Greenhouse Gas Impacts of Direct Use of Gas (displacing electricity) in NZ

Summary

This paper responds to the question - should Auckland Council encourage householders and businesses to switch from electricity to gas to reduce the city's carbon emissions?

The context for this is the 400,000 homes expected to be built in the Auckland region by 2040.

EECA's analysis shows that under any emissions factor scenario, the direct use of gas will increase CO_2 emissions where it displaces electricity.

Our analysis is underpinned by the assumptions that:

- The electricity generation system is an integrated, national system – calculating emissions factors on a regional basis would be misleading
- Actions must reduce carbon at a national level
- The electricity generation built between now and 2040 will be predominantly renewable (though not necessarily all renewable).

We considered four emissions factor scenarios when considering electricity generation:

1. A scenario modelling approach
2. Average electricity emission factor
3. Calculated 2025 average emission factor
4. Long run marginal emission factor.

None of these approaches show gas as having lower emissions than that of electricity. Electricity is the lower-carbon fuel.

This paper focuses on the CO_2 impacts of electricity and gas. However, there are a range of wider issues that are also briefly discussed. A key issue is the economics of each fuel option, and also the role of gas in displacing more CO_2 intense fuels (e.g. coal) and replacing older less efficient technologies which cause high particulate emissions (e.g. open fires which adversely affect air quality).

Should Auckland Council encourage householders and businesses to switch from electricity to gas to reduce the city's carbon emissions?

This paper considers an Auckland householder's energy choice between direct use of gas and electricity, and how this choice affects New Zealand's overall CO_2 emissions.

EECA's analysis shows that the **direct use of gas will increase CO_2 emissions** where it displaces electricity.

Scope

This paper only considers the direct use of gas as a replacement for electricity in households.

It does not look at whether it is 'better' to use gas directly in homes and businesses versus using gas to generate electricity in a power station as this is not a decision that the Council can readily influence. This is a decision made by the electricity market, and central government policy settings.

This paper takes the view that actions must reduce carbon at a national level

We are assuming that the overall goal is to reduce New Zealand's total emissions, not a single household's or region's emissions.

This paper does include consideration of other factors (e.g. economics, fugitive emissions etc)

While we have mainly focused on the effect fuel switching would have on CO_2 emissions – we include a consideration of the consumer costs of gas versus electricity as this may have an impact on any policy decisions.

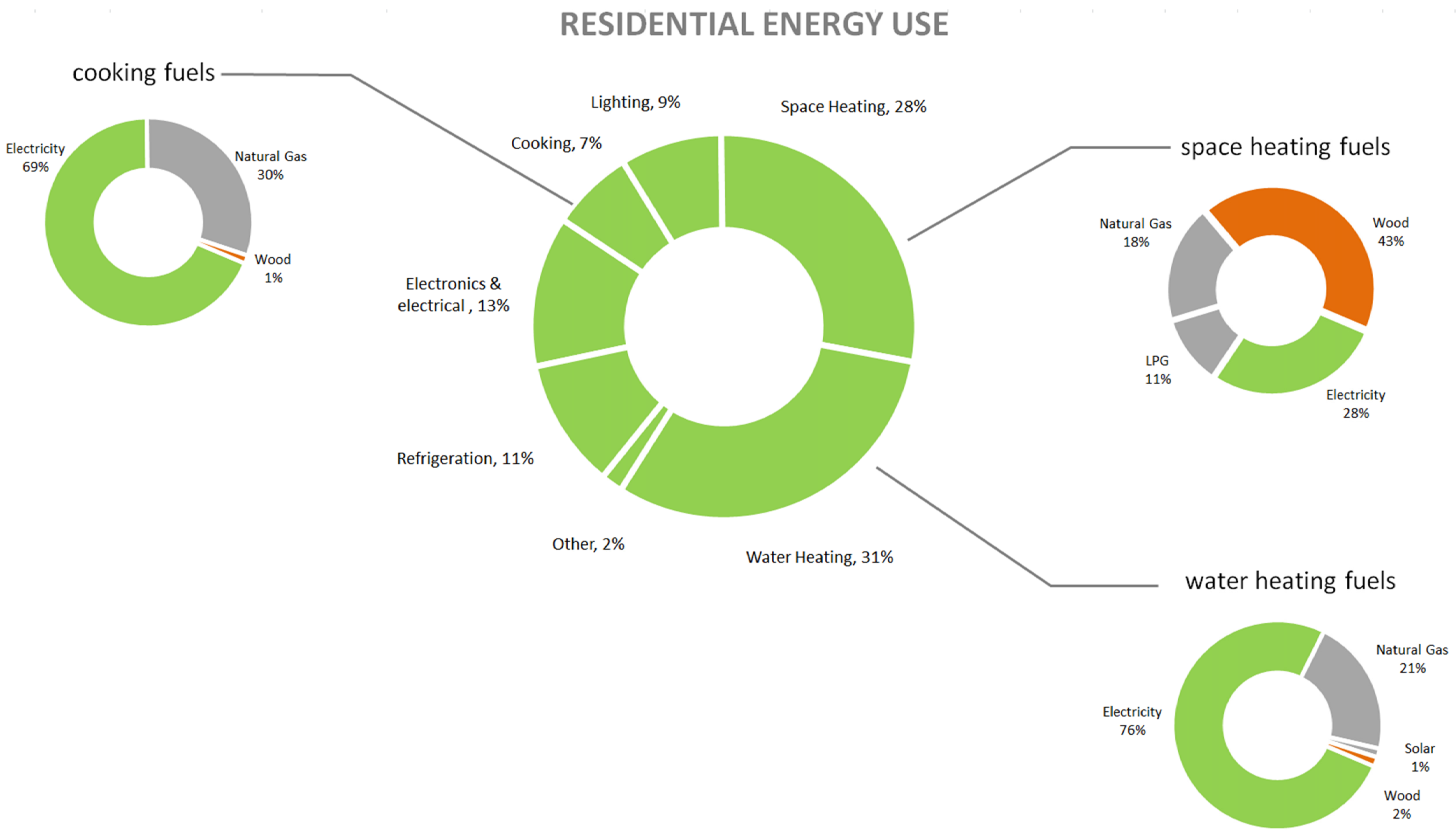
We also discuss the issues of heating capacity (e.g. the effectiveness of gas heating), fugitive emissions, and particulate emissions (i.e $PM_{2.5}$ - PM_{10}). It is difficult to quantify the impact of these issues in this short paper, so they are covered qualitatively.

The approach

We have looked at a number of areas in considering this topic.

- Is there enough flexibility in consumer energy end-use to allow people to switch fuels?
- What is the emissions impact of an incremental increase (and decrease) in gas use
- What is the emissions impact of an incremental increase (and decrease) in electricity use
- Are there any instances where fuel switching causes significant end-use efficiency changes
- Compare electricity versus direct gas use, and identify the lowest CO_2 emission option, and
- Consider the economics and other issues with the above scenarios.

Figure 1 - Graphs of typical energy use (segmented by quantity and fuel type) in Auckland households.



Is the volume of residential fuel switching large enough to matter?

Typical residential energy use

On average, a household's energy use is split into the proportions shown in figure 1 above (data from EECA's end-use database). While electricity is the predominant fuel (and many households are 100% fuelled by electricity), there are a variety of other fuels used in some instances. These other fuels include:

- Reticulated gas (for cooking, space and water heating)
- Bottled gas – 9kg (cooking)
- Bottled gas – 45kg (cooking, space and water heating)
- Wood (space heating, and water heating via 'wetbacks')
- Solar (water heating).

Figure 1 shows that water heating, space heating and cooking make up about two-thirds (66%) of a typical home's energy use, and these three sectors can use either gas or electricity.

This is a significant volume of potential fuel switching, although the period under consideration is out to 2040. If all of the 400,000 new Auckland homes projected to be built by 2040 used gas to meet 66% of their household energy needs, then about 20 PJ/yr of gas would be required[1].

Greenhouse gas emission factor for direct use of gas

The emission factor for the direct use of gas is 0.2 $kgCO_2$/kWh (see Ministry for the Environment, http://www.mfe.govt.nz/publications/climate/guidance-greenhouse-gas-reporting-2011/voluntary-greenhouse-gas-reporting-emissions-factors-2011.pdf)

This emission factor incorporates the gas distribution and transmission losses (but not losses caused by end-use efficiency). This means that for every kilowatt-hour of gas used (or saved), 0.2kg of CO_2 equivalent greenhouse gas is emitted (or saved) on a national basis.

Greenhouse gas emission factor for electricity

Determining the emission factor for electricity is more difficult than for gas because electricity is made up of multiple fuels, and the emission factor changes over time, so we have looked at three scenarios.

1. *Average electricity emission factor*, 0.129 $kgCO_2$/kWh (see Ministry for the Environment, http://www.mfe.govt.nz/publications/climate/guidance-greenhouse-gas-reporting-2011/voluntary-greenhouse-gas-reporting-emissions-factors-2011.pdf)
2. *Calculated 2025 average emission factor*, 0.03 $kgCO_2$/kWh (assuming we reach the 90% renewable electricity target by 2025, and have 10% gas fired generation)
3. *Long run marginal emission factor*, given the majority of new generation build is renewable, this emission factor is close to zero.

[1] New Zealand's total residential direct natural gas use is currently only about 6 PJ/yr.

The detail of these scenarios is presented in the appendix; **but note that under all scenarios, electricity has a much lesser greenhouse gas impact than the direct use of gas.**

While a discussion of electricity emission factors is important in this paper, there is debate within industry about how these are calculated, and when each method is applicable. Therefore, EECA proposes a simpler and more suitable approach to determining the electricity emissions related to fuel choice in new Auckland homes. The long timeframe under consideration lends itself to a *modelling approach*. This modelling approach is outlined soon, but first some further context is required.

Regional emissions factors

The electricity generation system is an integrated national system, so it would be misleading to use regional emissions factors.

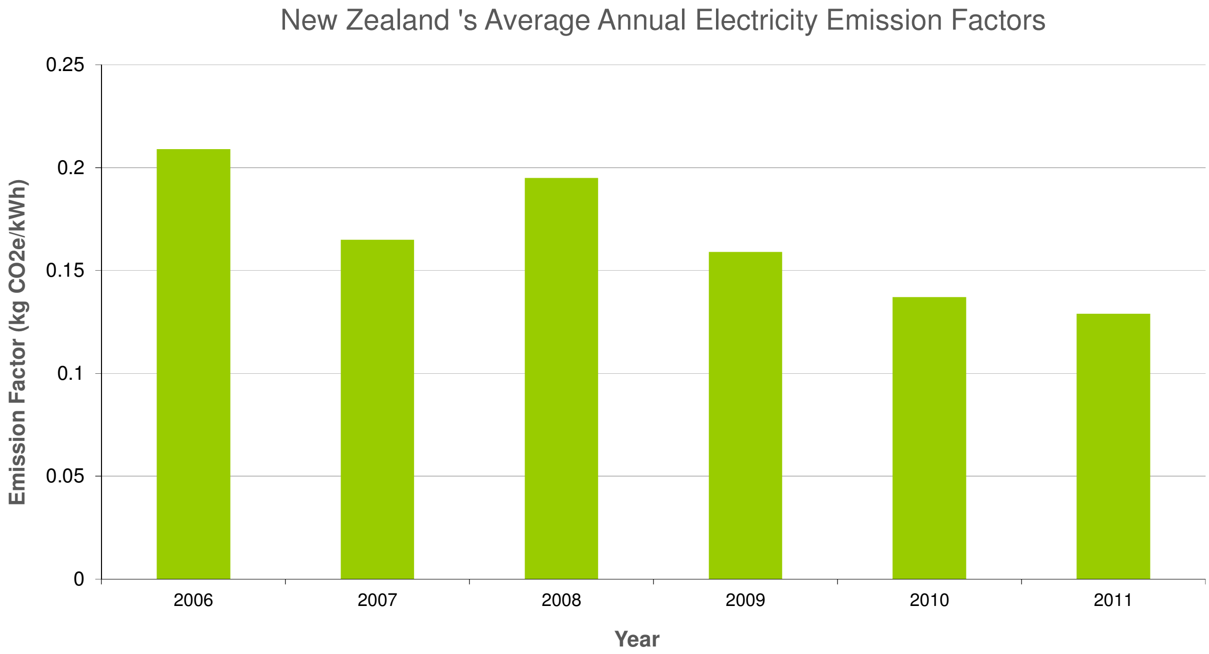
Many generation assets provide essential electricity services that extend beyond regional borders (e.g. frequency control, instantaneous reserves, voltage support, and dry-year backup). The North Island gas and coal power stations are as important to keeping the lights on in Wellington and Invercargill as they are to Auckland. Therefore, the electricity system has only one national emission factor – it would be a distortion to apply regional emission factors to such an interdependent system.

Further evidence for the use of a single system-wide emission factor arises when we consider new investment in generation. If we were to use regional emission factors (e.g. for Auckland), then there would appear to be a case for specifically investing in renewable electricity generation in the Auckland region. However, this would be a very poor outcome because it would result in:

- No additional CO_2 abatement (renewable electricity would most likely have been built elsewhere anyway); and
- Higher-cost electricity for all of New Zealand than otherwise required because Auckland doesn't necessarily have the best renewable resources, but electricity is a national market.

The electricity market is designed to provide the least-cost generation options (from anywhere in New Zealand) to meet the growing demand across New Zealand. The market allows for the cost of the generation plant (capital and operating costs), and the cost of transmission losses in getting the electricity to where ever it is needed. This is why South Island wind and hydro projects have still been progressed in recent years, even though demand is greatest in the Auckland region – it is cheaper to build these remote projects, even allowing for transmission losses in getting the power to the where it is needed. Given generation investment (which drives the emission factor) is on a national basis, we need to consider the electricity emission factor on a national basis.

Figure 2 – Decline of electricity emission factors over time, as the new renewable generation dilutes the average generation mix.



Is one fuel more efficient than the other?

Table 1 – Comparison of efficiencies by fuel and end-use technology (the cooking efficiencies are from US Department of Energy, all other efficiency data is from EECA).

Fuel	Technology	Efficiency[2]	notes
Cooking	Electric stove top	60%	
	Gas stove top	40%	
Space heating	Flued gas heater	85%	Flue losses
	Electric resistive heater	100%	
	Electric heat pump heater	350%	
Water Heating	Gas hot water cylinder	65%	External heat source, & located outside the house
	Instant gas hot water	80%	External heat source / flue losses
	Electric heat pump water heater	220%	
	Electric hot water cylinder	85%	Internal heat source and located inside the house

[2] The outcome of the analysis in this paper does not hinge on these efficiencies. These efficiencies are shown for completeness, and to provide context to gas industry information shown in addenda 1.

The end-use conversion efficiencies are typically higher for electricity (compared to gas) when standard technologies are used; in addition, electricity has a significantly higher efficiency if heat pump technology is used for space heating or water heating.

Also, the areas of higher efficiency are the areas of largest residential energy use (see figure 1), so this potential for more efficient use of electricity is significant in terms of potential CO_2 benefits.

A modelling approach to compare gas versus electricity emissions

As noted above, the direct gas related emissions are relatively easy to calculate for the scenario the Auckland Council is considering (i.e. comparing the emissions impact of direct use of gas versus electricity use in the 400,000 new homes expected to be built to 2040). The gas emissions projection is shown by the grey line on the graph below (see Figure 3). This is easily calculated from the number of homes estimated to be built each year, the proportion of gas assumed used in each home, and the typical end-use gas appliance efficiency.

The future electricity emissions are more difficult to forecast. This is because it depends on the type of generation to be built. However, we can look at credible scenarios for types of generation expected to be built (and resulting emissions). We can also look at what proportion of gas fired generation would have to be built to make electricity a higher emission option, and then test if this scenario is credible.

The 'credible' scenarios for electricity emissions are shown by the green shaded area in the graph below (see Figure 3). Note that electricity emissions are expected to be significantly lower than direct use of gas emissions. The range shown by the green shading represents 70% to 90% of new electricity generation coming from renewable resources.

EECA believes that this predominantly renewable generation scenario is a credible scenario because:

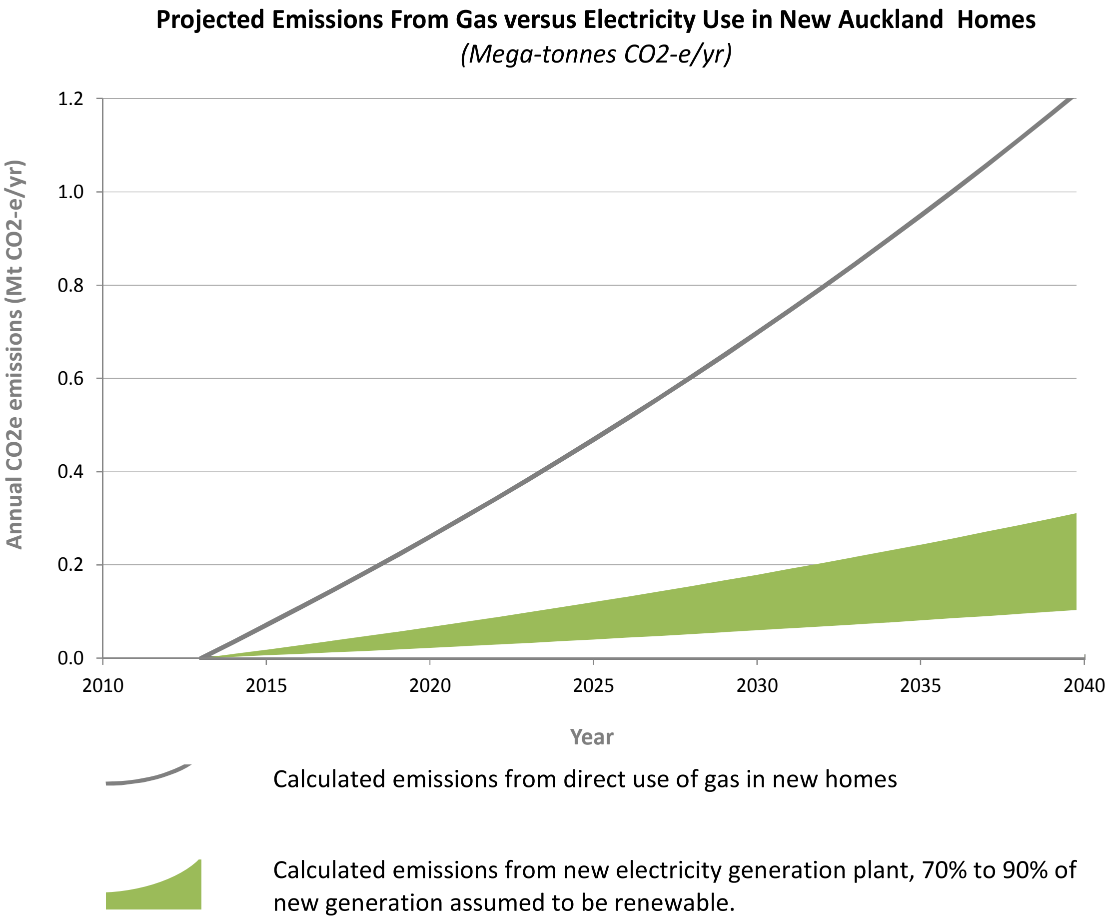
- Current electricity market driven generation investment is observed to be predominantly renewables
- The publicly available generation cost information shows renewables are least cost (e.g. Ministry of Business, Innovation and Employment information[3])
- There is more than 3,500MW of renewable generation projects consented and available to be built (see Electricity Authority website http://www.ea.govt.nz/industry/monitoring/forecasting/long-term-generation-development/list-of-generation-projects/)
- There appears to be support for the '90% renewable electricity by 2025' target across the main political parties.

All of new electricity generation would have to be gas-fired generation before electricity had similar emissions to direct use of gas for the new Auckland homes. This is clearly not a credible scenario. There is no evidence to suggest that future electricity generation will all be from gas fuelled generation.

[3] Note that MBIE information (the 'Interactive Electricity Generation Cost Model') not only shows renewable generation as cheapest, it also shows that new coal based generation is more expensive than gas based generation.

Therefore, it is EECA's considered opinion that promoting direct use of gas in the 400,000 new houses to be built in Auckland (by 2040) will lead to considerably higher greenhouse gas emissions compared to using electricity in those households.

Figure 3 – Comparison of projected emissions from a direct use of gas versus electricity scenario.



Other factors to consider in relation to fuel switching

Cost-effectiveness

The greenhouse gas impact of fuel switching that the Council has sought advice on is an important issue. However, EECA suggests that greenhouse gas impacts should not be considered in isolation; they should be considered alongside the cost-effectiveness of each fuel choice (including appliance costs and any fixed network costs etc).

Both EECA and the Gas industry Company (GIC) have undertaken analysis in this area. The GIC report is available on their website[4], and EECA's information takes the form of an online tool[5] to help consumers

[4] See the Gas Industry Company's report on cost-effectiveness of residential water and space heating fuels: http://gasindustry.co.nz/sites/default/files/publications/consumer_energy_options_report_final_22_november_183275.1.pdf

[5] http://www.energywise.govt.nz/tools/water-heating

identify the best option for their needs (currently only a water heating tool is available, a space heating tool is under development).

The consistent message from both the GIC and EECA is that there is no 'golden rule' of one fuel source always being cheaper than the other from a consumer viewpoint; it is highly situation specific due to night time electricity rates, daily fixed charges and upfront costs for appliances. That said, the executive summary of the GIC report notes that for space heating, wood burners and heat pumps are often more cost-effective than gas based heating. The situation is less clear for water heating (key variables are whether or not an off-peak electricity rate is available, and if a fixed daily charge applies for gas).

Please note that the GIC report also considers greenhouse gas emissions. EECA does not believe that the greenhouse gas related conclusions in the GIC report are applicable to the Auckland Council's emissions question. This is because the timeframe the Council is considering is out to 2040, but the GIC analysis is done on a 'short run marginal' basis and is understood to only apply to a very small change in fuel types and over a relatively short time frame.

Fugitive Emissions

Fugitive emissions arise where leaks, planned work, or unplanned incidents cause unburnt gas to escape into the atmosphere. Natural gas is mainly comprised of methane which is approximately 20 times worse than CO_2 in terms of greenhouse warming potential[6]. Therefore, even a relatively small volume of fugitive gas emissions may be material. Unfortunately it is difficult to find publicly available specific data on fugitive gas emissions rated to New Zealand gas distribution networks. However, the fugitive emissions do not affect the outcome of this analysis; accounting for fugitive gas emissions will only increase the margin by which gas related greenhouse gas emissions exceed those of the electricity option.

Air quality

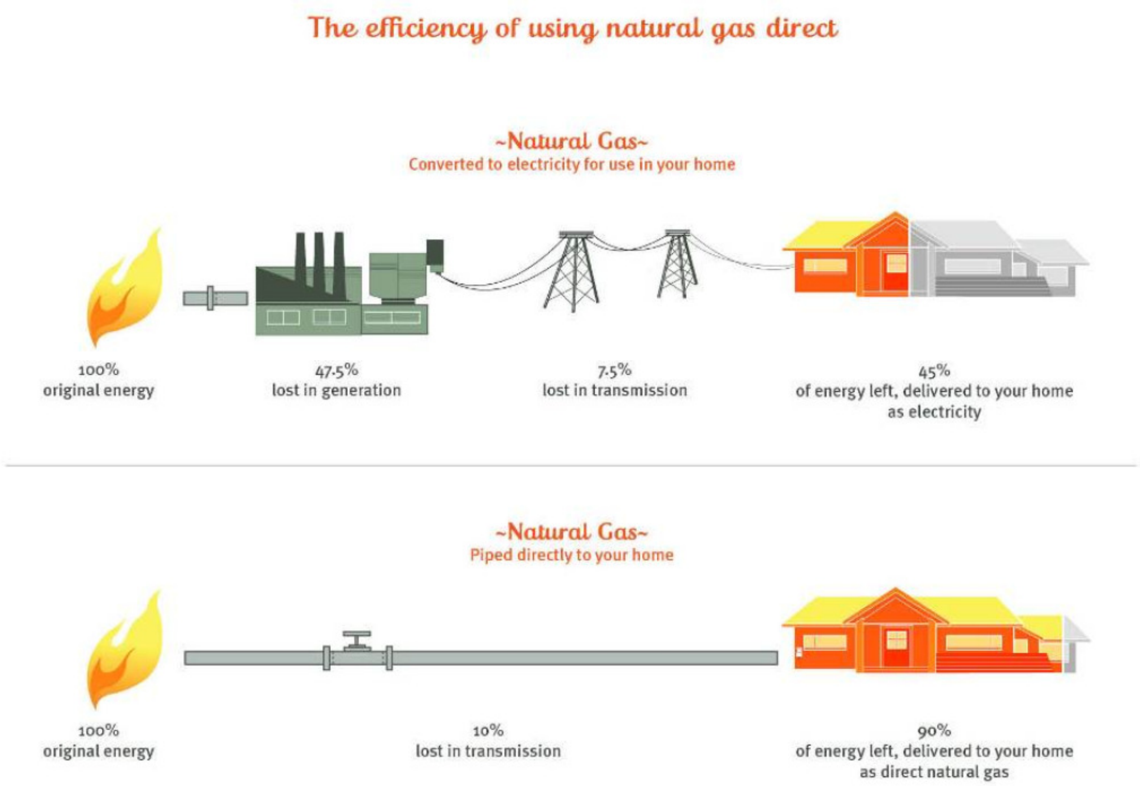
As noted above, wood burners are amongst the lowest cost sources of residential space heating. They also have a high heat capacity, and in some circumstances wood burners are a more cost-effective option to achieve a warm dry home than retro-fitting wall insulation in typical old New Zealand homes. However, older wood burners often contribute to poor air quality by emitting significant quantities of particulates (micron-scale particles of soot). Particulates can be a material health hazard, so some Councils are restricting the use of lower efficiency wood burners (and open fires) in areas of low air quality.

Heat pumps and electric resistive heating are not always the best alternatives to replace these wood burners because of lower heat capacity (they may struggle to maintain desired temperatures during very cold periods in draughty homes). This is an area where gas has the advantage of high heat capacity and no particulate emissions.

[6] See Intergovernmental Panel on Climate Change data
http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

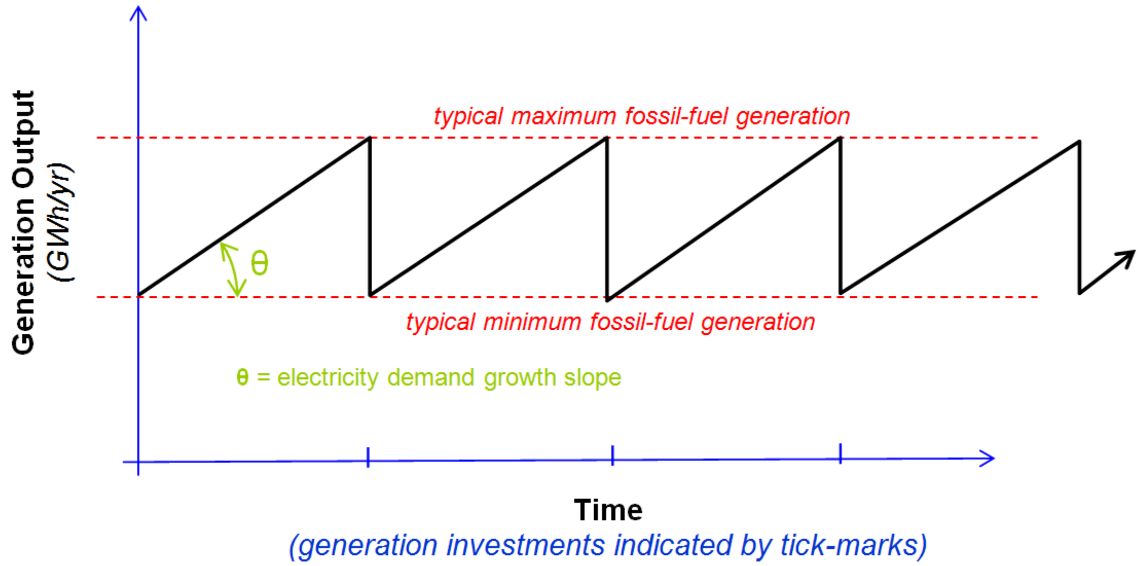
ADDENDA – 1 Marketing material[7] from 'Gas hub'

http://www.thegashub.co.nz/Its-easy-on-the-planet/Carbon-emissions/



[7] Note that when end-use efficiency is included, electricity is about the same efficiency as gas in a typical home. However, efficiency is not the only issue; cost-effectiveness on a national and consumer basis is also very important (and CO_2 emissions).

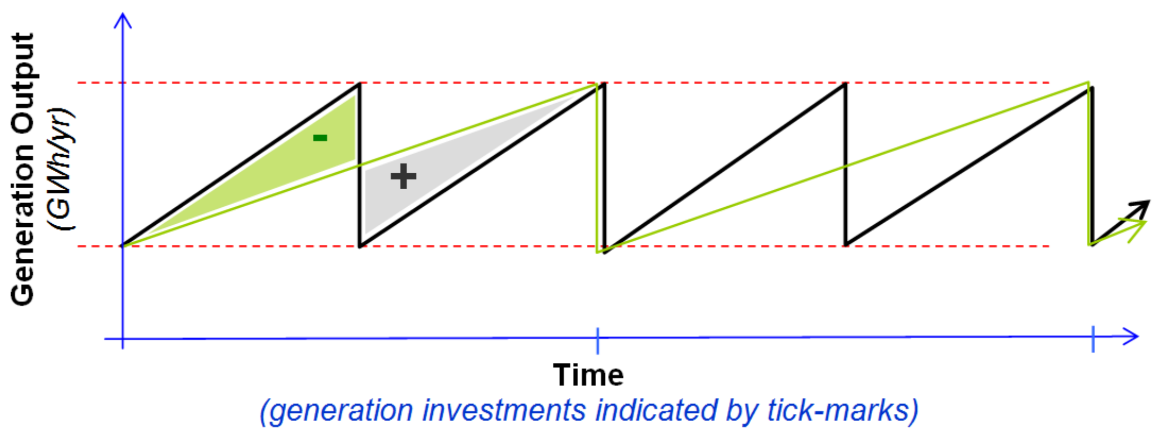
ADDENDA – 2 Variation of Fossil Fuelled Electricity Generation



Marginal fossil-fuelled generation (e.g. Huntly) has a 'saw-tooth' generation profile[8], this is because:

- Over a year, we tend to use all the renewable generation we can (because it's 'must-run' generation), and meet the rest of our electricity demand with fossil-fuelled generation;
- this means that year on year demand growth is met by increased fossil generation from existing plant, until we get to the maximum fossil generation, at which point we need new investment in additional generation (predominantly renewable in future);
- when the new renewable generation is built, there is a step-wise decrease in fossil generation output as the new renewable plant is typically 'must-run' (or very low short-run cost) generation.

Now, consider the case of reduced electricity demand (though still a net increase year on year) as shown below by the green line. We can see that overall the time until new generation investment is doubled, and that while there is an initial decrease in emissions (compared to the above scenario), it is balanced out by an increase after what was the investment timing in the previous scenario – overall the net effect is no change in fossil generation or fossil emissions over the medium to long term.



[8] This ignores hydro variability and annual demand variability (e.g. due to warmer winter).

ADDENDA – 3 Calculation for 90% target 2025 emission factors

Gas based scenario:

Gas carbon intensity by energy: 0.191 kgCO2-e/kWh (MfE data)

CCGT cycle thermal efficiency: 57.5% efficiency[9]

CCGT cycle emission factor: 0.33 kgCO_2/kWh (0.191 kgCO2-e/kWh divided by 57.5%)

2025, 90% target electricity average emission factor 0.033 kgCO_2/kWh (0.33 kgCO2-e/kWh * 10%)

Coal based scenario:

Coal carbon intensity by mass: 1.95 kgCO2-e/kg_{coal} (MfE data)

Coal energy intensity by mass: 21 MJ/kg_{coal} (MBIE, Energy Data File)

Coal carbon intensity by energy: 0.35 kgCO2-e/kWh (calculated from the above)

Rankine cycle thermal efficiency: 36% efficiency[7]

Rankine cycle (e.g. Huntly) emission factor: 0.96 kgCO_2/kWh (0.35 kgCO2-e/kWh divided by 36%)

2025, 90% target electricity average emission factor 0.096 kgCO_2/kWh (0.96 kgCO2-e/kWh * 10%)

[9] "Thermal Power Station Advice" Report for the Electricity Commission, PB Power, July 2009.

ADDENDA – 4 Electricity Emission Factors

We have looked at three electricity emission factor calculation methods, these are outlined below.

1. Average electricity emission factor, 0.129 kgCO_2/kWh (see Ministry for the Environment, http://www.mfe.govt.nz/publications/climate/guidance-greenhouse-gas-reporting-2011/voluntary-greenhouse-gas-reporting-emissions-factors-2011.pdf)
2. Calculated 2025 average emission factor, 0.03 kgCO_2/kWh (assuming we reach the 90% renewable electricity target by 2025, and have 10% gas fired generation)
3. Long run marginal emission factor, given the majority of new generation build is renewable, this emission factor is close to zero.

1 - Average electricity emission factor

The average electricity emission factor for 2011 (latest data available) is 0.129 kgCO_2/kWh. This is based on a simple calculation of the CO_2 content of coal and gas (along with low, or CO_2 free, renewable fuels) used to generate electricity, divided by the total amount of electricity consumed in that year.

The benefit of this calculation is its simplicity; it is very easy to understand. It also shows that our electricity system is very low-carbon.

We can see in figure 2 (below) that the electricity emission factor is declining over time. However, this does not mean that the total CO_2 from our electricity system is reducing. The declining trend in figure 2 is mainly caused by the dilution effect; a similar amount of total CO_2 is emitted from electricity generation year to year, but as electricity demand increases over time, and is met by renewable generation, the average emission factor reduces. This issue is explored further below.

2 - Calculated 2025 average emission factor

New Zealand is unusual in that a variety of renewable generation options (hydro, wind and geothermal) are economic and lower cost than gas or coal based electricity generation. There are some sizeable renewable energy projects currently under construction (eg Mill Creek, Ngatamariki, Te Mihi) and more than 3,500 MW of renewable generation has been consented, but not yet built.

As demand grows (albeit slowly[10]) and more renewable generation enters the system, there is a reduction[11] in the electricity emission factor over time.

Assuming we reach the Government's target of 90% of our generation to come from renewable resources by 2025, and the remaining 10% of non-renewable generation is either coal or gas based[12] the emissions factors are as follows:

[10] Demand growth is expected to increase on average for the foreseeable future. The most recent demand reduction is caused by an unseasonably warm winter, and the effect of the recession, and underlying efficiency improvements, as opposed to any long term downward trend.

[11] This emission factor may occasionally increase due to rainfall (and thus hydro generation) variability, but the trend on average is expected to be downward.

- Coal based scenario: 0.1 kgCO_2/kWh (see Addenda 3 for calculations)
- Gas based scenario: 0.03kgCO_2/kWh

All of these average emission factors (existing and expected in future) are lower than the emission factor for direct use of gas. Therefore, unless gas has a much higher end-use efficiency, we would expect electricity to deliver lesser CO_2 emissions overall, than direct use of gas .

3 – Long run marginal emission factor

The 'marginal' emission factor changes over time, based on electricity market conditions. It is defined as the change in CO_2 emissions arising from a change in electricity demand. Similar to marginal costs, marginal emissions can be looked at in the short or long term. Given the timeframe of analysis here (out to 2040), the long run approach is required. This change in emissions can arise from two possible changes in generation:

a) An increase in demand bringing forward the construction of an upcoming fossil fuel generation plant; or
b) A reduction in demand resulting in a reduction of fossil fuel use in existing coal and/or gas electricity generation plant.

Option 'a' suggests a zero emission factor for an increase in electricity demand, because on average it is renewable plant being built[13]. New Zealand is in the unique position of having renewable electricity (i.e. wind hydro and geothermal) as currently the cheapest options for new generation. The previously mentioned 3,500MW of consented renewable generation is about 20 years of demand growth.

Under option 'b' it is often assumed that electricity efficiency (e.g. installing LED lighting) or any other reduction in electricity demand reduces CO_2 emissions. In reality, it depends on your frame of reference. If you solely look at the household where the LED lighting was installed, then their emissions may have reduced; however, if your frame of reference is 'New Zealand', then New Zealand's emissions haven't reduced because on-going electricity demand increases elsewhere will outweigh the small efficiency gain, and thus existing fossil fuel generation is unaffected (and so CO_2 is not reduced overall).

Effectively, electricity efficiency only slightly reduces the overall rate of electricity demand increase (e.g. from 1.5%p.a. to 1.0%p.a.); we don't see a sustained electricity demand reduction from one year to the next (e.g. -0.5%p.a.).

In summary, the marginal CO_2 emission factor for electricity is currently close to zero. This may seem counter-intuitive, but it arises because new electricity generation is built to meet new demand, and if demand growth is incrementally increased or decreased we are simply speeding up (or delaying) the build of renewable generation.

[12] A further simplifying assumption is that the impact of geothermal CO_2 has negligible effect because the fields generally have lower emission intensity than gas fired power station, and because the future prospects for geothermal capacity are much lesser than wind and hydro.
[13] While some small gas based generation plant may be built, renewables will predominate.

Summary

Figure 3 below summarises the analysis of emission factors for various fuels. It shows that electricity is the cleaner fuel (regardless of which version of the electricity emission factor is used).

Further, given the potentially much higher efficiencies possible with electricity end-use (Table 1), electricity is a much lower CO_2 fuel source in New Zealand compared to direct use of gas.

For reference, light passenger transport emissions have been included in the graph below to show relative carbon intensity.

Figure 3 – Summary of energy sector emission factors for various fuel types and uses.