framework, if there is an increase in baseload demand, this will be met by an increase in baseload generation. In a market which is in equilibrium (i.e. there is not significant over- or under-capacity), this will be met by building *new* generation, the type of which will be determined by whichever is most cost-effective at baseload.

During the late ‘90s and through to the mid-2000’s, the most economic new-build baseload option in New Zealand was a gas-fired CCGT. Accordingly, an increase in baseload demand would have resulted in an increase in CCGT generation, and the emissions factor of baseload demand should be considered to be equivalent to that of a CCGT. (Approximately 0.37 tCO_2/MWh).

However, more recently the cost of a CCGT has gone up significantly due to an increase in wholesale gas prices and the introduction of a cost of CO_2. At the same time, advances in renewables technology, coupled with a higher NZ$ exchange rate, has resulted in significant reductions in the cost of renewables options. As a result, over the last five years baseload demand growth in New Zealand has been met by new renewable generation – particularly geothermal, coupled with some wind. As things currently stand, barring a major game-changing event such as a significant new gas field find which leads to a major drop in gas prices (coupled with expectations that CO_2 prices are unlikely to rise significantly), this situation of baseload demand growth being met by new geothermal and wind projects looks set to continue for the foreseeable future.

Accordingly, in this new paradigm, the emissions factor of baseload demand should be considered to be equivalent to that of geothermal and wind. Assuming new geothermal stations have an emissions factor of approximately 0.15 tCO_2/MWh[42], and that 70% of new baseload generation will be geothermal (with the other 30% being comprised of 17.5% wind and 12.5% CCGT[43]), this gives a baseload emissions factor of approximately 0.153 tCO_2/MWh.

While this is considered to be an appropriate factor for the emissions intensity of baseload demand, it does not necessarily represent the emissions factor that would be associated with a peaky demand profile such as that used to satisfy space heating demand.

If demand were only to increase at peak times, such extra demand would be met by an increase in peaking generation[44]. As Figure 63 above shows, thermal generation is by far the most economic option to meet such demand because at low capacity factors, compared with renewable generation options, the benefit of lower capital costs more than outweighs the higher variable fuel and CO_2 costs.

As Figure 63 also shows there are a range of potential thermal generation options, including diesel OCGTs, gas OCGTs, CCGTs and coal-fired steam plant. Also, if such increased demand occurs at mid-merit times rather than the very peak, there is the option of running *existing* thermal plant harder at slightly higher capacity factors rather than building new plant. All of these thermal options have different emissions factors as illustrated in Table 6 below.

Table 6: Thermal generation emissions factors

Generator	Huntly		CCGT	OCGT	
Fuel	Coal	Gas	Gas	Gas	Diesel
Fuel emissions factor (t CO2/GJ)	0.091	0.053	0.053	0.053	0.073
Generator heat rate (GJ/MWh)	10.5	10.5	7.1	9.6	9.6
Generator emissions factor (tCO2/MWh)	0.96	0.55	0.37	0.51	0.70

Source: Concept estimates based on a variety of data sources

Exactly which generator will increase output in a response to an increase in demand at mid-merit or peaking times is subject to inherent uncertainties due to factors such as future fuel prices (coal, gas, diesel), the future costs of gas fuel flexibility (or 'swing'), future CO_2 prices, and the scale of annual fixed costs and capital expenditure required to keep Huntly units operational.

Concept has a model of the New Zealand electricity market, FONZ, which it uses to project possible market futures, and in particular to project which types of plant are likely to be built, retired, and operated based on underlying market drivers such as fuel and CO_2 prices, demand growth etc.

In order to estimate what types of generation would be called upon to meet what types of demand, FONZ has the ability to be run with and without an extra quantity of load of a particular shape, and

[42] Geothermal schemes emit CO_2 released from the underground gases. Different schemes emit different levels of CO_2, with a few having emissions equivalent to a coal-fired station. The figure of 0.15tCO_2/MWh is considered broadly representative of the average emissions intensity of new geothermal stations based on analysis of various sources, including data tables within the Climate Change regulations, and data compiled by the New Zealand geothermal association.
[43] This is a weighted probability over a range of possible scenarios for future gas prices. In some credible scenarios gas prices drop to a level where it becomes economic to build new CCGTs to meet baseload demand.
[44] It is likely that some increased demand for energy services at times of peak may be met by demand-side response. However, it is also likely that demand *net of such demand-side* response could increase at times of peak.

the difference in plant build and operation over the 15 year projection period analysed. This difference in generation enables estimation of the marginal plant required to meet this particular demand shape, and the consequent emissions factor.

Such analysis was repeated for a range of different fuel and CO_2 price scenarios, and revealed that the marginal plant to meet certain types of demand can be sensitive to changes in such parameters. However, with respect to an increase in demand at mid-merit and peaking times, the analysis revealed that such demand growth is almost always met by an increase in an output of fossil generation. However, precisely which fossil option meets such peaky demand growth was found to be sensitive to factors such as fuel and CO_2 price, and the cost of keeping Huntly plant operational.

Thus, unlike baseload demand which is considered to have a low emissions intensity, it is likely that any electricity demand profile which has a relatively peaky shape will have a relatively high emissions intensity.

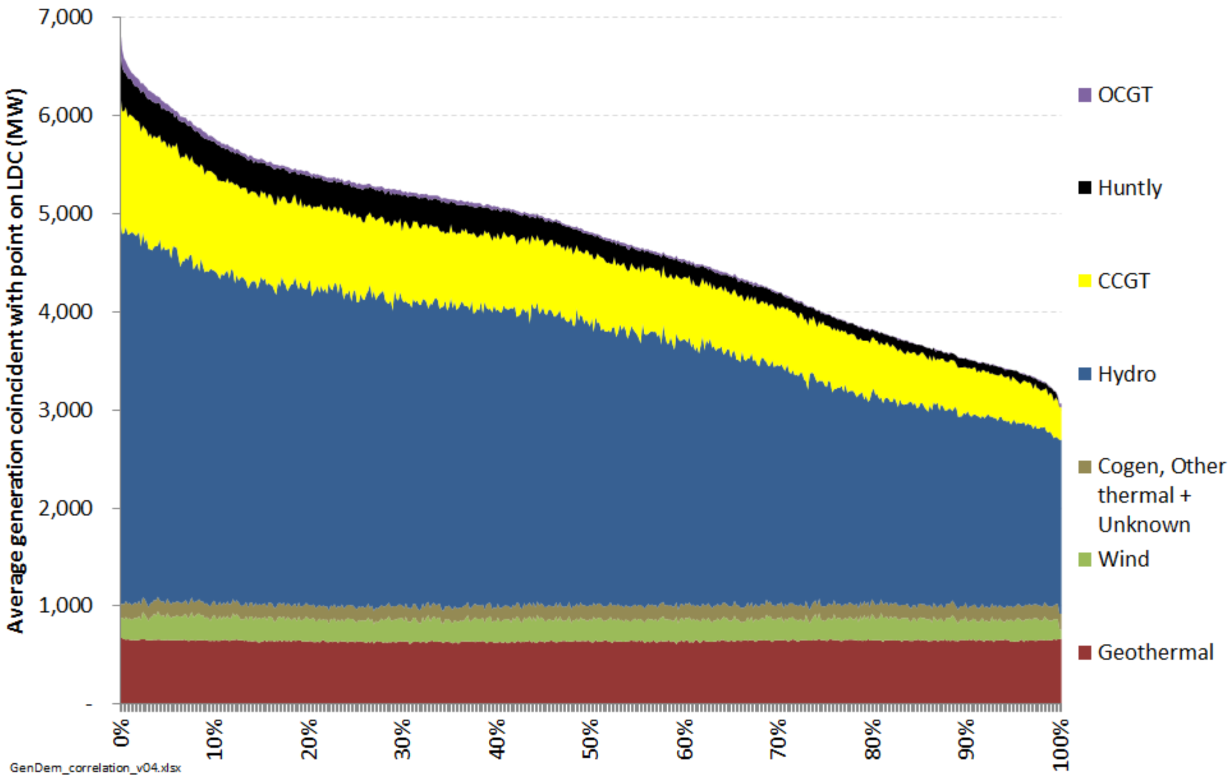
In this respect, as is set out in more detail below, space heating demand has a very peaky profile (particularly on a summer / winter basis), and water heating has a moderately peaky profile.

The one potential factor which may mean that the above analysis is not correct is if existing hydro generation had the capability to increasingly 'sculpt' its output away from low demand periods and into high demand periods to meet any growth in mid-merit and peaking demand. This would reduce the need for increased output from fossil generation plant at such times, and the reduction in hydro generation at times of low demand could then be met by developing new baseload generation. This would mean that a peaky demand profile such as that for space heating would not have as high an emissions intensity as it would if such demand were predominantly met by fossil generation.

This is an important potential issue to consider because New Zealand is unusual internationally in that it has a large amount of hydro generation capability (equivalent to approximately 60% of its demand), much of which has storage capability.

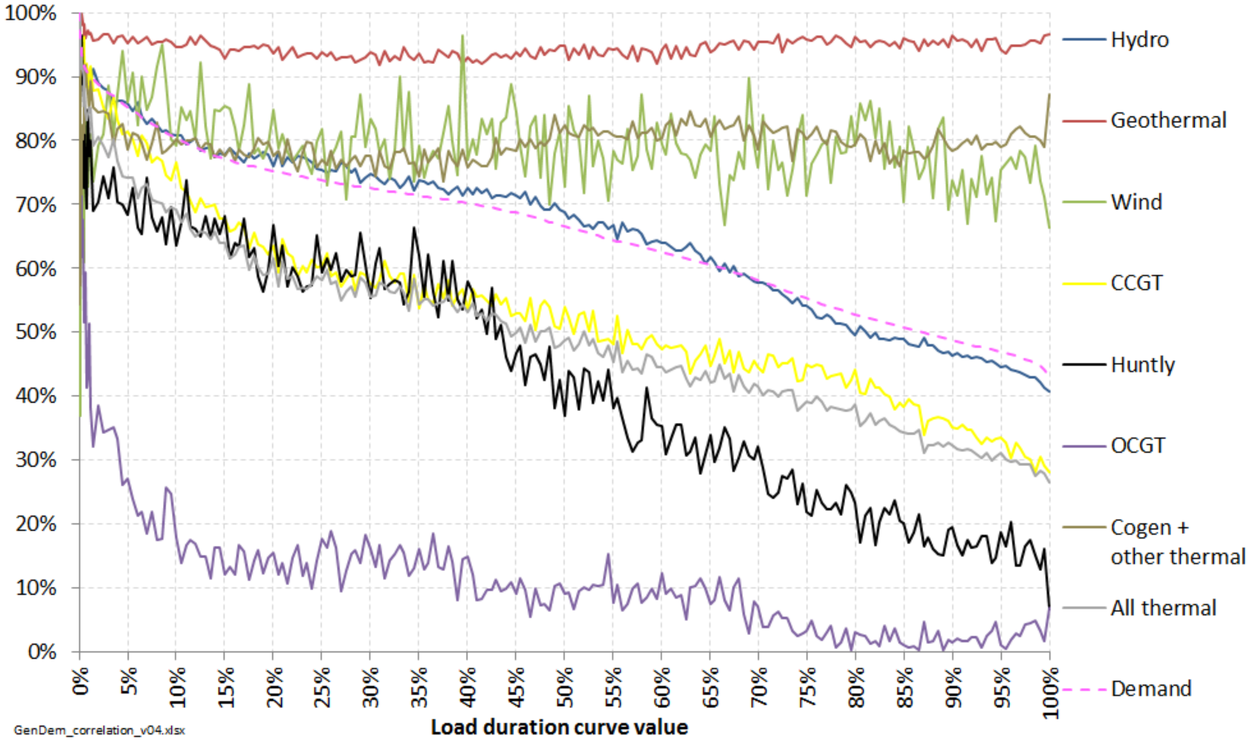
This is best illustrated with reference to Figure 64 and Figure 65 below.

Figure 64: Average generation coincident with point on load duration curve for 2011



Source: Concept analysis using Electricity Authority centralised data set data

Figure 65: Average proportion of output (compared with observed maximum in year) coincident with point on load duration curve for 2011



Source: Concept analysis using Electricity Authority centralised data set data

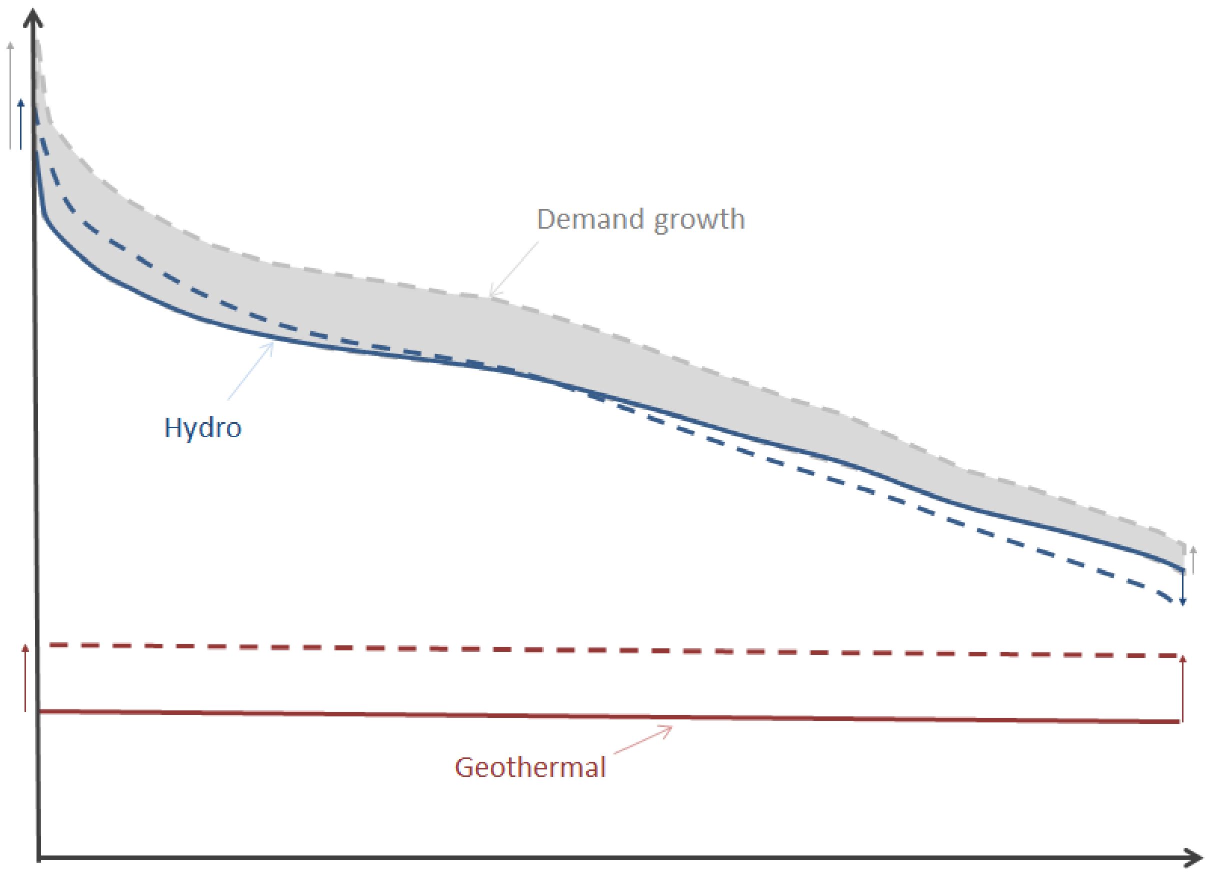
As can be seen, the hydro generation has been sculpted into higher demand periods, thereby reducing the requirement for thermal mid-merit and peaking generation.

If hydro generation has the potential to increase the extent to which such sculpting were to occur, then if demand growth was relatively peaky it could potentially be met through increasing the amount of new baseload renewable generation and increasing the amount of water 'sculpted' into the demand peaks.

If there were no constraints on the ability to sculpt water in this way, this could theoretically result in peaky demand growth being entirely met from new baseload renewable generation, and thus peaky demand having a very low emissions factor the same as baseload demand.

This is stylistically represented in Figure 66 below:

Figure 66: Illustration of hypothetical combination of geothermal build plus increased sculpting of hydro to meet peaky demand growth



DUog_Miscellaneous_v03.xlsx

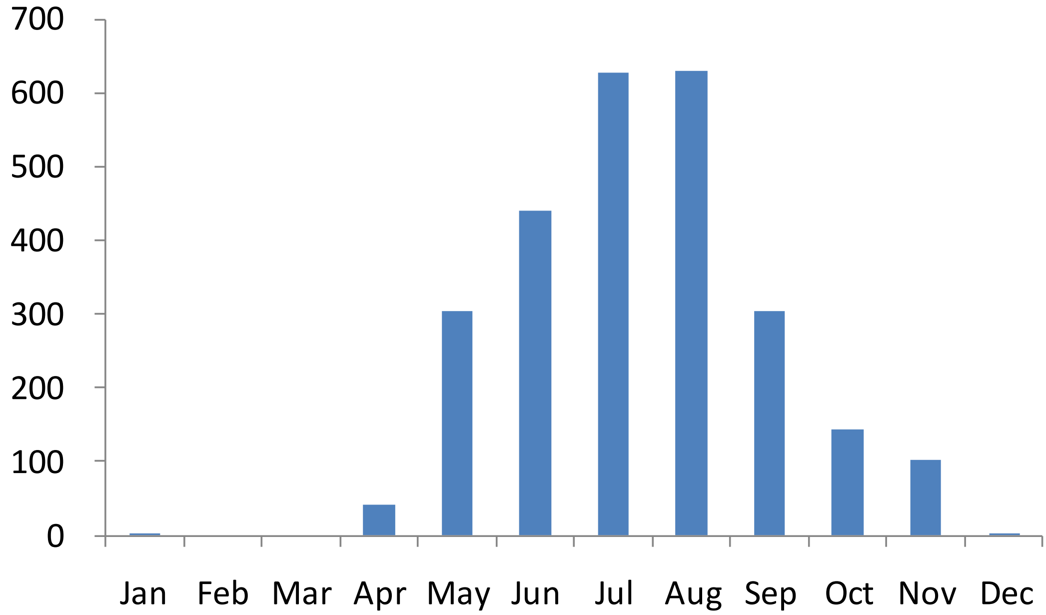
In Figure 66 the solid blue and red lines represent the hydro and geothermal generation profiles at the start of the period, and the dashed lines represent their respective generation profiles at the end of the period (e.g. after ten years) in order to meet the peaky demand growth represented by the grey shaded area.

It shows hydro generation being used less during low demand periods, with water stored for use at such times to enable increased generation at high demand periods in order to meet the peaky nature of the demand growth. This reduced hydro generation at low demand periods is met by increased geothermal generation, the scale of which is greater than the scale of demand growth at such low demand periods.

In reality, there are constraints on the ability of hydro generation to increasingly sculpt its output. Only the Waitaki scheme has storage capacity of a size of any real significance that is capable of effectively storing water for three to four months. All other schemes have much lower storage capabilities and/or are unable to effectively store water in significant quantities more than a few weeks (or days in some cases). This means there are limited opportunities to shift significant quantities of water from one season to the next.

Indeed, a significant proportion of New Zealand's hydro generation must use any inflows within a month or two of it arriving, with any storage capability being limited to weeks (or even days) rather than months. This is a serious constraint on the ability of hydro generation to increase the amount of sculpting to meet space heating demand because, as Figure 67 below illustrates, space heating demand is concentrated in a four month block from mid-May to mid-September.

Figure 67: Concept modelled monthly kWh heat load distribution for a medium Wellington heating load



There are also resource constraints which limit the ability of hydro schemes to sculpt their generation – in particular the requirement to maintain minimum rivers levels significantly reduces their ability to sculpt generation away from low demand summer periods.

Similarly, at the other end of the spectrum, the physical generation capacity of the plant is a hard constraint limiting the maximum amount of generation that can be produced.

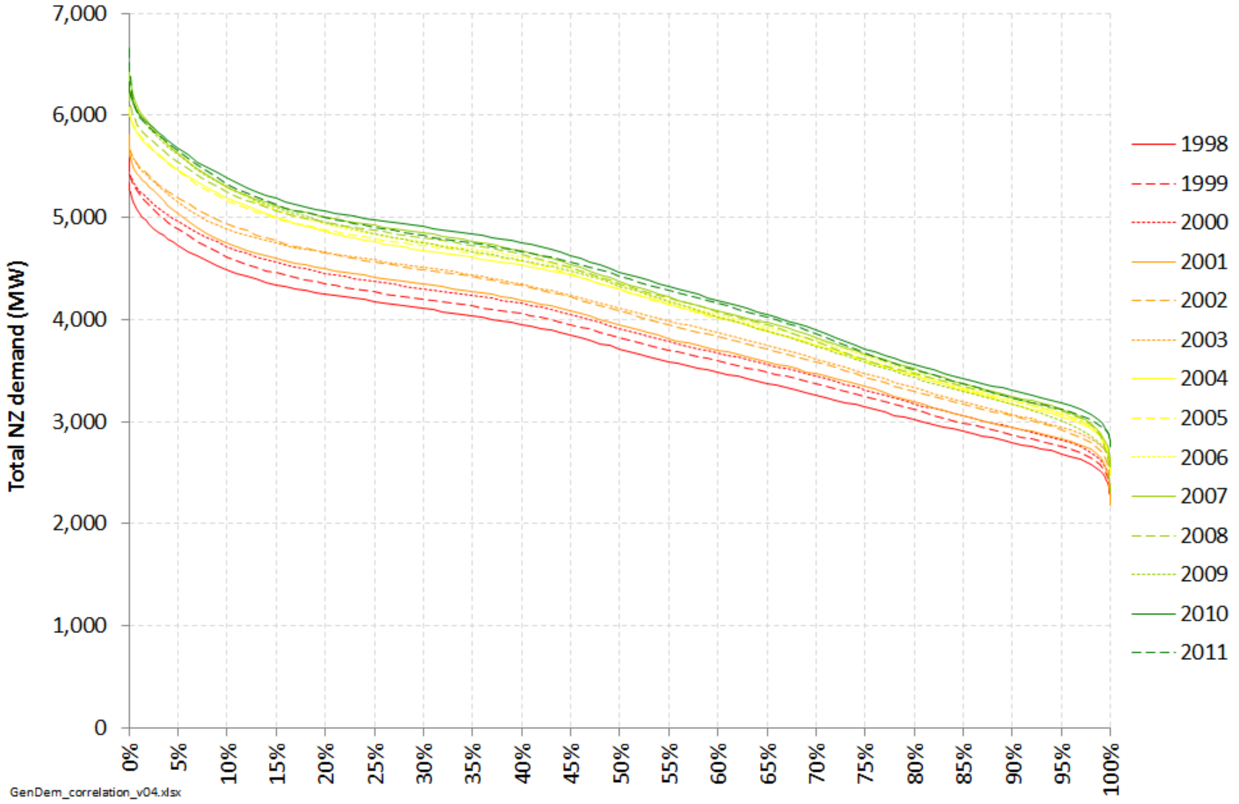
FONZ has functionality which enables the extent of hydro sculpting to vary with changes in demand shape. However, it also has constraints built within in it to limit the extent of this sculpting to reflect the constraints outlined above.

It is largely because of these constraints that an increase in peaking and mid-merit demand is largely[45] met by increased thermal generation.

To check whether this result is likely to tie in with reality, observed market outcomes over the last 14 years were examined. As Figure 68 below shows, there has been considerable demand growth over this period which, as Figure 69 shows, has been quite peaky. Thus, demand at peak times has grown by approximately 1,100 MW over this period, while demand in low-demand periods has only grown by approximately 430 MW.

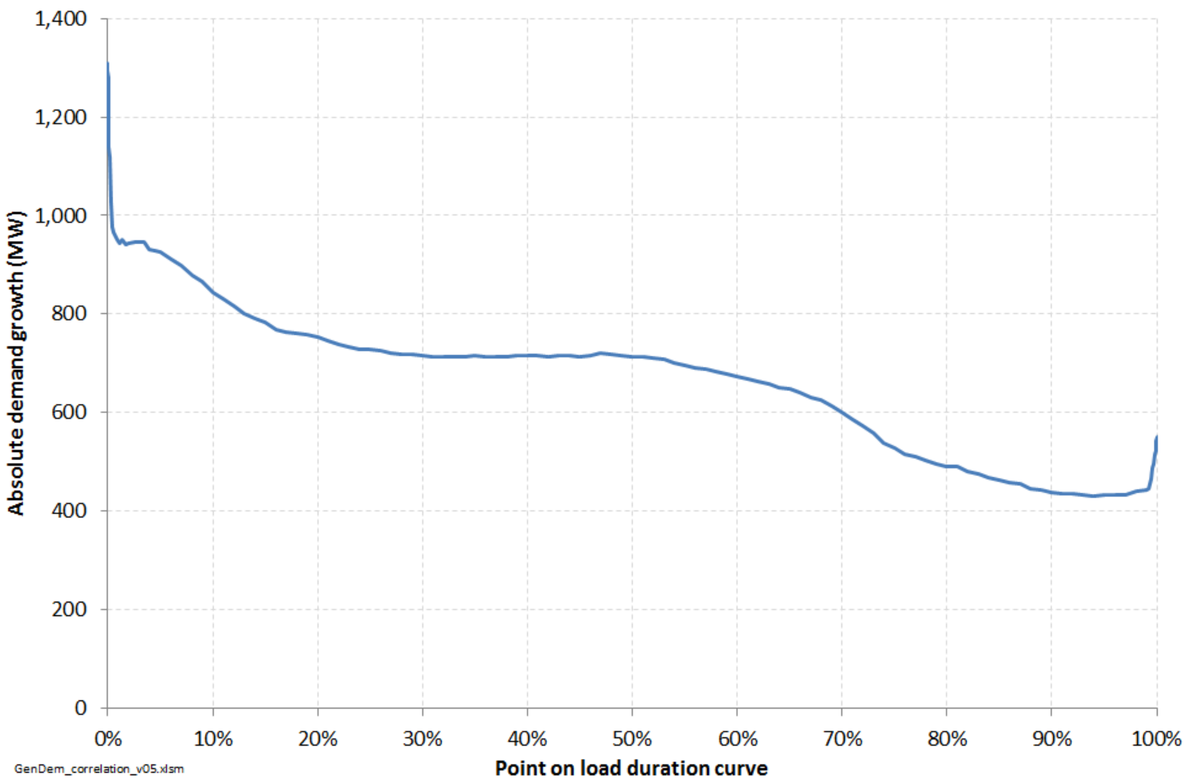
[45] The model does indicate that there is some limited increase in sculpting to meet growth in mid-merit demand.

Figure 68: Historic load duration curves for total New Zealand demand



Source: Concept analysis using Electricity Authority centralised data set data

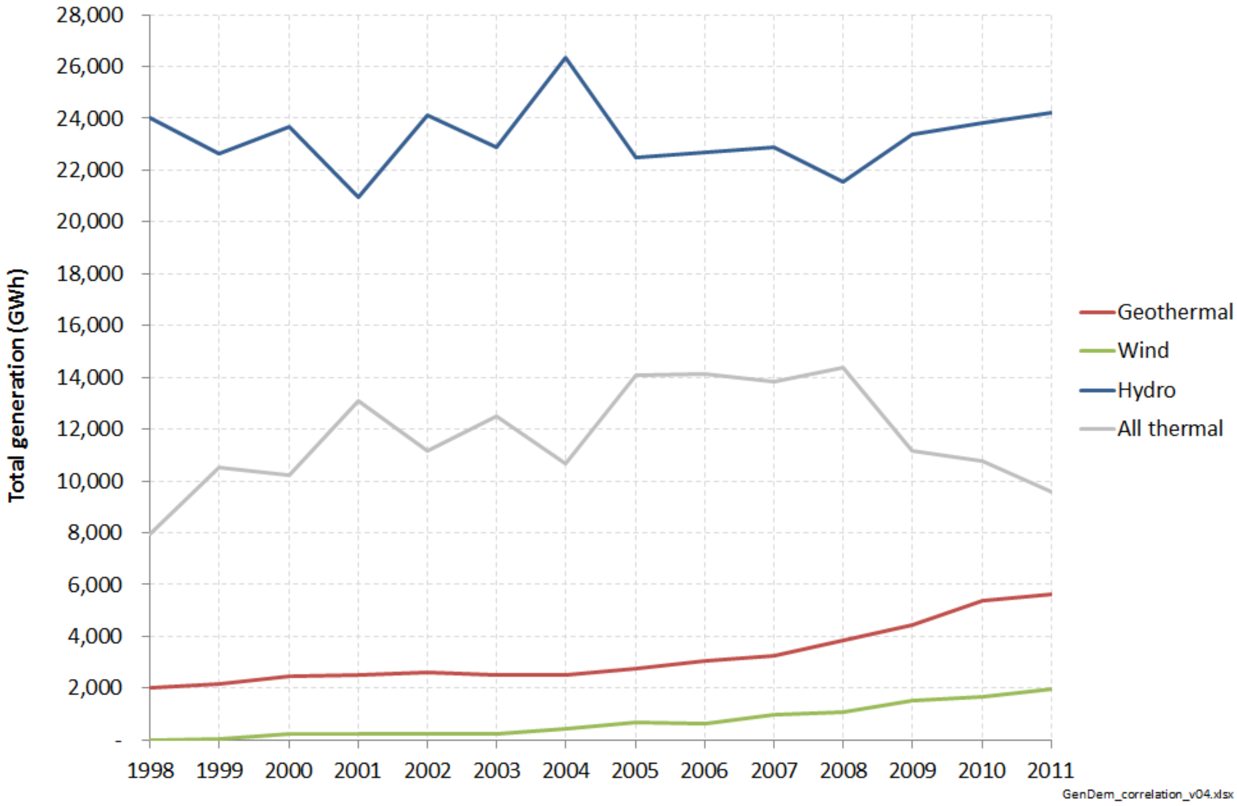
Figure 69: Differential growth in the national demand load duration curve from 1998 to 2011



Source: Concept analysis using Electricity Authority centralised data set data

As Figure 70 below shows, this increase in demand has been met in large part with an increase in geothermal and wind generation – both of which are baseload options[46] – plus some increase in thermal generation.

Figure 70: Change in renewable generation from 2001 to 2011



Source: Concept analysis using Electricity Authority centralised data set data

Thus, if there is the potential for hydro generation to increase the degree to which it sculpts its water, it would be expected that this peaky demand growth over this period would be met by an increasingly peaky shape to hydro generation in New Zealand as water is increasingly sculpted to meet this higher demand in peak and mid-merit periods.

However, as Figure 71 below illustrates, this has not happened, rather the shape of the hydro generation curve coincident with the demand duration curve has remained relatively stable over this period, with the only variation being a general shifting up and down from year to year corresponding with relatively 'dry' and 'wet' periods. Indeed, the hydro generation curve for 2011 is almost identical to the curve for 1998.

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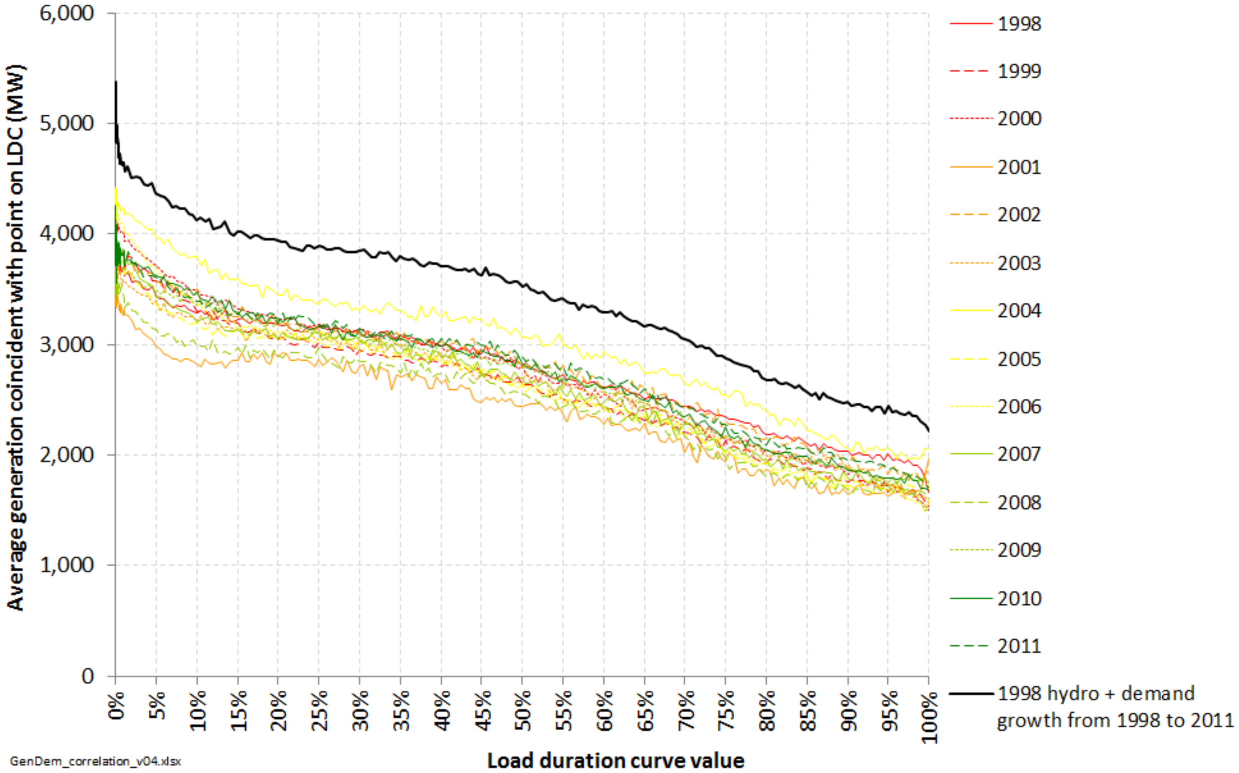
[46] Although wind is a variable technology that randomly varies from full to zero output during the course of the day and year, from the perspective of considering its contribution to the electricity market it is most appropriate to consider it a baseload technology.

Figure 71: Average hydro generation coincident with point on the national load duration curve

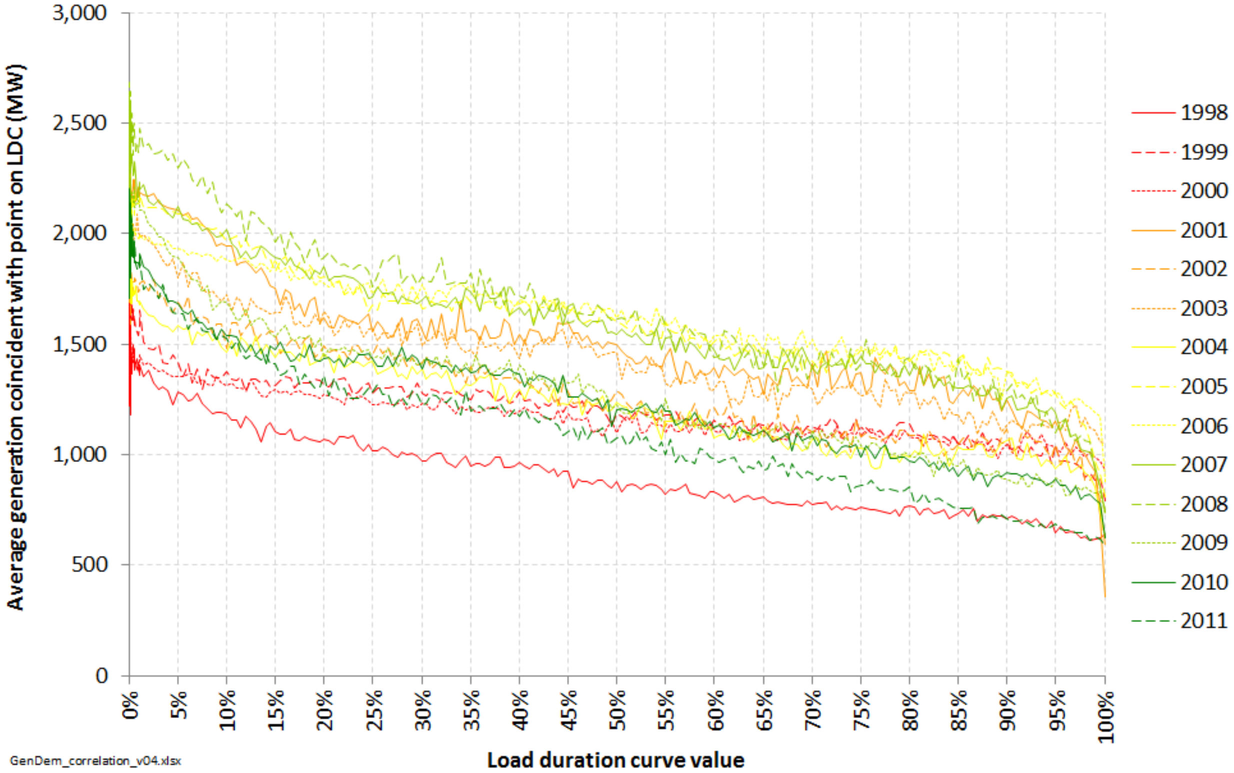


Source: Concept analysis using Electricity Authority centralised data set data

Thus, although there has been a need for hydro to increasingly sculpt its water into meeting this significant growth in peak demand (a lá the fashion stylistically represented by Figure 66), this has not happened.

Instead, as indicated by Figure 72 below, this increased growth in mid-merit and peaking demand has largely been met by an increase in thermal generation – which has also experienced a high degree of year-to-year variability from acting to balance the variation in hydro output in 'dry' and 'wet' years.

Figure 72: Average thermal generation coincident with point on the national load duration curve



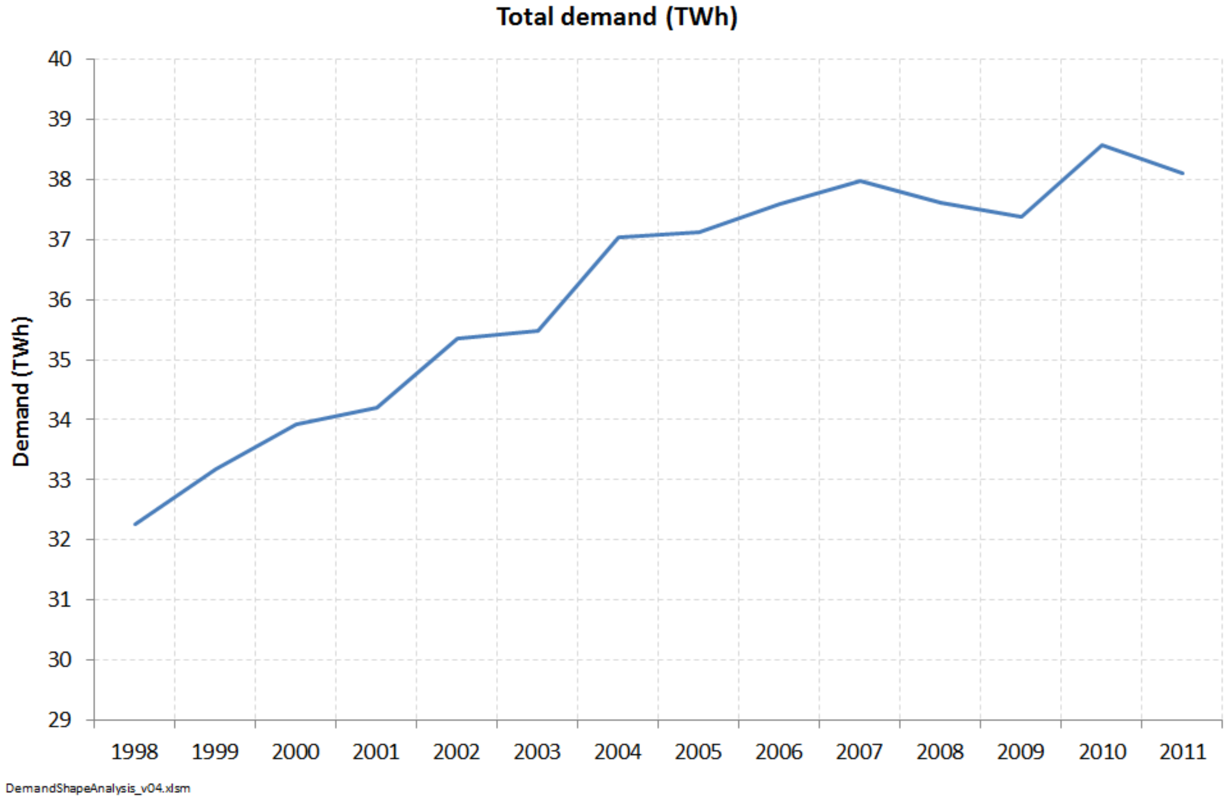
Source: Concept analysis using Electricity Authority centralised data set data

It would therefore appear that the forecast outcomes modelled by FONZ – i.e. mid-merit and peaky generation predominantly being met by an increase in thermal generation – tie in with observed market outcomes of the last 14 years.

That said, closer observation of Figure 72 would suggest that this phenomena of increased thermal demand at mid-merit and peaking periods appears to have reversed over the last three to four years (i.e. thermal output has been progressively sinking) by more than could be expected due to dry and wet year hydrology variations.

However, further analysis of the data would appear to suggest that this has been due to 'over-build' of baseload geothermal and wind options in the last three to four years compared to that required to meet the growth in baseload demand. This is because although there has been new-build generation to meet demand growth over these last few years (as shown in Figure 70 above), there *hasn't* been a material growth in demand over this period as illustrated in Figure 73 below.

Figure 73: Total national demand



Source: Concept analysis using Electricity Authority centralised data set data

Thus, from 1998 to 2007 annual demand growth averaged approximately 1.82% per annum. However from 2007 onwards, demand growth appears to have temporarily stalled, with demand growing at approximately 0.08% per annum during this period.

This is believed to be predominantly due to a mixture of the global financial crisis and the Christchurch earthquake. The scale of this demand reduction appears to have been unanticipated by the industry as a whole, with organisations such as Transpower, MBIE (previously the MED), and the Electricity Authority (previously the Electricity Commission) all having significantly revised their demand forecasts downwards over the last few years. Further, generators have announced that they have put on hold or postponed a significant quantity of new baseload generation development projects due to this reduction in demand. However, it is noteworthy that new peaking thermal generation projects by Contact and Todd energy appear not to have been impacted to the same extent.

Thus, it is considered that this apparent displacement of thermal generation by new geothermal and wind that has been experienced over these last three to four years is largely[47] due to an over-build of such generation due to an unanticipated material reduction in demand growth. However, as the market adjusts to this temporary generation surplus to get back into equilibrium, it is considered that the fundamental conclusions of the analysis that a growth in peaking and mid-merit demand will predominantly be met by increased fossil generation remain sound.

[47] It is likely that some of this displacement has occurred due to 'genuine' economic reasons due to the economics of new renewables improving to an extent that it is cost-effective to build new renewables to displace existing thermal generation from relatively high capacity factor mid-merit duties. This phenomenon is something that is forecast from FONZ when the economics of the different generation options change in such a fashion. However, it is limited to relatively high capacity factor mid-merit duties – certainly not to the low capacity factor operations associated with space heating demand.

The only factor which hasn't been considered in the above analysis is the extent to which other market settings may have impacted on the incentives of hydro generators to store water in the summer to release in the winter.

The only factor which has been suggested as having the potential to cause distortions in hydro generators' release decisions has been the HVDC charge. This has been charged to generators based on their peak anytime output during a year. It is understood that this has impacted on some south island hydro generators' incentives to generate at their peak capacity. As such, it is potentially the case that the proposed change to transmission pricing put forward by the Electricity Authority may remove this distortion and therefore enable hydro generation to increasingly sculpt its output to meet any growth in winter / peaking demand.

However, there are two factors which suggest any change may not materially affect the conclusions with regards to the emissions intensity of electricity to meet a space heating demand profile:

- Firstly, the distortion on generators' incentives is focussed on relatively short periods of extreme peak demand. Space heating, on the other hand, is spread over a much larger period of four to five months of winter. Thus, this distortion should not materially affect generators' incentives with regards to storing water from the summer for release in winter, even if it may affect their incentives with regards to release of that water for a small number of peak periods within those winter months.
- Secondly, even if this distortion was having a material effect on seasonal storage / release decisions, if and when it is removed the market would move to a new equilibrium over a period of a few years. Thus, given that the ability of the hydro system to increase sculpting of its generation into winter and away from summer is limited by physical constraints, the dynamics outlined above would re-establish themselves after this transition period, such that in the long-term a growth in winter / peaking demand would continue to be predominantly met by fossil generation.

Short-term 'static' considerations versus longer-term 'dynamic' considerations

The above analysis has been focussed on likely changes in generation *over the long-term* due to changes in demand.

In the short-term, i.e. less than two to three years, there are much fewer opportunities for changes in the composition of the generation fleet to occur (e.g. through building new power stations) to meet changes in demand.

Instead, a change in demand will predominantly be met by a change in operation of the existing generation fleet.

In this respect, it is considered that almost all changes in demand over the course of a year will be met by changed output of existing *fossil* stations. This is because:

- Geothermal and wind plant operate on a must run basis, and thus their output for a given year is largely independent of demand during that year; and
- This is also effectively the case for the operation of hydro plant. This is because, although hydro plant does sculpt its output to meet demand, the way that hydro plant are offered into the market through the use of water value curves means that an increase or decrease in demand in one week (relative to an 'expected' level of demand) will result in a corresponding decrease or increase in the amount of water released in subsequent weeks. This 'self-correcting' nature of water value curves ensures that water release is optimised and that the total amount of hydro generation in a given year is predominantly a function of inflows, rather than demand in that year.

Using such a framework a change in demand, including baseload demand, will predominantly be met by a change in fossil generation. This is consistent with the observed outcomes illustrated in Figure 72 above which illustrate how an 'over-build' in geothermal and wind generation (equivalent to a reduction in demand for all other types of generation) has resulted in a material reduction in fossil generation.

For this conclusion that short-term demand changes (i.e. within a two to three year timeframe) will be predominantly met by changes in fossil generation to be incorrect, it would have to be believed that existing renewable generation routinely 'spill's a lot of its available 'fuel' (i.e. water, wind, or geothermal steam) in order to pick up the slack associated with changes in demand. However, this behaviour is not what is observed.

In estimating what the effective emissions intensity of a change in demand will be (e.g. through a consumer purchasing a heat pump instead of a gas-fired heater, say), it is assumed that the short-term emissions intensity values (i.e. predominantly fossil including for baseload) will solely apply for the first 1.5 years, but that after 3 years the long-term emissions intensity values (i.e. predominantly renewable for baseload demand, but fossil for mid-merit / peaking demand) will apply, with the intervening 1.5 years being an average of the two. This is consistent with a view that generation investment decisions have a lead time of approximately three years (once consents have been secured) and thus it will take approximately two to three years for altered demand outcomes to flow through to altered generation investment patterns.

Estimation of the carbon intensity of different-shaped demand profiles

As the above discussion has identified:

- in the long-term, growth in mid-merit and peaking demand will generally be met by an increase in thermal generation whereas baseload demand growth will predominantly be met by an increase in renewable generation;
- in the short-term, changes in any type of demand will predominantly be met with changes in thermal generation output.

However, precisely which generation will meet any change in demand is sensitive to a number of factors with inherent uncertainties. Further, the point at which high capacity factor mid-merit demand growth would be met by renewable rather than thermal generation is impacted by the same inherent uncertainties – the scale of which are such that in some futures with very low gas prices and low CO_2 prices it is likely that *baseload* demand growth would be met by increased CCGT thermal generation rather than renewable generation.

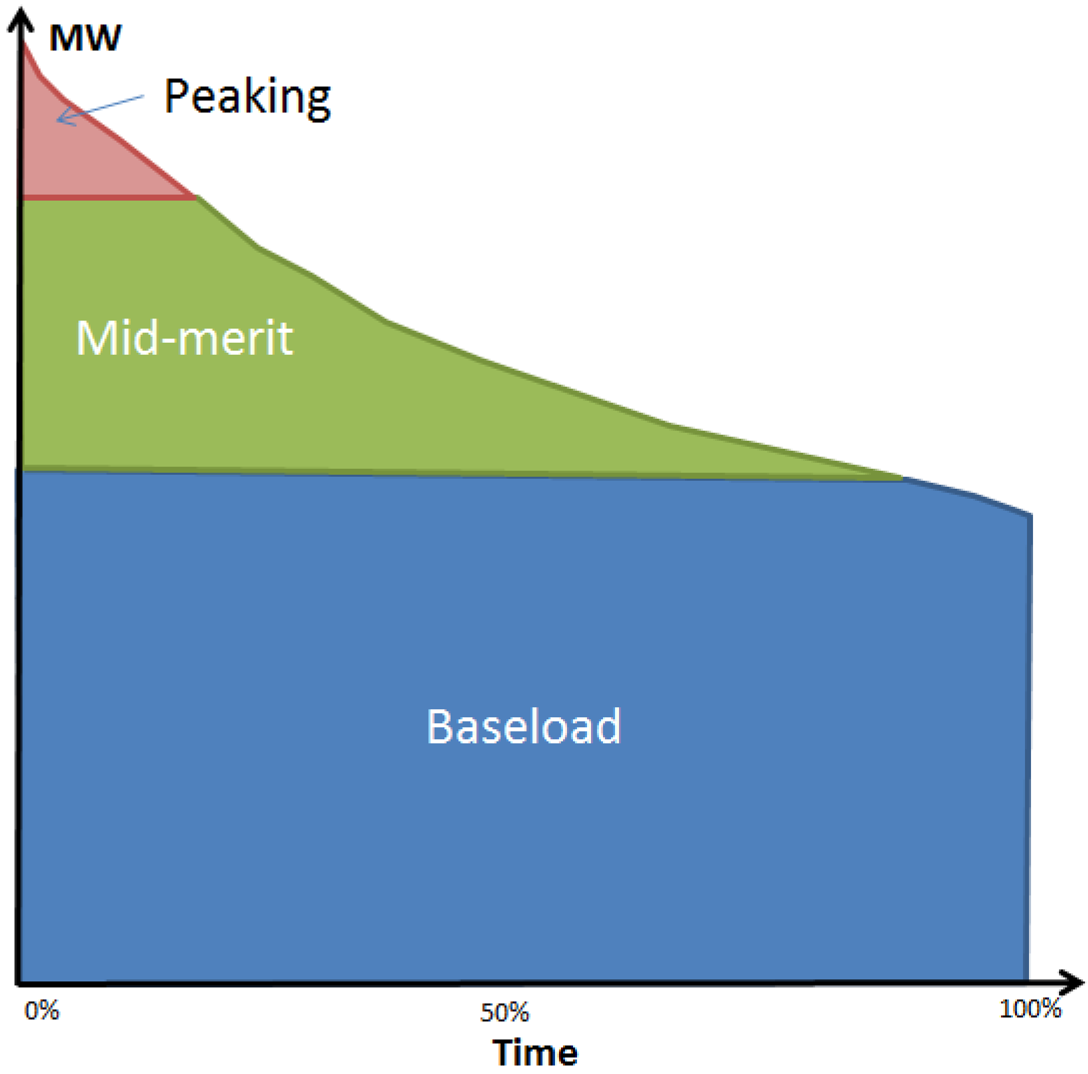
In addition, as the analysis in sections 2.1.1 and 3.1.1 has demonstrated, there are many different demand shapes associated with the different types of space and water heating options.

Given all of the above, for the purposes of making this analysis tractable, demand periods were simply grouped into three categories as follows:

- Baseload periods were classed as those where national demand had a load factor of greater than 85%
- Mid-merit periods were classed as those where national demand had a load factor between 20% and 85%; and
- Peaking periods where classed as those where national demand had a load factor of less than 20%.

This is illustrated in Figure 74 below

Figure 74: Illustration of demand classification

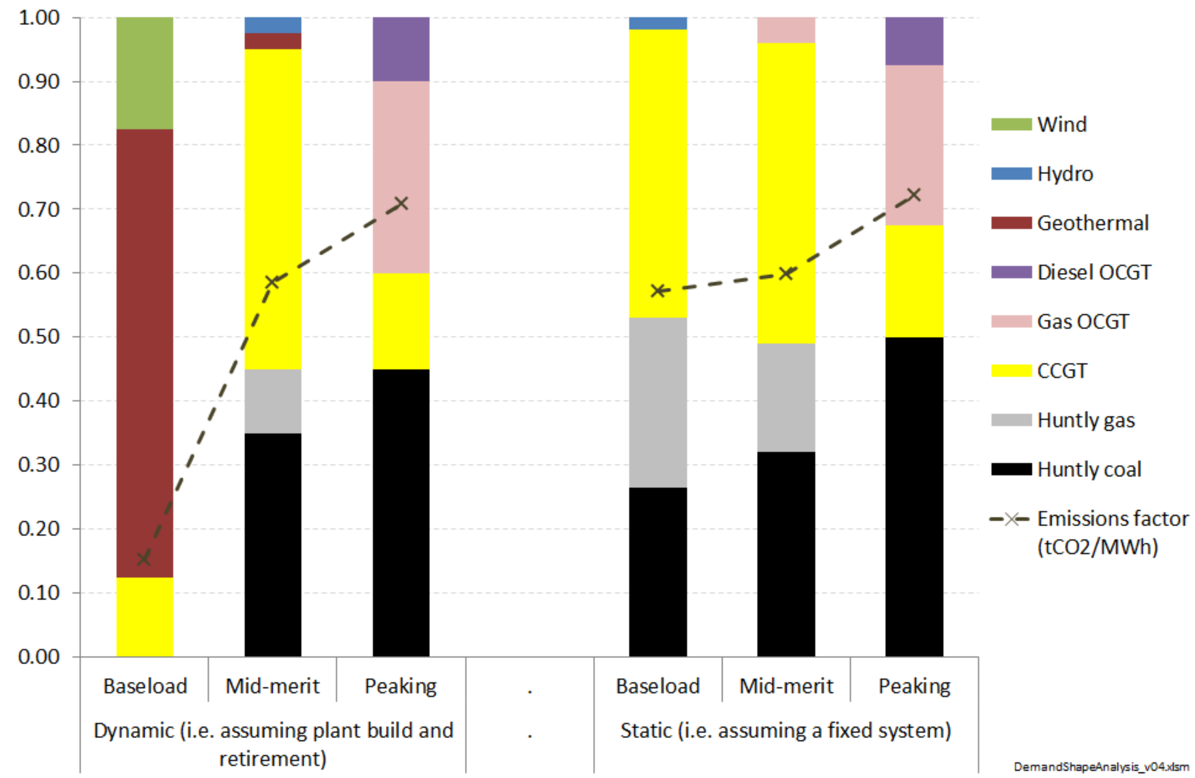


DUog_Miscellaneous_v03.xlsx

For each of these demand periods, a weighted average of the types of generation that would increase in order to meet an increase in demand was determined based on FONZ projections spanning a range of possible scenarios considering factors such as fuel and CO_2 prices.

These proportions, and the consequential emissions factors, are illustrated in Figure 75 below. (Note: both the proportions and emissions factors work to the same y-axis scale.)

Figure 75: Plant types projected to meet growth of demand at different times



Source: Concept estimates

The framework was then developed further in that chronological time was split into nine blocks as follows: Three within-day periods (Day, Night and Peak), for three seasonal periods (Summer, Winter, and Shoulder).

For each of the demand shapes under consideration, the proportion of load which fell into each time-block was calculated using the demand profiles described in section sections 2.1.1 and 3.1.1. The results of this are shown in Table 7 below.

Table 7: Proportion of load in different time-blocks for different electricity heating load shapes

	Sum day	*Sum night*	*Sum peak*	*Win day*	*Win night*	*Win peak*	*Shl day*	*Shl night*	*Shl peak*
Space heating	0.0%	0.1%	0.0%	43.3%	7.4%	38.2%	6.6%	1.8%	2.5%
Night storage heater	0.0%	1.6%	0.0%	0.0%	79.2%	0.0%	0.0%	19.2%	0.0%
Cylinder - anytime	11.6%	4.4%	5.1%	25.6%	9.6%	11.3%	17.9%	6.7%	7.9%
Cylinder - night only	0.0%	21.0%	0.0%	0.0%	46.5%	0.0%	0.0%	32.5%	0.0%
Cylinder - night + boost	5.8%	15.2%	0.0%	12.8%	33.7%	0.0%	8.9%	23.6%	0.0%
Solar + electric	3.0%	3.6%	4.2%	17.2%	21.0%	24.4%	7.3%	8.9%	10.4%

Source: Concept analysis

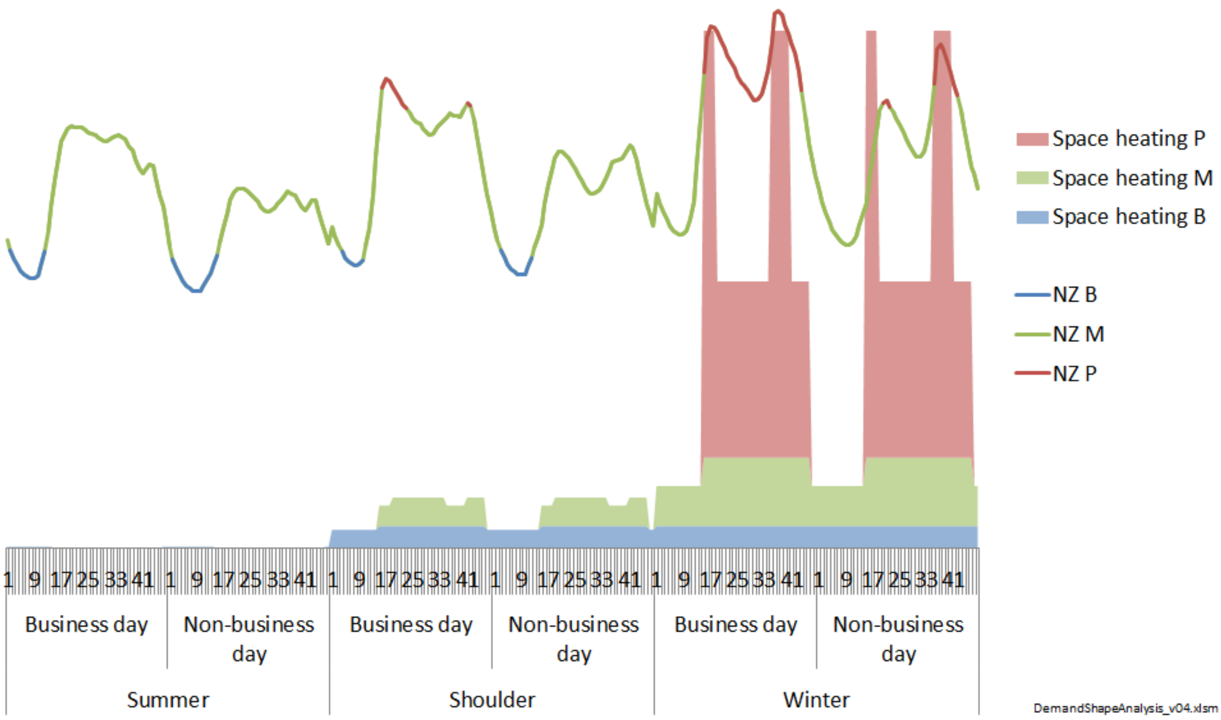
For each of these time blocks, a tool was developed which determined the proportion of load which fell into the “Baseload”, “Mid-merit” and “Peaking” time classifications as follows.

This is illustrated in Figure 76 below which shows national demand, and a space heating profile for six sample days (business day and non-business day for summer, winter, and shoulder months).

National demand is illustrated via the line, and each time period has been coloured as to whether it is a “Baseload”, “Mid-merit” or “Peaking” time period (noting that it is national demand which determines how a time period is classified).

The shaded area illustrates the heating demand profile under consideration (in this case space heating), which has been calculated based on the proportions set out in Table 7 above. The profile has been shaded according to whether the demand would be considered to be an increase in *system* baseload, mid-merit or peaking demand.

Figure 76: Illustration of the classification of space heating demand into baseload, mid-merit, or peaking

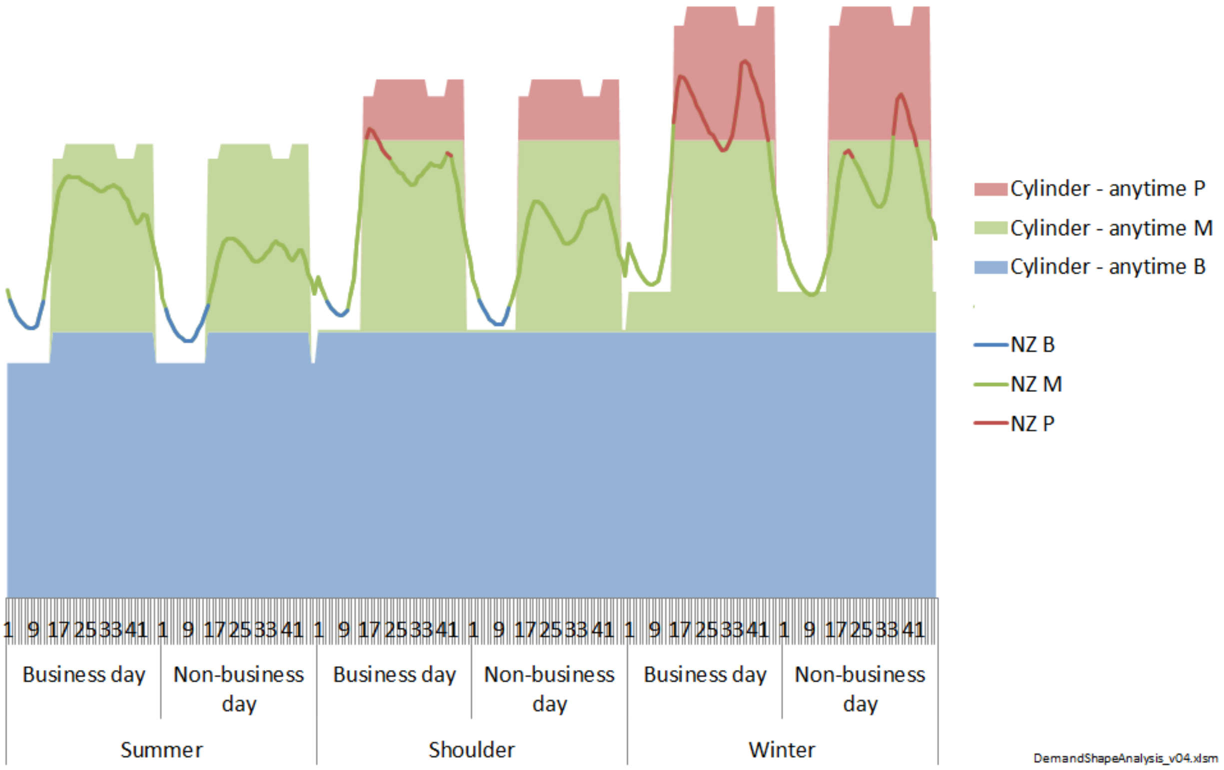


Source: Concept analysis

As can be seen, approximately 60% of space heating demand would be categorised as contributing to peaking generation requirements, with only 14% being considered contributing to baseload generation requirements.

Figure 77 below illustrates the same approach for considering cylinder-based water heating demand.

Figure 77: Illustration of the classification of cylinder-based heating demand into baseload, mid-merit, or peaking



Source: Concept analysis

As can be seen, because the demand for water heating is much more constant throughout the year, the majority (approx. 59%) of water cylinder-based water heating load should be considered to be baseload.

Results of calculation of fuel emissions factors

This analysis was carried out for the different electricity heating profiles set out in Table 7 above. The resulting proportions of baseload, mid-merit and peaking demand were then cross-multiplied with the emissions factors associated with such demand as illustrated in Figure 75 above to give a final emissions factor associated with a demand shape.

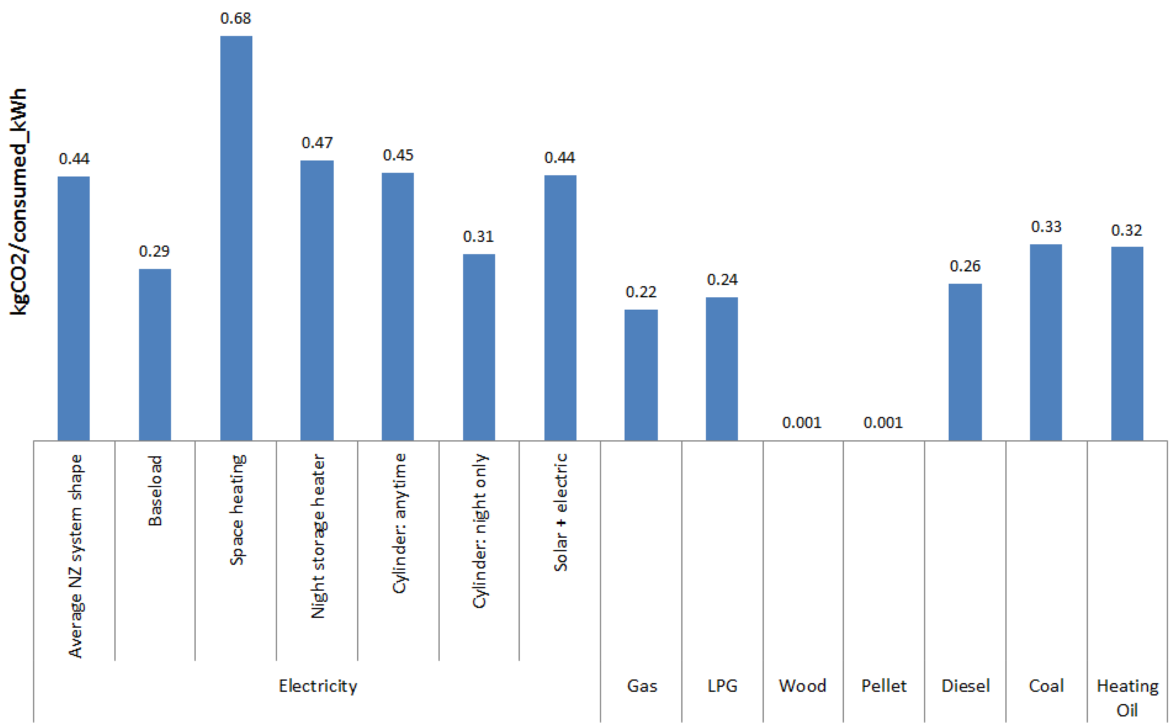
These final emissions factors for the different fuels are given in Table 8 and Figure 78 below, along with the emissions factors for the non-electricity fuels which were sourced from the CAENZ study.

Table 8: Derivation of delivered fuel emission factors[48]

Fuel	Demand profile	Resource emission factor kgCO2/GJ	Processing losses	Transmission losses	Distribution losses	Delivery factors kgCO2/GJ	Delivered emission factor kgCO2/GJ	Delivered emission factor kgCO2/kWh
Electricity	*Average NZ system shape*	112	0.00%	3.40%	6.30%	0.00	122.6	0.441
Electricity	*Baseload*	73	0.00%	3.40%	6.30%	0.00	79.7	0.287
Electricity	*Space heating*	171	0.00%	3.40%	6.30%	0.00	187.6	0.675
Electricity	*Night storage heater*	118	0.00%	3.40%	6.30%	0.00	129.9	0.468
Electricity	*Cylinder: anytime*	113	0.00%	3.40%	6.30%	0.00	124.2	0.447
Electricity	*Cylinder: night only*	79	0.00%	3.40%	6.30%	0.00	86.8	0.312
Electricity	*Solar + electric*	113	0.00%	3.40%	6.30%	0.00	123.4	0.444
Gas		58	3.35%	0.50%	1.75%	0.00	61.0	0.220
LPG		60	9.10%	0.00%	0.00%	0.65	66.5	0.240
Wood		0	0.00%	0.00%	0.00%	0.34	0.3	0.001
Pellet		0	0.00%	0.00%	0.00%	0.28	0.3	0.001
Diesel		70	4.65%	0.00%	0.00%	0.22	73.0	0.263
Coal		91	0.02%	0.00%	0.00%	0.20	91.4	0.329
HeatingOil		90	0.00%	0.00%	0.00%	0.22	89.9	0.324

Source: Concept analysis and CAENZ

Figure 78: Central estimate of effective fuel emission factors ($kgCO_2/kWh$)



Source: Concept analysis and CAENZ

For comparison, the emissions intensity of electricity assumed by the Ministry for the Environment for the purposes of industrial allocation of CO_2 allowances (called New Zealand units) under the New Zealand Emissions Trading Scheme is 0.537 $kgCO_2/kWh$. This is comparable to the 0.44 kgCO2/kWh figure shown in Figure 78 above for the average New Zealand system demand shape.

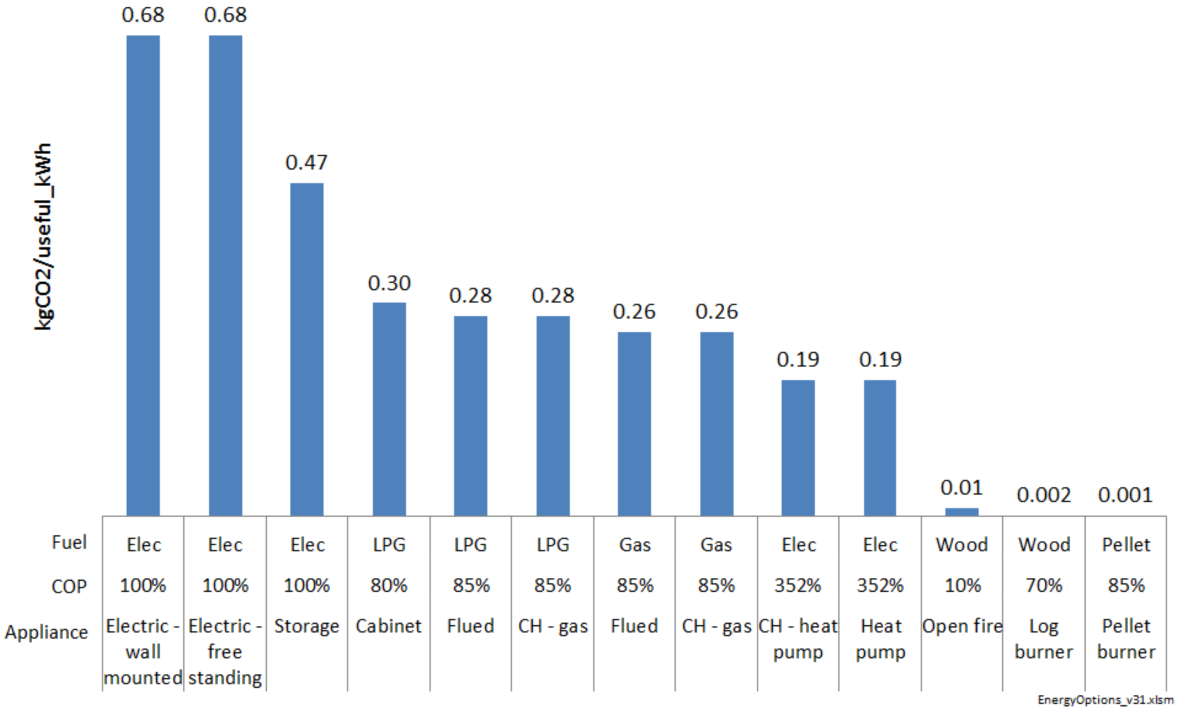
48 The resource emission factor of Wood and Pellet fuel is considered to be zero because it is assumed that any CO_2 released by burning such fuels will be sequestered again by the planting of trees to make more log / pellet fuel.

It should be recognised that there is some inherent margin of uncertainty relating to the electricity factors shown in Figure 78 due to the issues outlined above. It is considered that this is likely to be greatest for baseload demand shapes given that there is a real possibility of a change in New Zealand's gas position resulting in gas-fired baseload plant becoming the most economic option again. For peaky demand shapes such as space heating, however, it is considered that there is less likelihood of material changes given that there are fewer economic options to meet such a lower capacity factor mode of operation. That said, there is still material inherent uncertainty over the proportions of peak electricity that will be met by the various thermal options (Huntly (on coal or gas), CCGT, gas-fired OCGT, and diesel-fired OCGT). This will result in some inherent margin of error in relation to the emissions intensity of peak electricity.

The values shown in Figure 78 relate to the emissions intensity of fuels *delivered* to an appliance. However, as set out in sections 2.1.2 and 3.1.2, the different space and water heating appliances have very different efficiencies. Accordingly, in order to work out the emissions intensity per *useful* kWh of space and water heat, it is necessary to factor the fuel emission intensities by the appliance efficiencies.

This results in the emissions intensities for the different heating appliance as illustrated in Figure 79 and Figure 80 below.

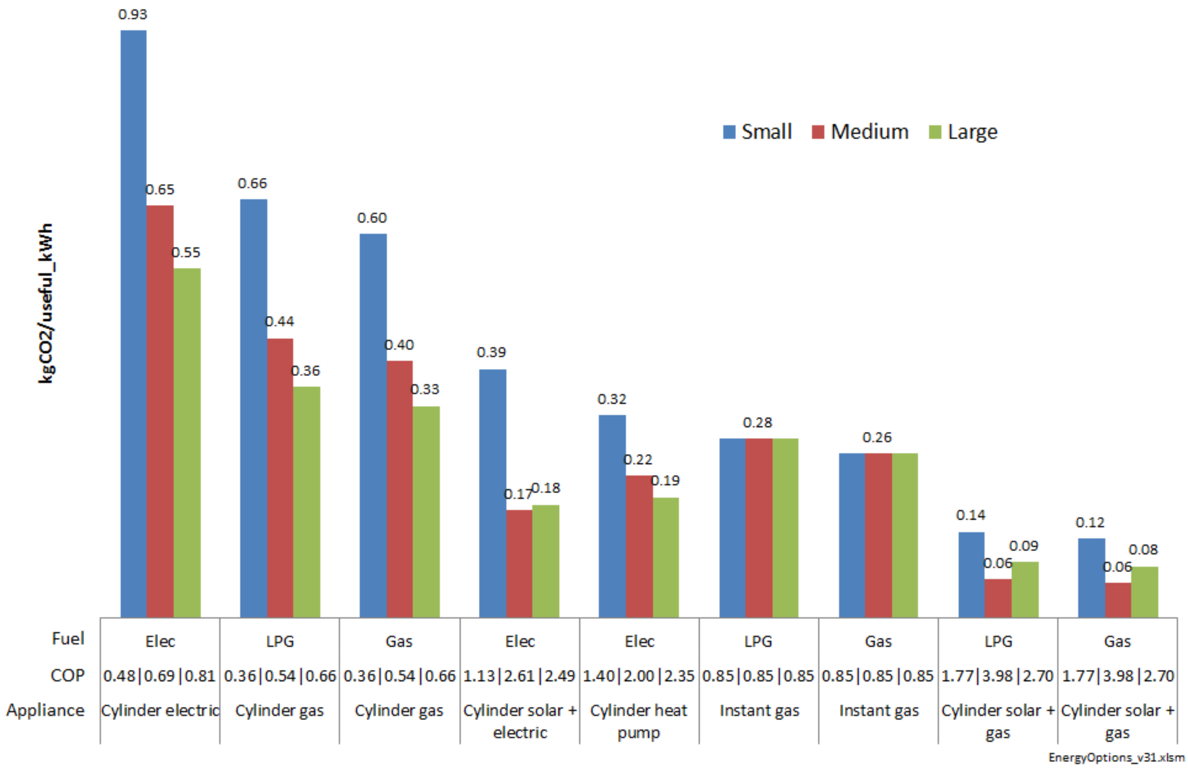
Figure 79: CO_2 emissions intensity of space heating options (kgCO_2/*useful*_kWh)



Source: Concept analysis Note: The heat pump COP chosen is for a Wellington location.

Thus, even though electricity space heating demand has an extremely peaky profile, with a consequentially high emissions intensity, the high coefficient of performance of heat pumps makes their emissions intensity slightly lower than for the gas space heating options. Log and pellet burners remain the best options from an emissions intensity perspective.

Figure 80: CO_2 emissions intensity of water heating options ($kgCO_2$/*useful*_kWh), assuming a central electricity emissions intensity scenario for small, medium, and large domestic water heating loads



Source: Concept analysis. Note: The heat pump COP chosen is for a Wellington location.

In considering the above chart it should be noted that:

- the water heating options which use a cylinder (i.e. all of them apart from instant gas) suffer substantial reductions to their COPs due to the high standing losses from such cylinders. In particular:
  - this is proportionately a much greater issue for consumers with small water heating loads than for large, as the standing losses vary much less than the amount of water consumed.
- the size of the losses varies among technologies, with:
  - gas cylinders suffering higher losses due to their being located outside a property.
  - 'Solar + gas' has far less losses due to the fact that the solar cylinder can have the water temperature kept at below 60˚C because the instant gas back-up can raise the water above this temperature in order to kill any legionella bacterium that may reside within the cylinder.
- the water heating options which use solar plus electricity or gas back-up need to have the contribution of the sun taken into account in order to derive a net coefficient of performance.

Overall, purely from an emissions perspective, gas heating options appear broadly similar with electric heat pump options (although for space heating, heat pumps are a bit better), superior to electric resistance heating options, but inferior to renewable heating options.