Electric Homes Technical Report

The energy, economic, and emissions opportunity of electrifying New Zealand's homes and cars.

Rewiring Aotearoa

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Peer reviewed by Professor Shaun Hendy MNZM FRSNZ.

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Acknowledgements

The Energy Efficiency and Conservation Authority (EECA) commissioned the dataset and contributed to the technical modelling. With specific contribution by Dr. Gareth Gretton. Final inputs and analysis are Rewiring Aotearoa's.

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About Rewiring Aotearoa

Rewiring Aotearoa is an independent non-partisan non-profit. It is a registered charity working on energy, climate, and electrification research, advocacy, and supporting communities through the energy transition. The team consists of New Zealand energy, policy, and community outreach experts who have demonstrated experience both locally and internationally.

Rewiring Aotearoa

www.rewiring.nz

Summary

New Zealand has reached the point where homes can electrify and get off fossil fuels while simultaneously saving money.

New Zealand is one of the first countries where the electrification of homes and vehicles can deliver both cost of living savings and emissions reduction simultaneously. Homes currently using gas or LPG appliances and petrol vehicles could save over $1,000 per year if they electrify their appliances and vehicles, and get their power from a combination of rooftop solar, home battery, and the existing electricity grid. In addition to reducing cost of living, this would add unprecedented energy resilience to New Zealand communities and reduce home energy emissions close to zero.

Costs of electric vehicles, appliances, rooftop solar and batteries have come down significantly over the past decade through economies of scale. As electrification uptake accelerates, prices are predicted to continue to drop further, saving homes more money over time. An energy system that has a higher amount of customer electrification with rooftop solar and batteries has profound implications for reducing the infrastructure needs of the energy transition. This impacts both the cost of living outcomes and the level of resilience communities will receive.

New Zealand | Gas/LPG and petrol home versus electrified home, annualised.

Sources: Rewiring Aotearoa Analysis. Residential Baseline Study 2021. EECA Energy End Use Database. MBIE Energy Prices 2023. 15 year lifetime and finance term. Average home is 2.8 people and 1.8 vehicles.

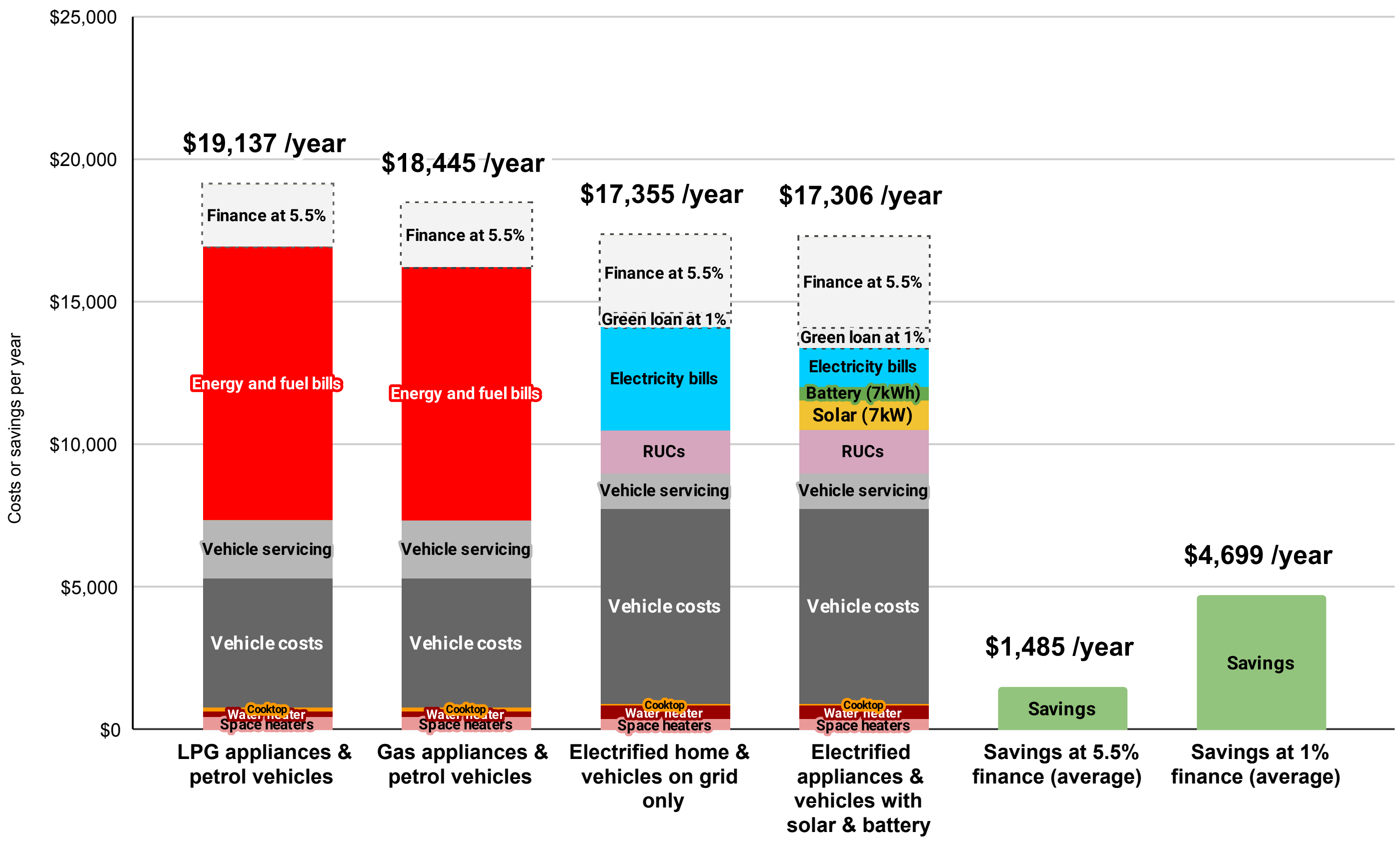


Figure 1 - Average home energy comparison. On the left are the annualised costs of homes with gas/LPG appliances and (non-hybrid) petrol vehicles (gas is more prevalent on the North Island, LPG on the South Island). In the middle are two homes with electric appliance and electric vehicles, on the right the electric home also includes a solar and battery install to lower costs and improve resilience. This chart shows that while the upfront cost of electric appliances and vehicles is higher, when energy bills are taken into account the all electric zero energy emission home is lower cost. The average New Zealand home could save over $1000 a year electrifying, and over $4,000 a year if they can do so with low interest finance. Every home is different and many factors will affect the amount of savings individual households realise, yet the benefits of widespread household electrification in New Zealand are clear.

What is this report?

This study focused on the energy, economic, and emissions impacts of electrifying New Zealand's homes including the vehicles they use. The work is split into two primary areas:

1. **Emissions mapping**
   Mapping New Zealand's emissions inventory into where the decisions are made that could eliminate those emissions. This is done to provide a new perspective on where and how emissions reductions can be made, to demonstrate how much of New Zealand's emissions household energy decisions contribute to.

2. **Household energy and economics**
   Modelling New Zealand household energy economics down to individual appliances and vehicles. This is done to provide perspective on the economics of each emissions purchase decision (for example, electric vehicle replacing petrol vehicle), in addition to the overall economics for the home when swapping all fossil fuel machines (appliances and vehicles) for electric equivalents and powering them through a combination of rooftop solar, home battery, and the existing electricity grid.

We constrain this study to using technologies that (a) we know work; (b) already exist at significant scale; (c) can be scaled up to the level required. We then investigate the interest rates and financing methods to make it work economically.

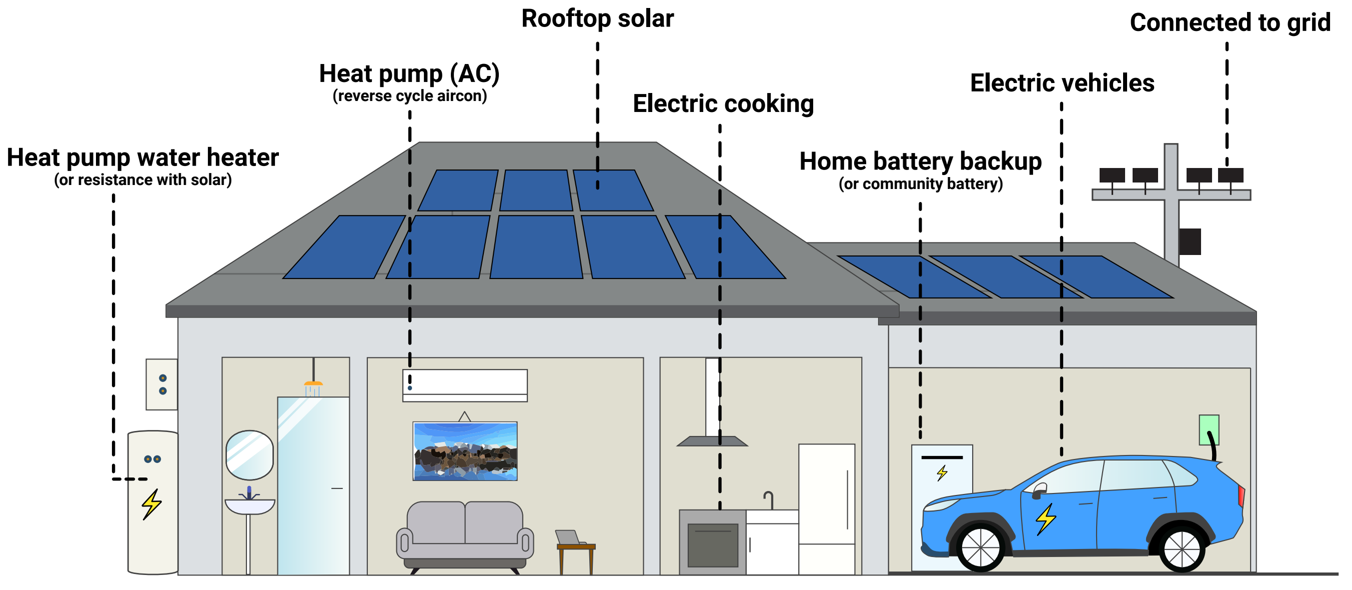
Global manufacturing economies of scale have been lowering the cost of renewable energy technologies, including electric vehicles, solar, batteries, and heat pumps. As these costs fall, there will be a point that replacing fossil fuel machines with electric machines becomes economical in addition to the emissions reduction benefits in no longer burning fossil fuels.

This study uses up to date energy and product costs across household appliances and vehicles to create a detailed understanding of the economics of household electrification today in New Zealand. It then uses international learning rate (economies of scale) forecasts to predict what costs may look like in the coming years.

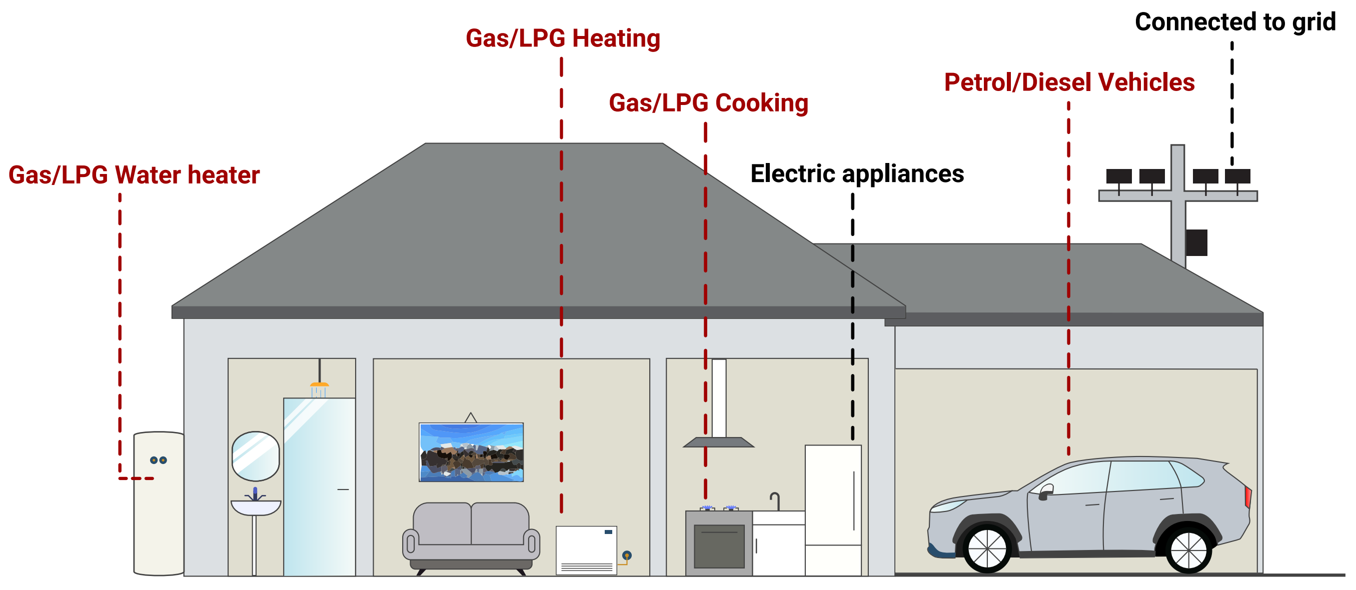
What is an electrified home?

Our lights, dishwashers, fridges, phones and more already run on electricity, but there are still a lot of households in New Zealand that burn fossil fuels for water heating, space heating, driving and cooking. An electric home swaps some or all of those fossil fuel machines for much more efficient electric equivalents and, if possible, adds solar panels to generate their own electricity and batteries to store that electricity for when it's needed. Note many homes in New Zealand are partially electrified, with some electric appliances, lots of heat pumps, some electric vehicles and some homes with solar. Here we compare both ends of the spectrum.

Electrified home



Gas/LPG and petrol/diesel home



Section 1
Emissions Mapping

Understanding where emissions decisions are made.

Under the United Nations Framework Convention on Climate Change (UNFCCC), New Zealand is required to count all emissions generated inside the country. This production-based accounting approach casts the emissions profile of countries into a certain light, which is consequential for export heavy nations like New Zealand. This is because a large proportion of emissions created locally are generated to produce products which are consumed in other nations. In New Zealand's case, this is most apparent in the agricultural emissions which go toward creating food that is consumed overseas.

The way we categorise emissions has implications for how we assess the levers available for emissions reductions. The categorisation of energy and emission sectors stems from historic economic sector definitions.[1] When thinking about transforming our energy economy and reducing emissions, this categorisation has constrained our understanding of where our emissions come from, and where the decisions to eliminate those emissions are actually made. The energy use and emissions across these historic economic sectors are intrinsically linked, especially with electrification. Mapping the actual emissions reduction decision points provides a clearer view of emissions reduction opportunities.

In this study we provide a new detailed mapping of New Zealand's national emissions inventory, where we use government and industry data to add further context to what areas of our economy have control over the decision points that can reduce those emissions.

In Figure 2 we have separated New Zealand's emission into two broad categories: [2]

- Domestic emissions that support our domestic economy; and
- Trade emissions that are counted towards New Zealand's emissions budget, yet turn out to be emissions that are associated with creating our exports for other countries.

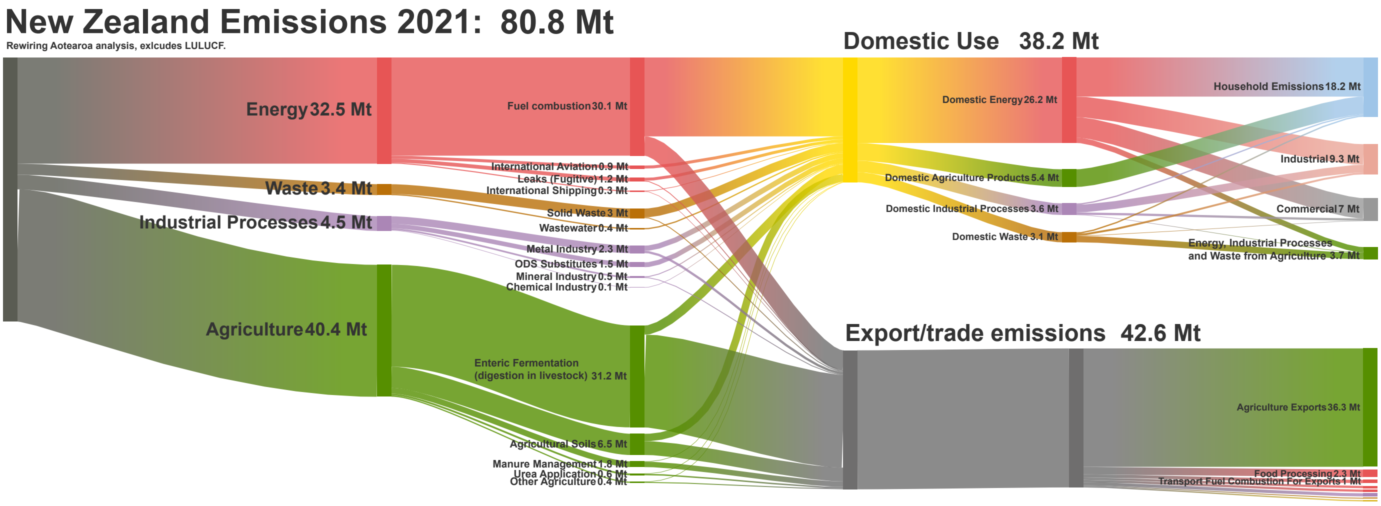


Figure 2 - National emissions inventory sankey. This is New Zealand's emissions inventory mapped to where emissions decisions are made. Sankey charts are read left to right. On the left of the sankey are the high level inventory categories. We further categorise those emissions into domestic use and export/trade emissions, and then into their respective sectors. In trade emissions, the largest emission type is enteric fermentation from digestion in livestock, the product of which is then exported for other countries to consume. In our domestic use emissions, households and their vehicles are the largest category of emissions. Primarily the millions of fossil fuel machine decisions that we make in homes across the country. While New Zealand's emissions conversation has been heavily focused on trade emissions, the potential for rapid emissions cuts in our domestic economy have not been fully recognised. Electrification of the domestic economy is an opportunity for rapid emissions reduction at scale with existing technology, while simultaneously lowering cost of living.

1 https://books.google.com.au/books/about/Understanding_the_national_Energy_Dilemm.html?id=zfPRAAAAMAAJ&redir_esc=y

2 Note that these charts include territorial emissions as in Aotearoa New Zealand's National Inventory Report. This accounting approach does not include emissions embodied in imports. This approach enables us to better understand where the clearest opportunities to decarbonise are. Although Aotearoa New Zealand does have significant imported emissions, in most cases, reducing those emissions is outside our control. Those decisions are made overseas by governments and organisations not influenced by everyday New Zealanders.

This distinction is important for multiple reasons. Firstly, the dialogue around trade emissions is understandably complicated. New Zealand generates large amounts of revenue from these activities, and they contribute significantly to our economy. Secondly, the timeline on which emissions are reduced is vital. Clear and realistic pathways to decarbonise New Zealand's economy are needed.

Export emissions are dominated by methane and nitrous oxide emissions from livestock. New Zealand does not have a clear short term pathway to reduce these emissions and technological solutions are not likely to be deployed in the short term. In contrast, most domestic economy emissions can be eliminated using technology available today, while bringing economic benefits to the New Zealand people including savings on cost of living and increased energy productivity. Through domestic economy emissions reductions, we can rapidly begin to bend the curve on our carbon dioxide emissions and put New Zealand on a path to a low emissions economy, creating large cumulative emissions reductions.

In Figure 3 below, we break down the sources of our domestic use emissions and highlight where decarbonisation decisions are made. This shows that around 31% of domestic use emissions are related to energy decisions made by households. Households are often not thought about as a significant source of emissions (or opportunity for abatement), yet millions of small decisions across households in Aotearoa add up to form a significant part of our emissions profile.

New Zealand Domestic Use Emissions 2021 | 38.2 Mt
Excludes LULUCF

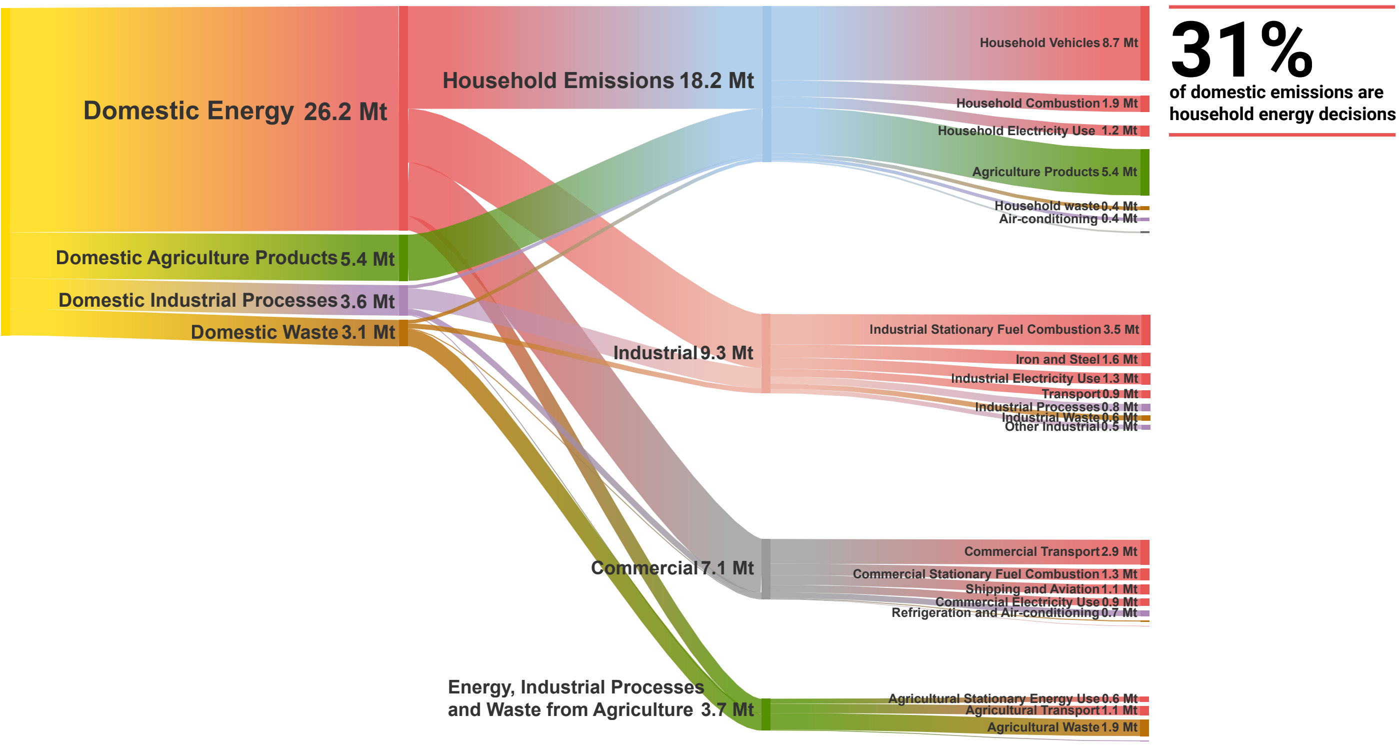


Figure 3 - Domestic emissions sankey. This sankey diagram further breaks down the domestic emissions categories in more detail to show that 31% of domestic economy emissions relate to household energy decisions. Significant amounts of small business emissions come from similar energy decisions.

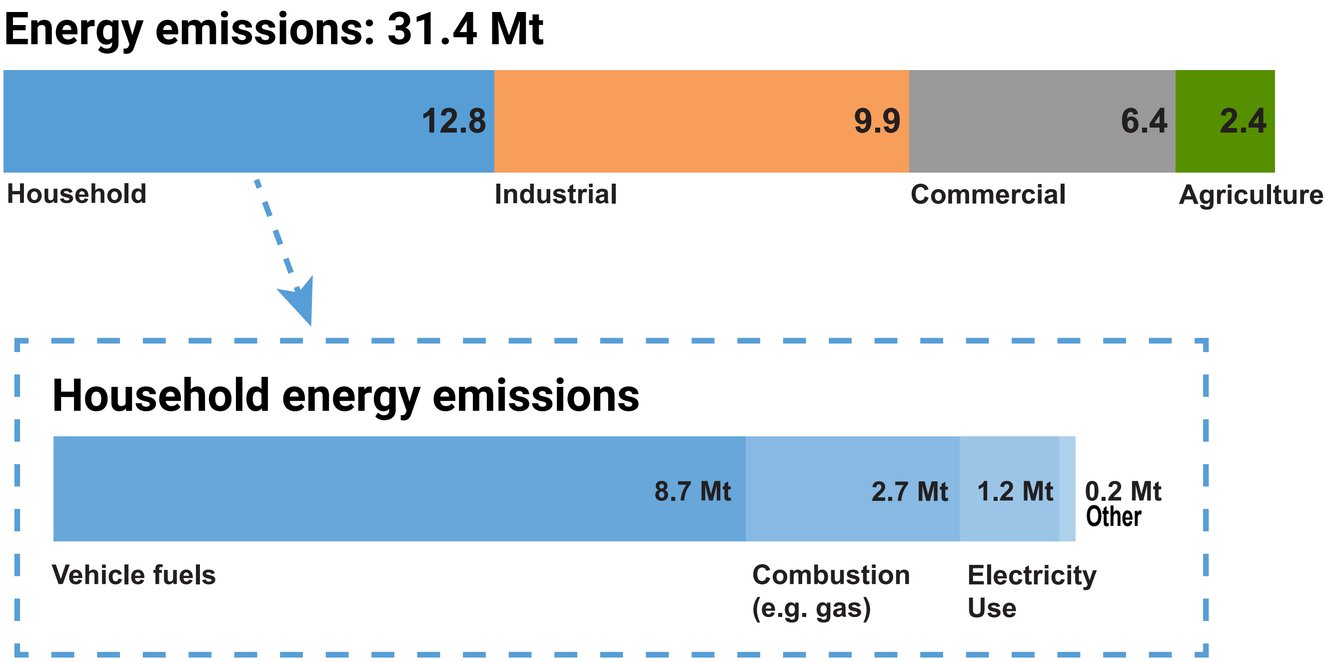


Figure 4 - Sectoral breakdown of New Zealand’s energy emissions and a breakdown of New Zealand’s household energy emissions.

New Zealand’s unique emissions profile

Aotearoa NZ’s emissions profile is unique among most developed countries. As figure 5 shows, around half of our greenhouse gas emissions come from agriculture (compared to the developed country average of 12%),[1] of which the vast majority in New Zealand is for export.

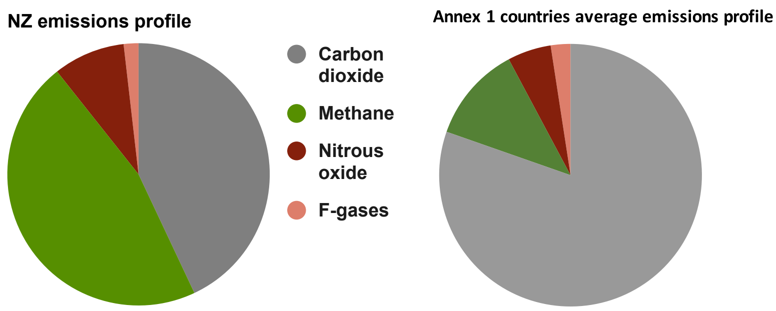


Figure 5 - New Zealand’s emissions profile split by gas (left) compared to the average of developed countries (Annex 1 UNFCCC countries) (right).

Agricultural emissions are mostly methane with a smaller contribution from nitrous oxide. The focus of this report is energy, however, which mostly relates to carbon dioxide emissions. Carbon dioxide is especially important for climate mitigation because it is a long-lived greenhouse gas that stays in the atmosphere for centuries to millennia. The more we emit, the more it builds up cumulatively and the more warming it causes. This is why carbon dioxide must be reduced globally to net-zero to stabilise the climate.

We have the technology to make deep cuts in our energy-related carbon dioxide emissions now. The International Energy Agency (IEA) anticipates that technologies available today can deliver more than 80% of the emissions reductions needed by 2030 to limit global heating to 1.5°C.[2]

1 UNFCCC Greenhouse gas emissions data by country. We have defined ‘developed country’ as UNFCCC Annex 1 countries

2 IEA (2023). Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach 2023 Update, International Energy Agency, p. 13. https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach

Energy does not dominate New Zealand's emissions profile like most developed countries, yet our energy-related emissions are surprisingly high. Per capita domestic use energy emissions are around 6.3 tonnes in Aotearoa NZ. Although we have a relatively high share of renewable sources (>80%) for electricity generation, the share of renewables in our total energy supply is only significantly less at around 30%. This reflects the ongoing dependence on fossil fuels for road transportation, industrial processes and numerous end-uses in households and business. It is these energy emissions that this report discusses.

Where are the machines? They are the actual decarbonisation decision points in the economy.

The best way to understand our energy emissions and develop an actionable work plan to zero emissions is to understand the machines that underpin the nation.[1] Replacing fossil fuel machines with zero emissions alternatives is critical to achieving a pathway to deep, permanent CO2 emissions reduction.[2] Understanding these machines, all of the emissions associated with using them, servicing them, installing them and manufacturing them, and especially the cost to replace them with zero emissions alternatives, creates a clearer picture of the task ahead for us to transform to a zero fossil fuel economy.

Here are two examples of the way that our current accounting approach compels us to overlook the solutions in front of us:

1. When looking at the emissions from gas heating in homes conventionally, all of the emissions which can be removed if the home is electrified are not counted. The distribution pipeline emissions required to deliver that gas to the home, the fugitive emissions in extracting the gas, and the diesel truck transport emissions used to deliver LPG bottles are accounted for separately. They are all accounted for under different sectors, and all looked at as separate problems to solve rather than one. Yet all these emissions are eliminated if households make one demand side electrification decision - to stop using that gas through electrification. That decision is the primary lever for the decarbonisation of all the emissions associated with it.
2. Transport sector energy emissions are often looked at separately from residential emissions, even though the majority of vehicles park at their owners homes. The bulk of the charging of those vehicles in future will likely be energy flows through the home or the community. The decisions to eliminate a large portion of transport sector emissions are made by millions of people when they decide what vehicle to drive. Larger rooftop solar installations ultimately help remove transport sector emissions by enabling people to buy an EV earlier and charge it at lower cost by providing the zero emission electricity infrastructure needed for the increased load. Understanding how these sectors, and indeed all sectors, are coupled together in an electric economy enables us to think clearly about emissions reduction and where the decisions are that can enable it.

1 https://saulgriffith.medium.com/one-billion-machines-48a7c3cf0694
2 IEA (2023). Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach 2023 Update, International Energy Agency, pp. 124–128. https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach

Understanding committed emissions

Understanding committed emissions is crucial for gaining a clear perspective on the cost/benefit analysis of emissions reductions. Every machine, whether it is a car, a gas water heater, or a coal power plant, has a natural lifetime before it is scrapped or replaced. For every new fossil fuel machine purchased or built, we lock in years or decades of further emissions. For a reality check on the task ahead, the machines that already exist in the world are expected to take us to about 1.8°C of warming.[1] That is, if every new car, new appliance, and new power plant purchased were all electric zero emissions, we would still exceed our 1.5°C target. This emphasises the need for early retirement of some fossil fuel machines and the need for all new machines to be zero emissions.

Because these purchase decisions are machines that generally last about 15 years, we lock in over a decade of forward emissions with the purchase of fossil fuel appliances and vehicles. This is important to understand when looking at how we can achieve large cumulative emissions reductions. An electrified replacement continues its annual emissions reduction every year going forward, not just in the year the decision was made. It enables us to take concrete steps towards a decarbonised economy. Committed emissions also expose consumers to the risk of high future carbon prices.

We still have an opportunity to avoid the worst impacts of climate change. It requires us to move fast. To meet the global 1.5°C target set out in the Paris Agreement, the world must rapidly reduce carbon dioxide emissions. Global CO2 needs to be halved by 2030, net zero reached around 2050, and then to achieve net negative emissions thereafter to address overshoot. Alongside this, we need deep reductions in methane and nitrous oxide.[2]

New Zealand's opportunity for rapid emissions reduction

Electrification is the key to unlocking the rapid emissions reductions required to put us on track to meet the 1.5°C goal. In households, we should take advantage of readily available technologies and existing highly renewable electricity grid to make deep, permanent emission reductions.

Electric appliances and vehicles will reduce emissions and when combined with rooftop solar and batteries will lower energy bills and build resilience for households. For households, we do not need to wait for technology any longer. We have readily available technology that we know can make deep reductions in our carbon emissions today and a population struggling with the cost of living. To achieve decarbonisation at the rate required to play our part in the Paris Agreement means we should prioritise electrification.

1 Committed emissions from existing energy infrastructure jeopardize 1.5°climate target. Tong, D., Zhang, Q., Zheng, Y. et al. Nature 572, 373–377 (2019)
2 IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3–32, doi:10.1017/9781009157896.001.

Section 2

Household energy and economics

In this section of the study we investigate New Zealand household energy economics today and into the future. We include the vehicles used by homes as part of the household energy picture, as they are purchase decisions made by households. The switch to electric vehicles necessitates thinking about how those vehicles will be charged at homes, and how the home energy and transport sectors which were conventionally separate will now be coupled through electricity as the primary energy source for both.

We compare individual appliance and vehicle economics in addition to full home energy economics.

The main comparison made is between a fully electrified household (electric appliances and vehicles, solar and battery) and a primarily fossil fuel household (gas space heating, gas water heating, gas cooking, and petrol vehicles, non-hybrid). Note that primarily fossil fuel homes still use electricity for many uses, for example refrigeration, lighting, TV etc.

These two home types represent different ends of the fossil fuels versus electric spectrum for home energy which is why they are the two compared. Note that while some homes are on both ends of this spectrum, there are many homes in between. For example, homes that use gas water heating and cooking yet already use an electric heat pump for space heating, or homes that use gas appliances yet have one electric vehicle. Many homes are partially electrified in which case the individual household journey may require less swap outs of appliances or vehicles, and they may already be receiving some of the economics available through electrification.

The primary energy use comparison in this study is done with the “average” New Zealand home’s energy needs. The average home in New Zealand has about 2.8 people and 1.8 vehicles. The amount of people in a home will impact its energy use, and so will the climate the home is located in. For example, a home in Dunedin is likely to use significantly more energy for heating than a home in Auckland. We include sensitivity analysis scenarios to demonstrate the difference higher and lower energy use makes to the economics.

We found that in general higher energy use leads to higher savings from electrification. The operational costs of electric machines are generally significantly lower than their fossil fuel counterparts, therefore if the upfront capital costs remain the same or similar the savings increase with higher energy use. For example, likely only one water heater is used by a home whether it has 2 tenants or 5 tenants. The upfront replacement and install cost still remains similar, yet the operating costs can change significantly if that same water heater is meeting the heating needs of 5 people or 2 people. The same is true for electric vehicles, which currently have a higher upfront cost, and significantly lower operating costs. A vehicle driving more than average can have higher fuel savings and therefore pay the same upfront cost but receive more savings from operational costs.

Every home’s electrification journey will be different. Understanding the lens of “average” home energy use is important for interpreting the results of this study and how they may change for individual home conditions.

Section 2.1

Individual appliance and vehicle analysis

This section of the report explores the major appliances in a home that can be electrified, alongside vehicles, and the energy, cost, and emissions implications of doing so.

Electric machines are - in general - significantly more efficient than their fossil fuel counterparts.[1] This is important to understand as it drives many of the cost savings available through electrification. In a fossil fuel system, a fuel is being burned and therefore heat is often lost that does not go directly into the task at hand. For example, in a petrol vehicle, only about 16%–25% of the energy in petrol is turned into motion.[2] Petrol and diesel engines work by producing thousands of small explosions to drive the vehicle. This heats the engine up, creating waste heat, vibrations and more, losing significant amounts of energy. In contrast, an electric vehicle converts about 87%–91% of the electricity it receives into motion at the wheels.[3] This is with charging losses accounted and regenerartive braking accounted for. An electric car is therefore about four times more efficient at converting energy into motion.

Electric efficiency gains are not just seen in vehicles. The benefits of using an electric heat pump (or reverse cycle air-conditioner) are well known in New Zealand. Heat pumps can provide about 3–4 times the amount of heating for the same amount of input energy as gas heaters. Most space heating options for homes have an coefficient of performance of below 100%, with electric resistance near 100%, gas about 80%, and wood fires about 65%.[4] Heat pumps have a coefficient of performance that is about 350% on average in New Zealand, with some heat pumps getting higher than this depending on region and temperatures. While currently less well known in New Zealand, heat pump water heaters are increasingly being adopted by homes and can provide similar efficiency benefits. Electric efficiency gains even extend to cooking, with electric induction cooktops being about three times more efficient than their gas counterparts.[5]

Combined, these electric efficiencies lead to significant energy savings in homes, which in turn can lead to significant cost savings.

We've spent years looking for small gains in efficiency of fossil fuel machines, with that efficiency often associated with sacrifice like shorter showers or driving less. This report demonstrates that electrification can provide greater efficiency gains without sacrifice. It demonstrates that in energy efficiency and emissions reduction, we don't need to be perfect, we just need to be electric.

1 Eyre, N. (2021). From using heat to using work: reconceptualising the zero carbon energy transition. Energy Efficiency, 14(7), 77.
2 https://www.fueleconomy.gov/feg/atv.shtml
3 https://www.fueleconomy.gov/feg/atv-ev.shtml
4 Warm Homes Technical Report: Detailed Study of Heating Options in New Zealand: Phase 1 Report (environment.govt.nz)
5 Residential Cooktop Performance and Energy Comparison Study Frontier Energy July 2019

Section 2.1.1

Space heating

Space heating is the largest energy use for New Zealand homes after vehicles, making it the largest energy use “inside” the average home.

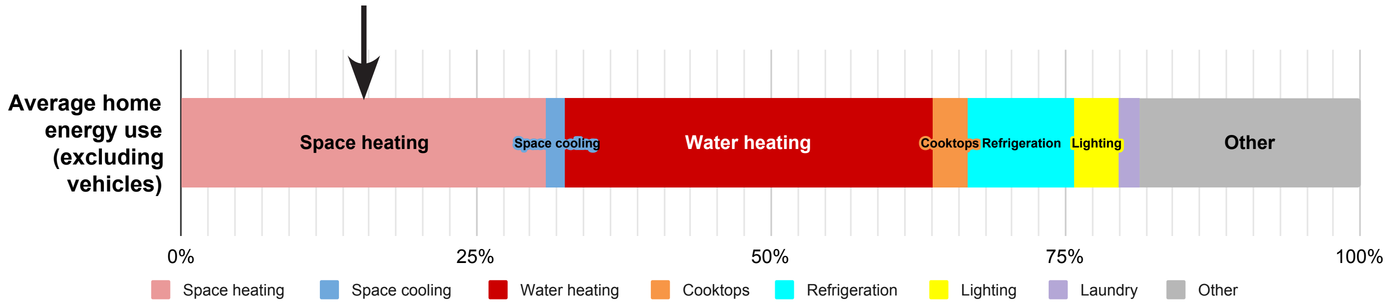


Figure 6 - Proportional energy use in an average New Zealand home.

There are a few main options for how to heat a home which we explore below. It becomes clear that the lowest cost and lowest emission method to heat a home in New Zealand is through an electric heat pump. Over a 15 year appliance lifetime and including upfront costs, a heat pump with solar can save about $10,000 over gas heating, and $16,000 over LPG. Wood heating sits in the middle, lower cost than gas or LPG but still higher cost than an electric heat pump. An electric heat pump is also the lowest emission option by far, having about 10 times less emissions than gas or LPG heating. Wood is also a relatively low cost and low emission option. It does produce significant emissions when burned, although the carbon has recently been drawn out of the atmosphere by the trees, so the net impact is small.

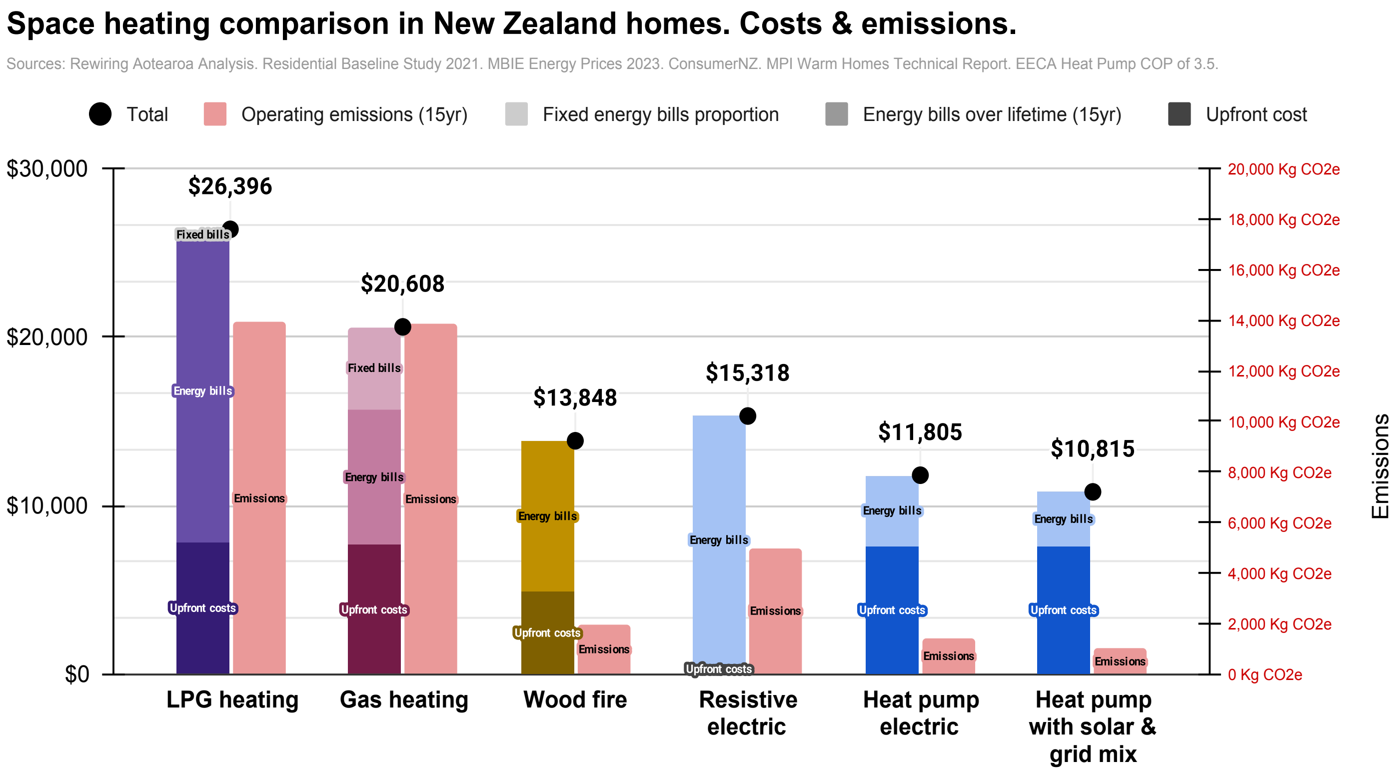


Figure 7 - Upfront and operating costs of different types of space heating over a 15 year lifetime. Emissions are shown in light red.

Energy efficiency

The energy efficiency of different heating options has a significant impact on their costs of operation. The clearest efficiency difference is seen between heat pumps and all other methods of heating. Heat pumps are significantly more efficient, because they are using fundamentally different methods to create heat in a home.

Conventional heating methods like gas heaters, wood fires, and electric resistance (bar/radiant) heaters all have an efficiency of below 100%. That is, for every unit of energy put into them, less than one unit is turned into heat in a room. A useful way to visualise this is with a wood fire, which has an efficiency in the range of 55–75%.[1] 100% represents all the possible heat that could be perfectly extracted from burning the wood, but a large portion of that heat goes up the chimney and isn't turned into heat inside the room. These same inefficiencies exist for gas heating appliances too, which have an energy efficiency of about 75%-85%.

Heat pumps use a fundamentally different method to generate heat and/or cooling. Most heat pumps (or air conditioners) have both a heating and cooling cycle, and are also known as reverse cycle air conditioners. Heat pumps "pump" a refrigerant (a liquid with a low boiling point) between indoors and outdoors, and utilise the temperature difference and compression/decompression of the refrigerant to absorb or release heat. This produces heating or cooling depending on which cycle the heat pump is on and is why heat pumps have a unit both inside and outside a home. The pumping of this refrigerant uses less than one unit of energy for every unit of heat it produces, which is why heat pumps can produce about 350% of heating to every one unit of electricity they use in New Zealand. This is compared to a resistance or bar heater, which produces just under one unit of heat for every one unit of electricity flowing through it. The efficiency of the heat pump depends on the temperature both indoors and outdoors, and the refrigerant used. In New Zealand, the average heat pump is around 350% efficient, in very cold environments this reduces and can be around 200%, still significantly more energy efficient than any other heating appliance. In warmer environments, heat pumps can be over 400% efficient.

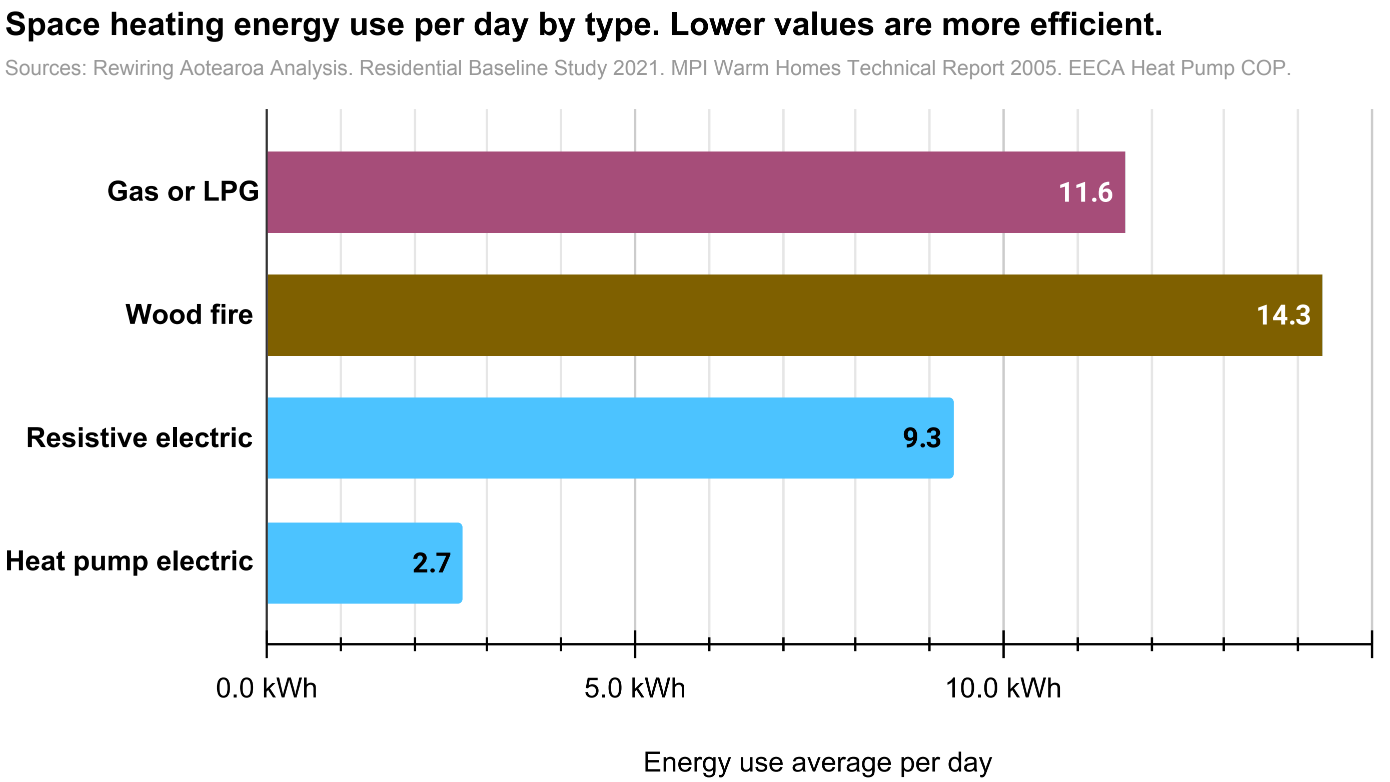


Figure 8 - Average energy use per day for different types of space heating.

1 Warm Homes Technical Report: Detailed Study of Heating Options in New Zealand: Phase 1 Report (environment.govt.nz)

Operating costs

The energy efficiency of each heating type combines with energy costs to create the running costs of each option. The example below is based on "average" heating needs of a New Zealand home containing 2.8 people. Derived from New Zealand space conditioning energy use data from the Residential Baseline Study 2021.[1] Heating needs in the real world will be impacted by region/temperature, how much of the home is being heated, insulation and leaks (thermal envelope) and more. In general, these numbers will all rise and fall depending on those factors. Heat pumps are likely to be the lowest cost option for virtually every home in New Zealand.

The chart below demonstrates that heat pump electric heating is the lowest cost option for homes. This cost can be lowered further if solar panels are installed and a portion of the heating is done during the day. On average most heating happens outside of the solar window, therefore fewer solar savings are available when compared to water heating or vehicle charging.

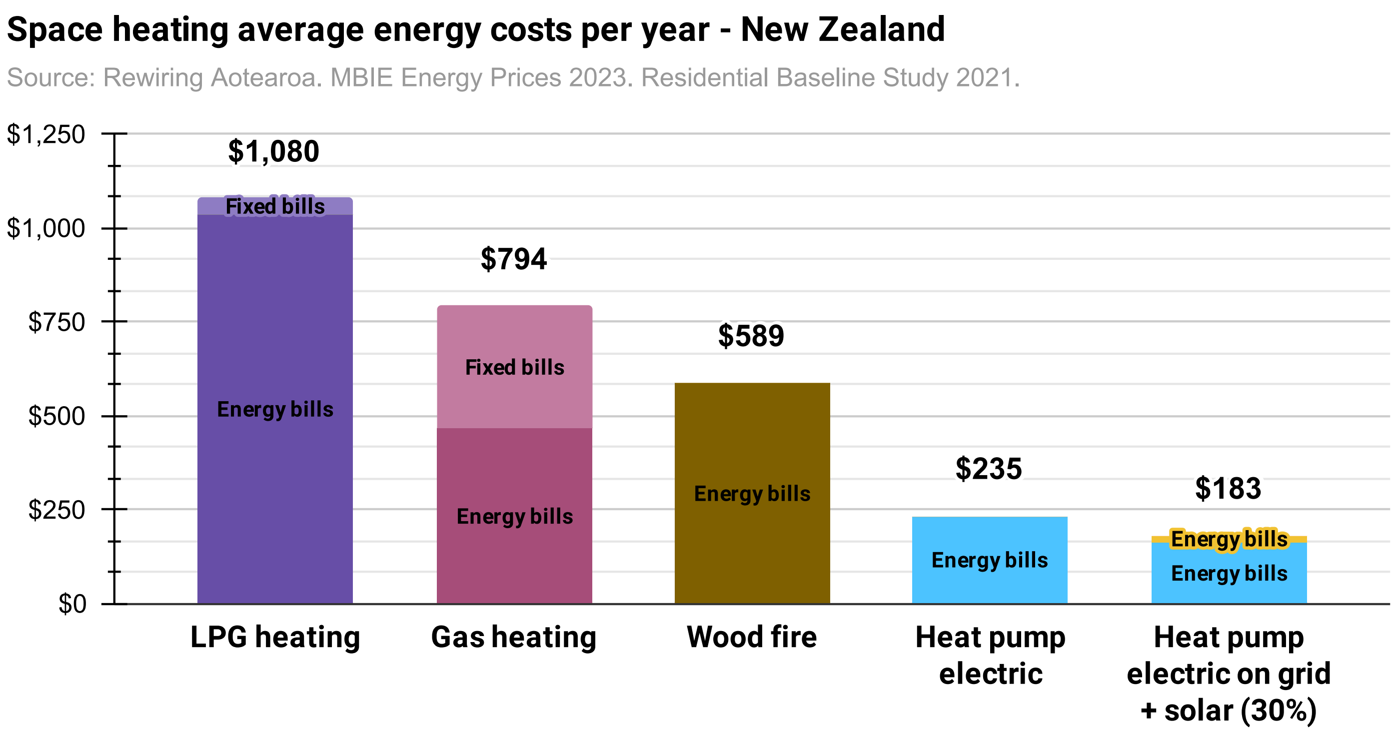


Figure 9 - Average annual operating costs of different types of space heating.

1 https://www.energyrating.gov.au/industry-information/publications/report-2021-residential-baseline-study-australia-and-new-zealand-2000-2040

Upfront and operating costs

The upfront costs of different appliances change significantly depending on the appliance chosen. For this paper, we have used an average of costs of "middle of the spectrum" appliances. This means savings for those who purchase appliances priced at the cheapest and most expensive ends of the pricing spectrum will differ. Installation costs also vary depending on household conditions and work required. In this study, we looked at a range of costs and used an average.

It is clear that electric heat pumps are the lowest cost heating option when including both upfront and operating costs. While resistive electric heaters (bar heaters and column heaters) are very cheap to buy upfront, the operating costs make them more expensive than electric heat pumps. Gas heating or LPG heating are both significantly more expensive over time because when the home buys the heater, they lock themselves into paying for years of gas costs. This lifetime cost of different heating options is important to consider, because sometimes a lower upfront purchase cost may be locking the home into higher bills and cost of living going forward.

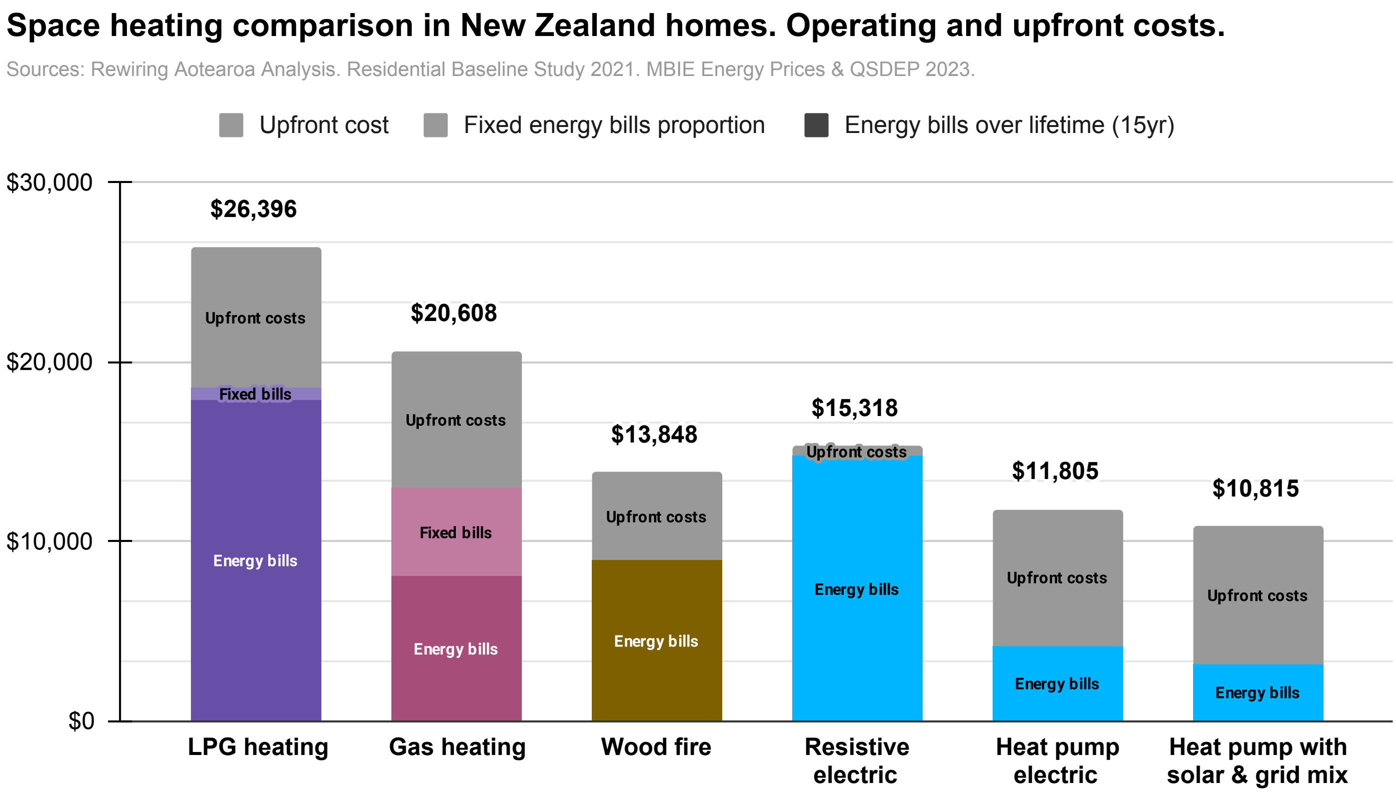


Figure 10 - Upfront and operating costs of different types of space heating.

Operating emissions over lifetime

Committed emissions are important to consider when households make appliance choices. When buying a new fossil fuel machine, a home locks in likely over a decade of forward burning of fossil fuels. The purchase point or replacement point of an appliance is the opportunity to permanently eliminate many years of emissions from the household and New Zealand as a nation.

Gas or LPG space heating has about 10 times more emissions than heating with an electric heat pump on New Zealand's existing electricity grid. As the grid becomes zero emissions, the advantages of electric heat pumps will extend even further. Electric machines can have zero operating emissions when supplied with renewable electricity, even today.

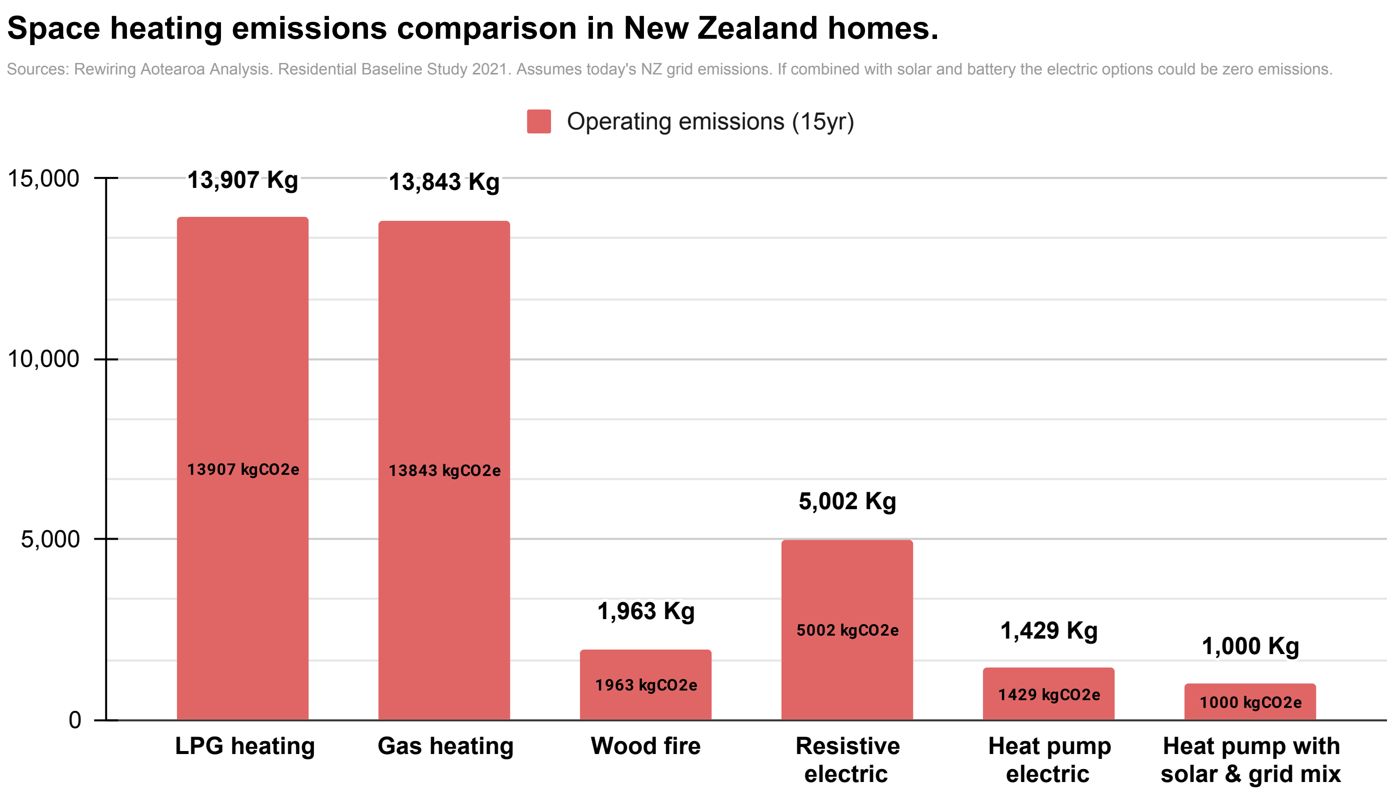


Figure 11 - Operating missions over the lifetime of a range of space heating appliances.

Section 2.1.2

Water heating

Water heating is the third largest energy use for New Zealand homes, coming after vehicles and just after space heating/air conditioning needs. This is based on average home energy needs, but some homes may use more for water heating than space heating depending on where the home is located, how much heating is needed, and how much hot water is used.

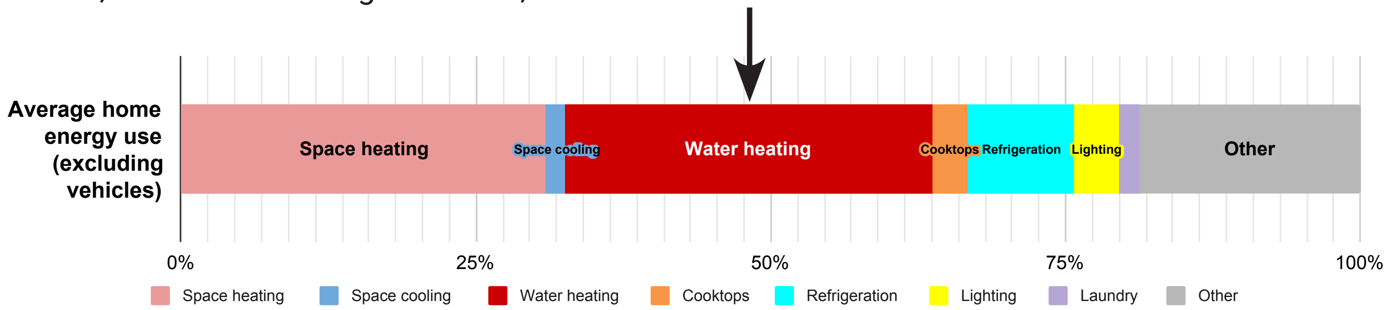


Figure 12 - Proportional energy use in an average New Zealand home.

There are a few main options for home water heating which are explored below. Water heating can also benefit significantly from the use of solar, which transforms water heating tanks into "thermal batteries" which can heat up with low cost solar in the middle of the day and keep the water hot for later to reduce bills.

From our analysis it becomes clear that the lowest cost and lowest emission method for water heating in New Zealand is an electric water heater powered by solar, either resistance electric or heat pump electric. Heating an average New Zealand home with a heat-pump-water-heater-with-solar will save about $450 per year in water heating costs compared to gas, or $650 per year compared to LPG. With upfront costs included over a 15 year lifetime, we can see savings of about $4,000 over gas, and $7000 over LPG. Heat pump water heaters have a higher upfront cost which should be taken into account, though their savings over time still often make up for the higher upfront cost. Another good option is a resistance tank water heater supported by solar, which has a lower upfront cost than a heat pump water heater and still a very low operating cost when combined with solar.

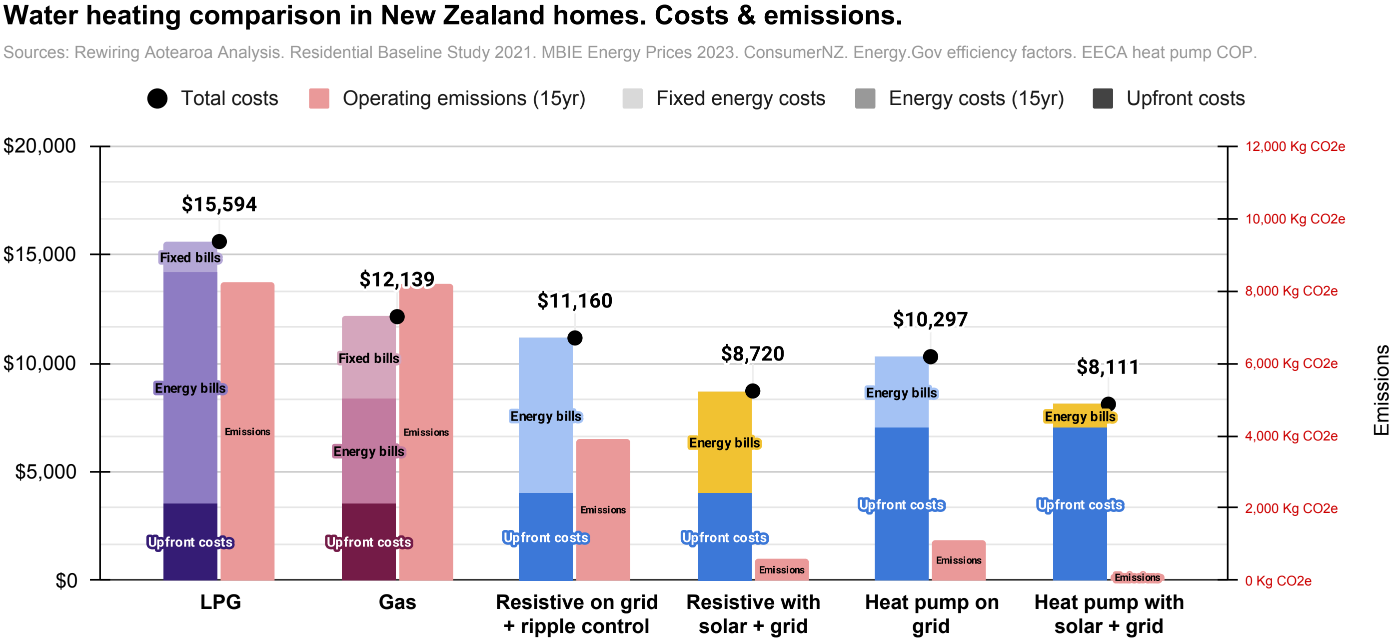


Figure 13 - Upfront and operating costs for different types of water heating over a 15 year lifetime.

Energy efficiency

The energy efficiency of different water heating options is explored below. The efficiency of each option has a significant impact on their costs of operation.

Conventional gas, LPG, and electric resistance water heaters all have similar energy efficiencies of around 80%-95%.[1] The biggest difference in these options comes in operating costs, which are impacted by what source of energy is used and at what time of day. This is explored in the following section on operating costs.

There are two types of water heaters that are significantly more efficient than conventional tank or tankless water heaters: heat pump water heaters and solar water heaters. Solar water heaters use sunlight to heat and circulate water, often seen as tanks and/or a row of tubes on a roof. Heat pump water heaters are just like an electric tank water heater, but use a heat pump to provide the primary heat source which increases efficiency by about 350%.

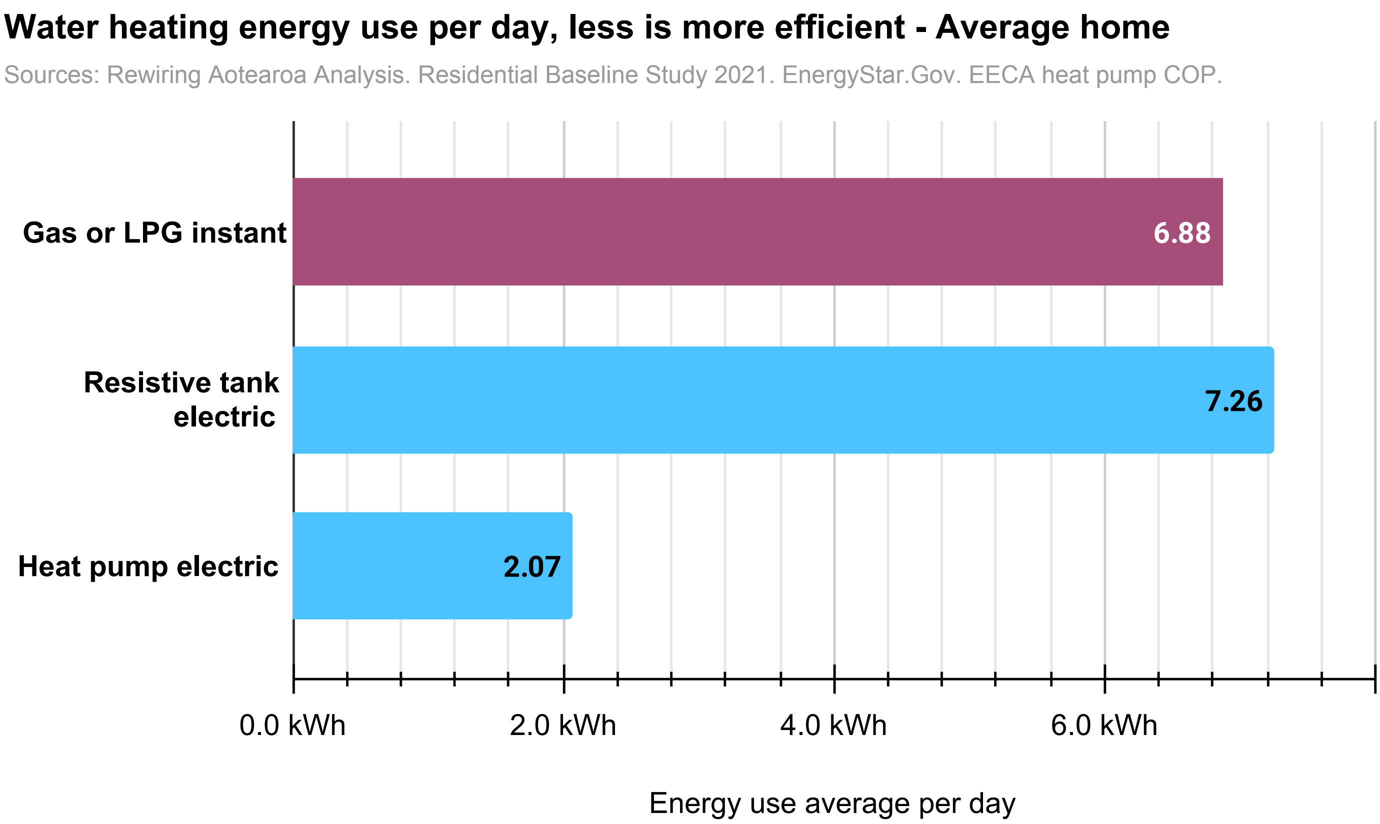


Figure 14 - Energy use per day for different types of water heating

1 https://www.energystar.gov/products/water_heaters/residential_water_heaters_key_product_criteria

Operating costs

The energy efficiency of each type of water heater combines with the cost of each source of energy to produce the operating costs. It is also important to note that water heaters can be significantly cheaper to run if households shift their energy demand to lower cost periods of the day; for example, by heating during the solar window (i.e. when the sun is shining) or at off-peak times overnight. New Zealand has many “ripple controlled” electric tank water heaters which have been in operation for many years. These benefit from avoiding peak electricity times to receive lower cost prices by having the electricity network send a signal to the water heater along the wire during peak times. This stops the water heater from consuming electricity during peak periods to lower network peaks and lower energy bill costs.

This same type of water heater timing (or load management) can also be used with rooftop solar to lower costs even further. Instead of being controlled by the electricity network, a home’s water heater is timed and connected to heat from its solar panels in the middle of the day. The water then remains hot for use later, while significantly lowering the costs of energy, and being able to top-up with grid electricity if more water heating is needed. The advantage of this is seen most clearly in the comparatively lower cost of the two solar options in the chart below.

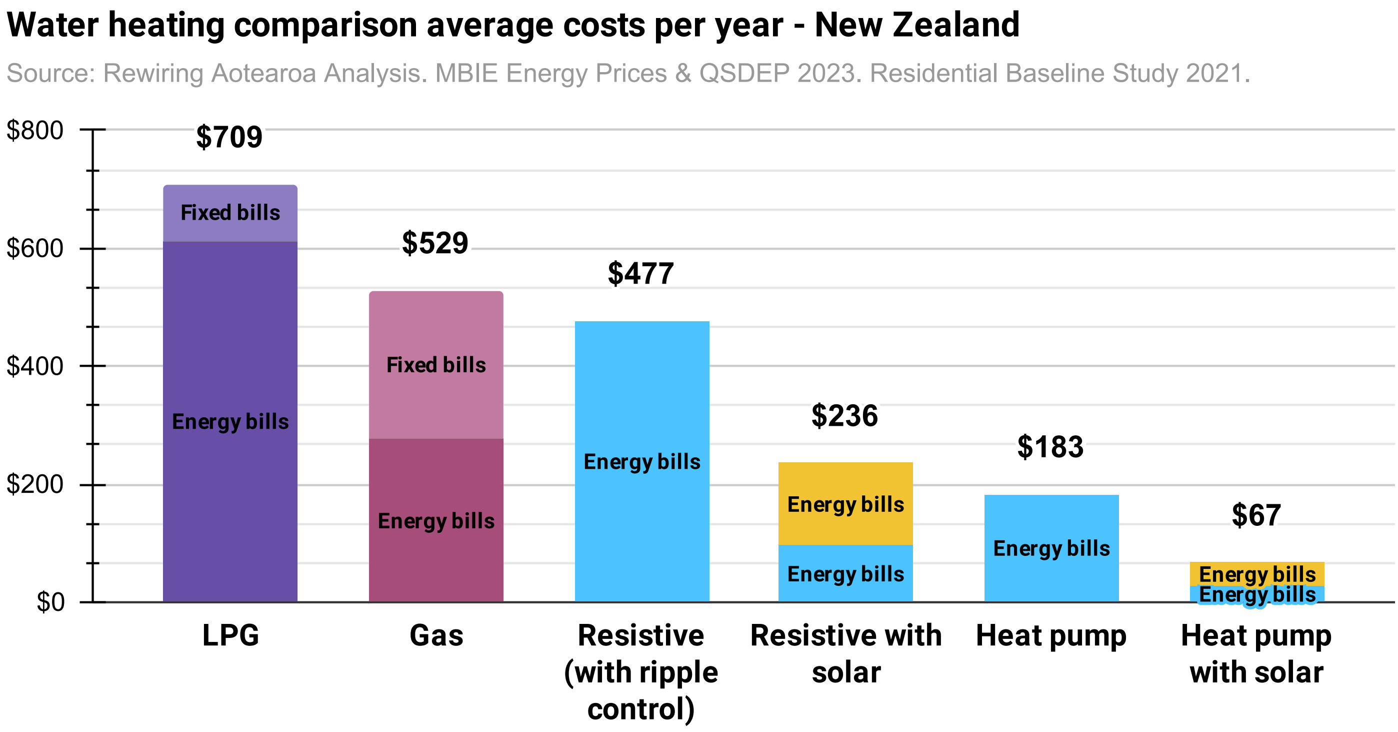


Figure 15 - Average annual operating costs of different types of water heating.

Upfront and operating costs over lifetime

When looking at the total costs of water heating the difference between upfront costs between each option becomes more apparent. Heat pump water heaters are significantly more expensive upfront, while being significantly lower cost to operate. Combining these costs over a 15 year appliance lifetime shows that heat pump water heating with solar, and resistive water heating with solar are the two cheapest options.

It is also worth noting that because of the stark difference between upfront and operational costs, the amount of energy used will have a significant impact. This average is based upon a home of 2.8 people, a family home with 4 or 5 people will likely have much higher operational costs across all options, leading to more savings from a heat pump because the upfront costs of water heating remain similar even if more energy is used in operation.

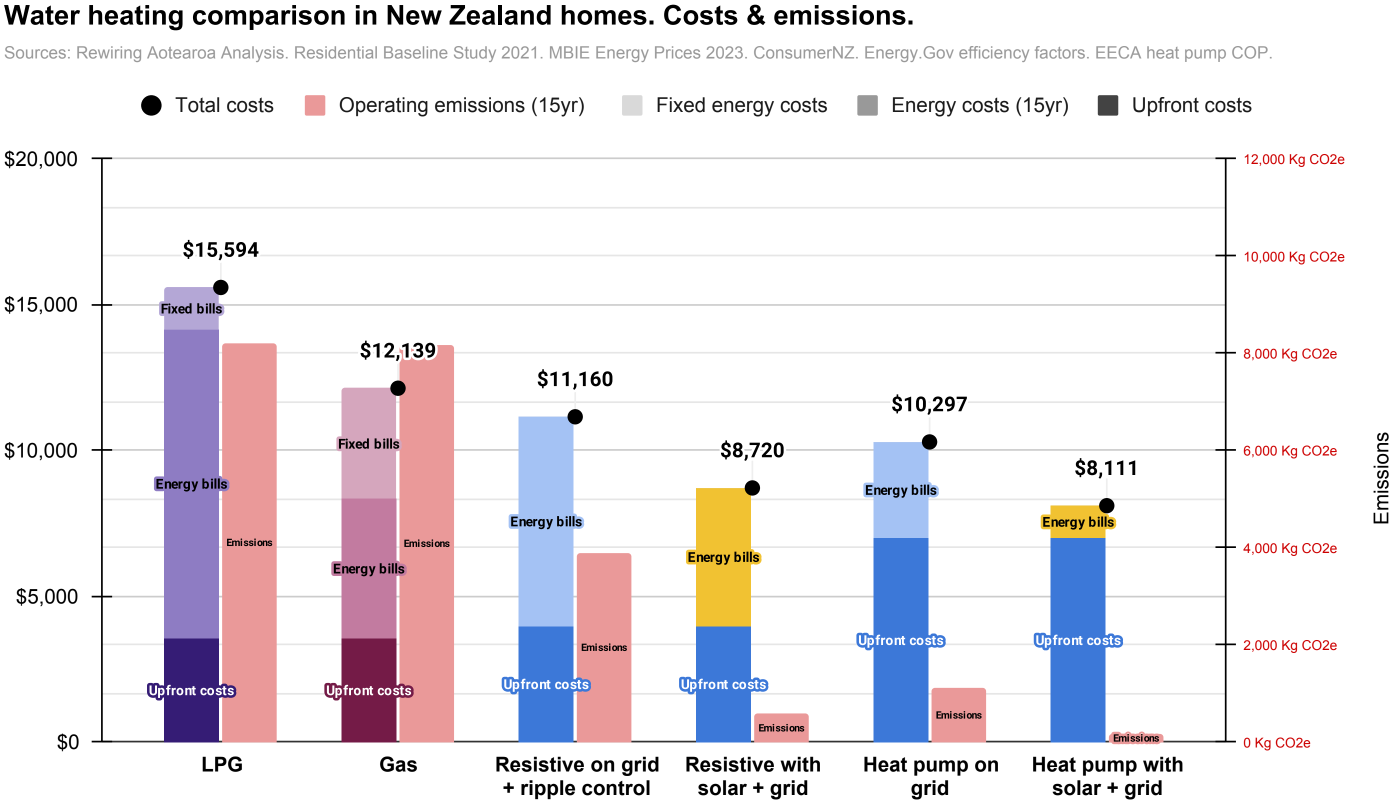


Figure 16 - Upfront and operating costs of water heating options in New Zealand homes over a 15 year lifetime.

Operating emissions over lifetime

The committed emissions over a 15 year lifetime of water heaters demonstrate the lowest emissions options are electric - by a significant margin. Electric heat pump water heating or resistance with solar will all save around 7,000 kg of emissions over 15 years when compared to gas or LPG water heaters.

Water heating emissions comparison in New Zealand homes.

Sources: Rewiring Aotearoa Analysis. Residential Baseline Study 2021. Assumes today's NZ grid emissions. Note if combined with solar and battery the electric options can be zero emissions.

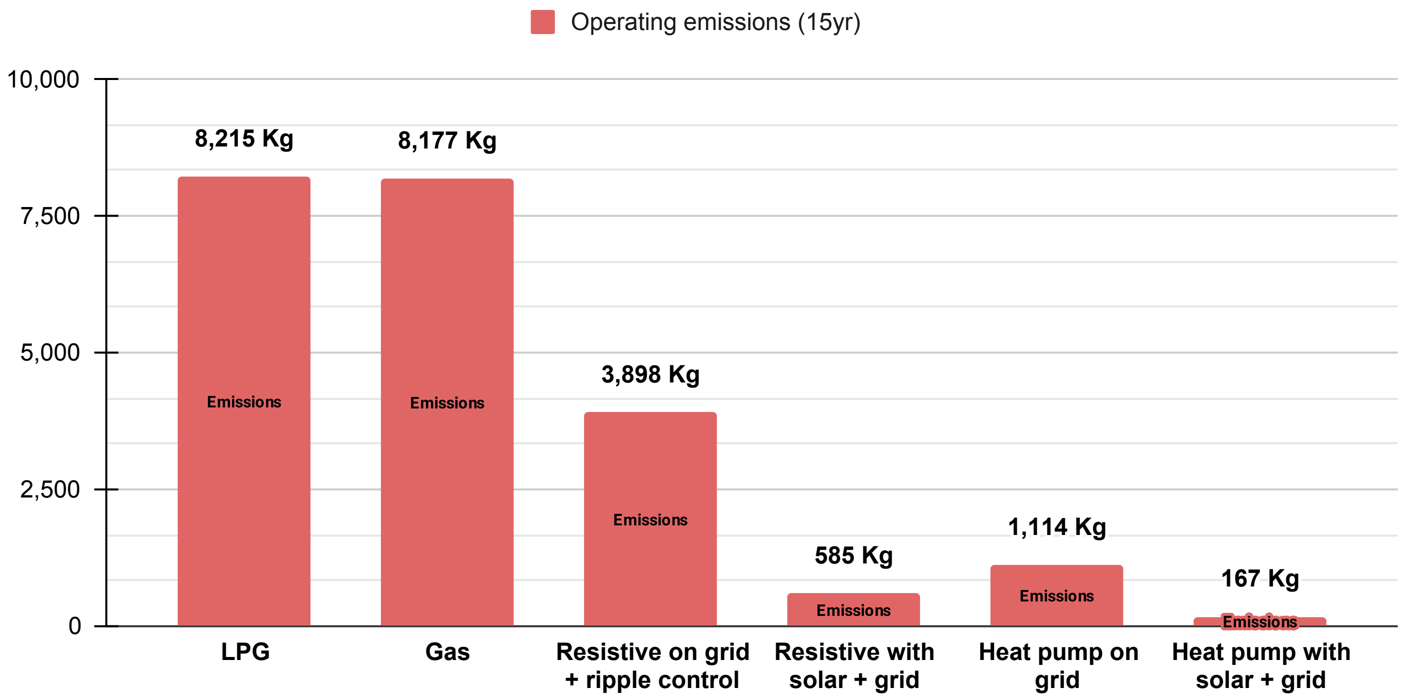


Figure 17 - Operating emissions over the lifetime of a range of water heating appliances.

Section 2.1.3

Cooktops

Cooking is a relatively small use of energy in most homes, and most cooking is already electric in New Zealand. Refrigerators and microwaves are electric and most ovens are electric too. But there is still a significant amount of gas/LPG cooktop use in New Zealand. Because the energy economics are so strongly in favour of space heating and water heating electrification, cooktop electrification presents an opportunity to disconnect from gas entirely and save even more by not paying a fixed or subscription gas cost.

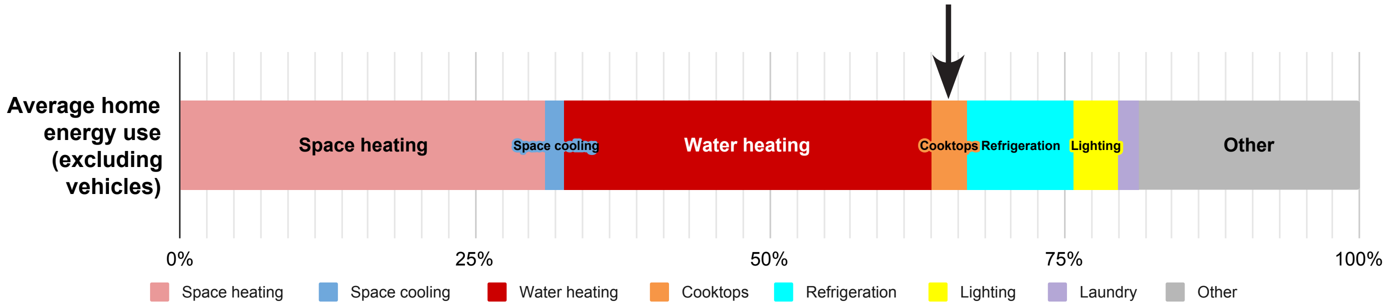


Figure 18 - Proportional energy use in an average New Zealand home.

Electric cooktops (either ceramic or induction) are generally about twice to three times as efficient as their gas or LPG counterparts. In addition to saving money and emissions, perhaps the primary reason to electrify cooking is for the health benefits. One-in-eight childhood asthma cases have been linked to gas cooktops in the United States.[1]

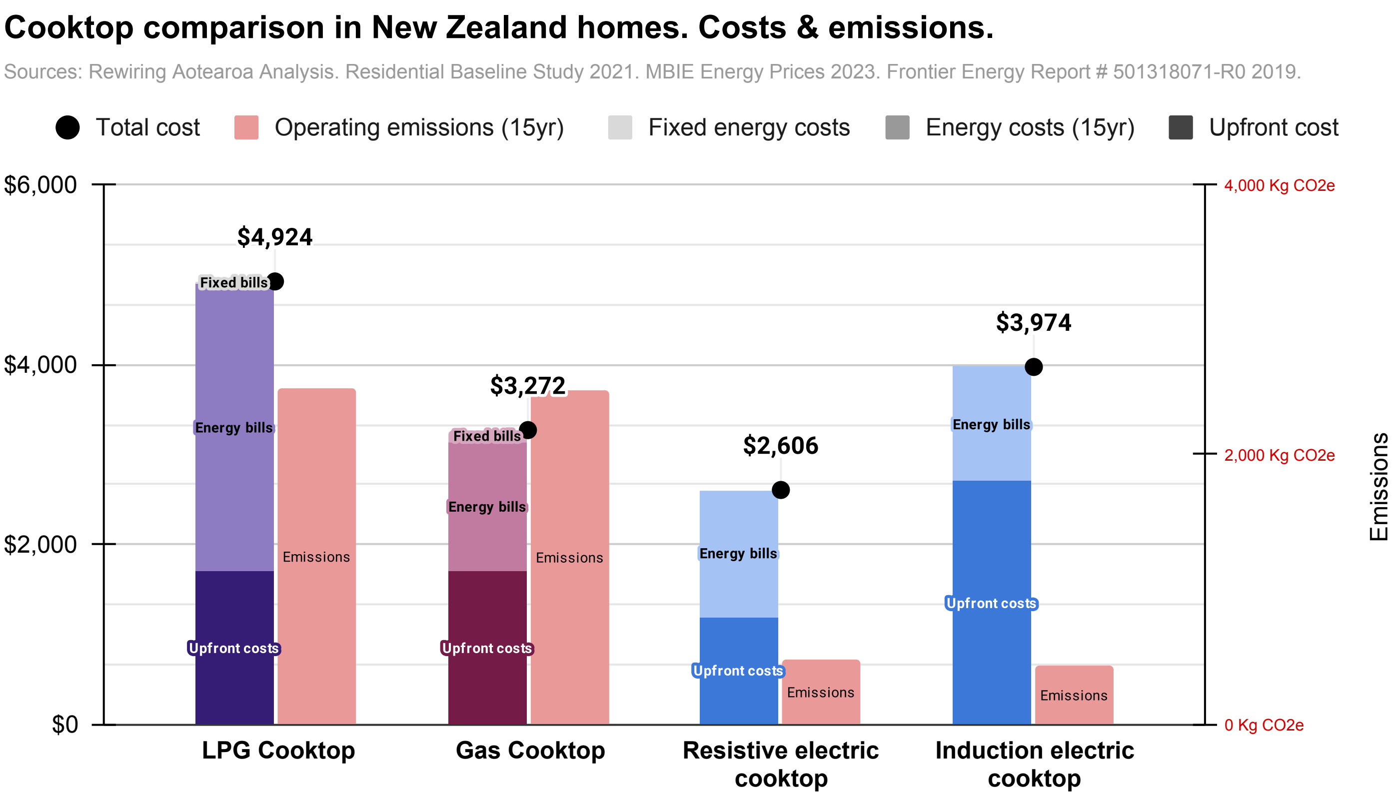


Figure 19 - Upfront and operating costs of different cooktop options in New Zealand over a 15 year lifetime.

1 https://www.mdpi.com/1660-4601/20/1/75

Energy efficiency

There are three main types of cooktop options in New Zealand homes: gas/LPG burner cooktops, electric resistance cooktops, and electric induction cooktops. Gas/LPG burner cooktops generally have an efficiency of about 30%,[1] meaning that only 30% energy stored in the gas is converted into heat in the food. Electric resistance cooktops have about 70%-80% efficiency and electric induction cooktops 80%-90%. This results in less than half the energy being needed for electric cooking.

Cooktop energy use comparison per day. Average New Zealand home.

Sources: Rewiring Aotearoa Analysis. Residential Baseline Study 2021. Frontier Energy Report # 501318071-R0 2019.

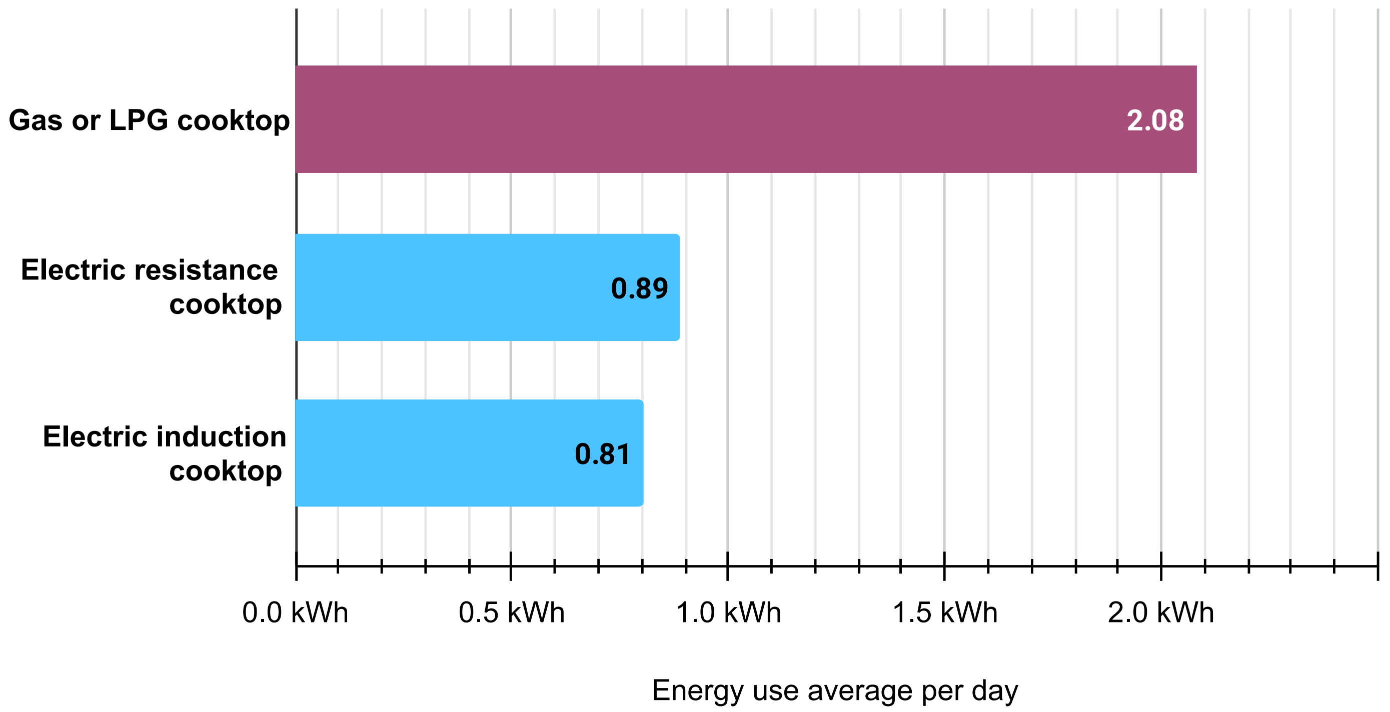


Figure 20 - Energy use per day for different types of cooktops.

1 Residential Cooktop Performance and Energy Comparison Study, Frontier Energy Report # 501318071-R0 July 2019
https://cao-94612.s3.amazonaws.com/documents/Induction-Range-Final-Report-July-2019.pdf

Yearly operating costs comparison

Electric cooktops have the opportunity to save a little money each year for New Zealand homes, but most of the savings will likely come from the ability to disconnect from gas if the cooktop is the last gas item in the home.

Cooktop average energy costs per year - New Zealand

Source: Rewiring Aotearoa Analysis. MBIE Energy Prices & QSDDEP 2023. Residential Baseline Study 2021.

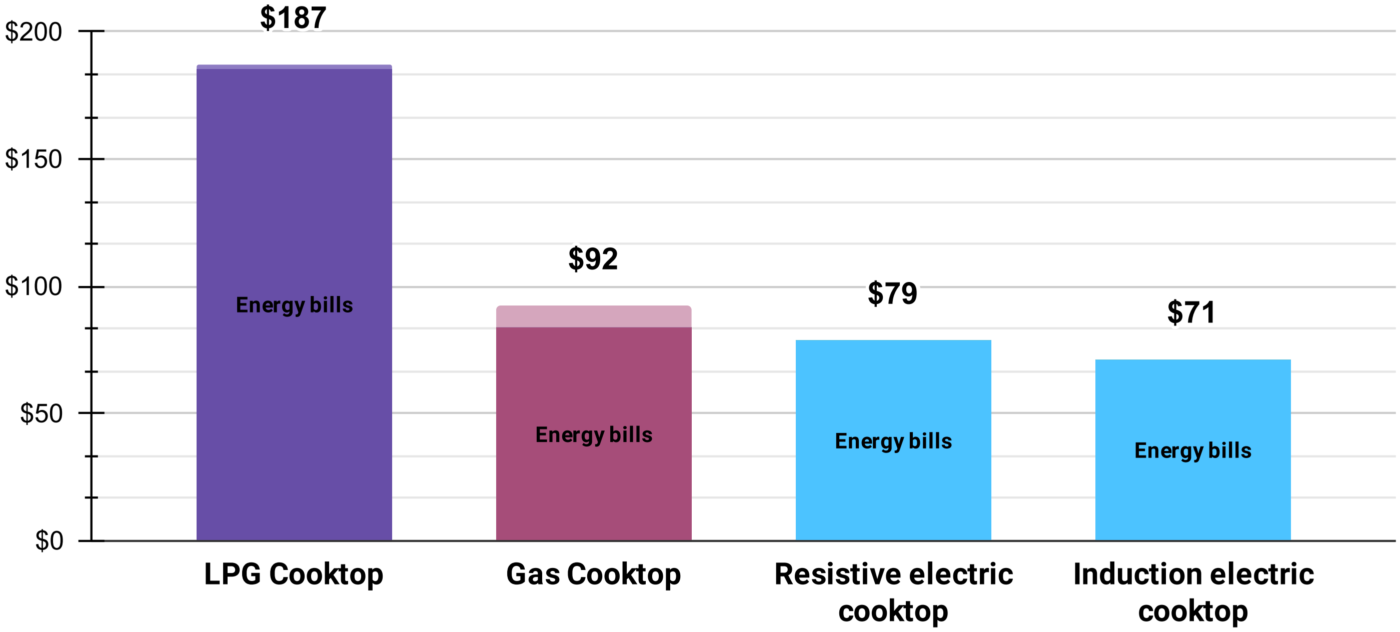


Figure 21 - Average annual operating costs of different types of cooktops.

Upfront and operating costs over lifetime

The upfront costs of cooktops vary significantly based on how “premium” the cooktop is. There is more variation caused by this premium nature than by the type of cooktop, though induction cooktops are generally more expensive upfront than gas or ceramic/resistance electric cooktops. Electric ceramic cooktops have most of the efficiency benefits of induction, and can easily be purchased for the same or less than the cost of gas/LPG cooktops.

Cooktop comparison in New Zealand homes. 15 year operating costs and upfront costs.

Sources: Rewiring Aotearoa Analysis. Residential Baseline Study 2021. MBIE Energy Prices & QSDEP 2023.

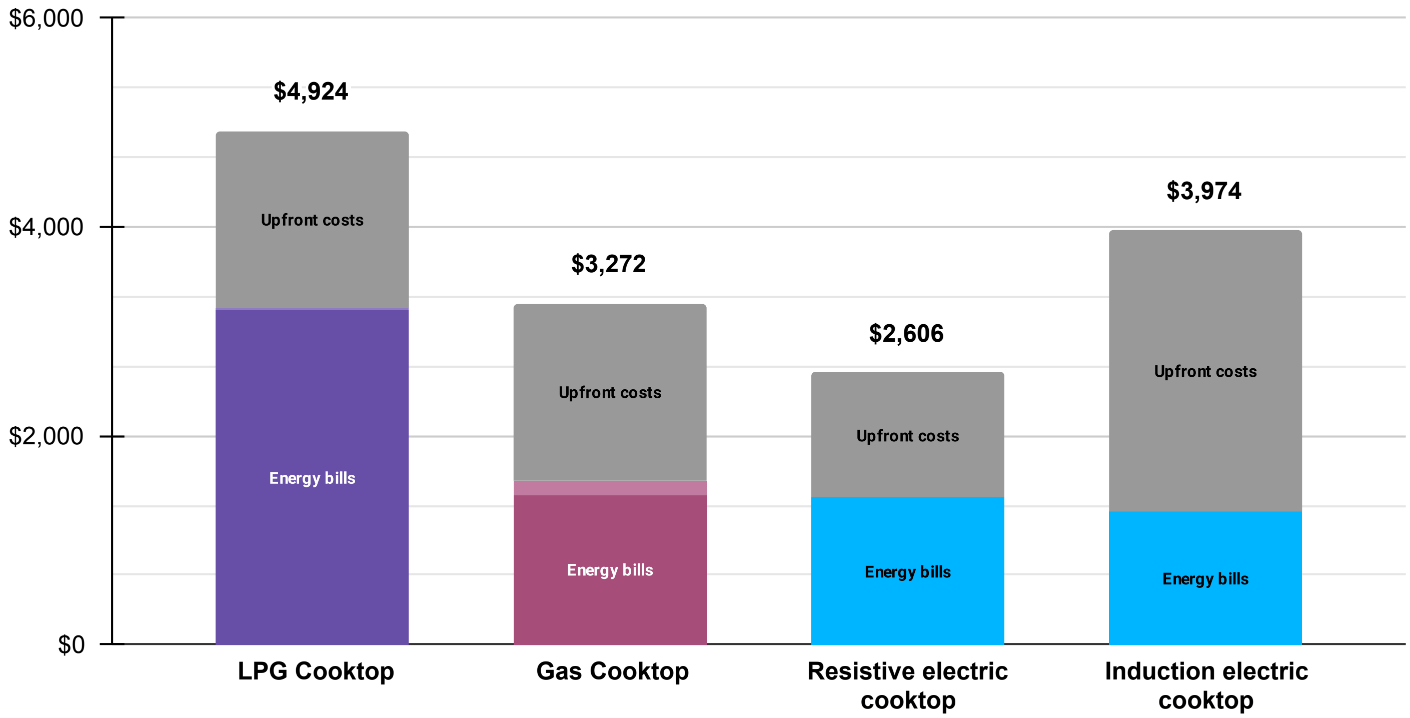


Figure 22 - Upfront and operating costs of different cooktop options in New Zealand over a 15 year lifetime.

Operating emissions over lifetime

Over a 15 year lifetime, switching from a Gas or LPG cooktop to an electric cooktop will save about 2,000 kg of emissions. With zero emissions electricity coming from the grid or from solar and a battery, electric cooking can be zero emissions.

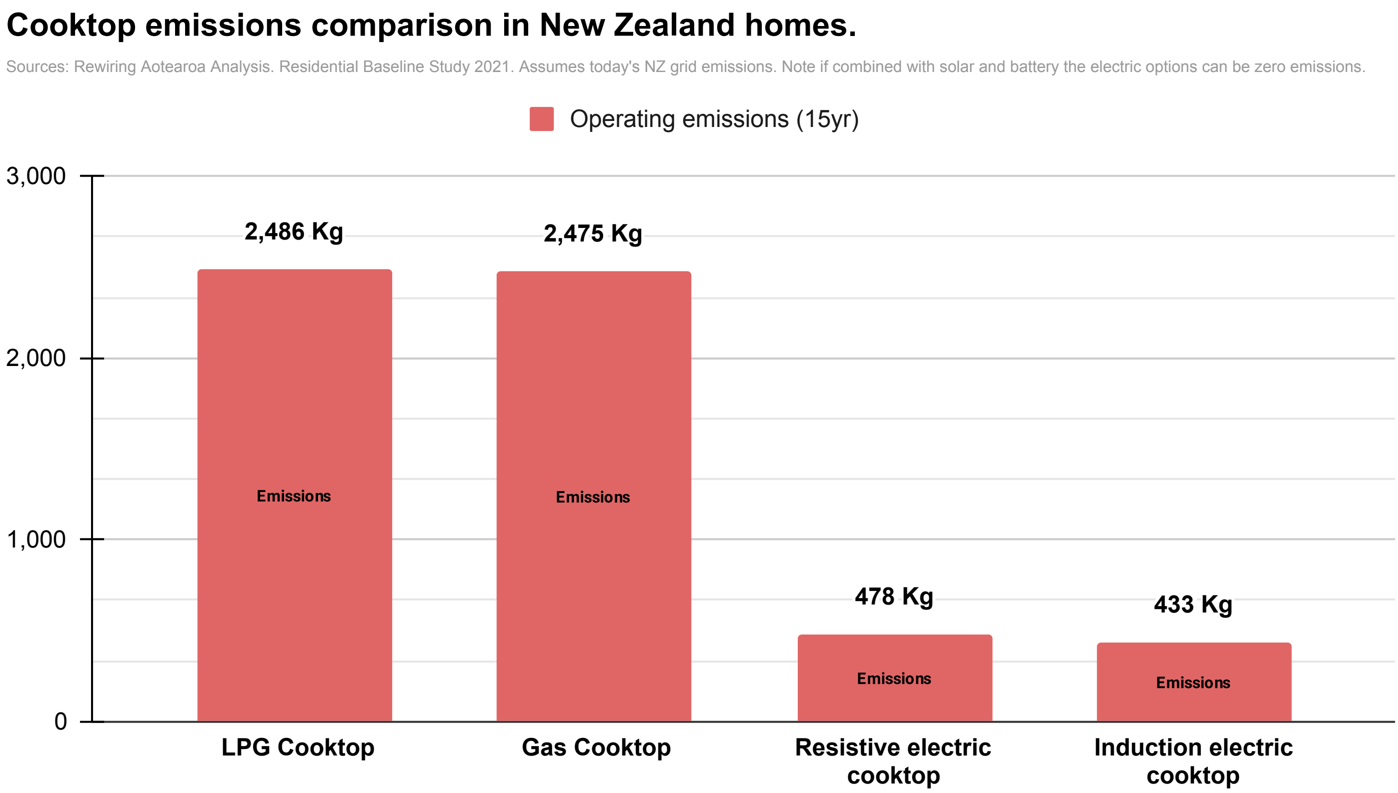


Figure 23 - Operating emissions over the lifetime of a range of cooktop options in New Zealand.

Section 2.1.4

Vehicles

Vehicles are the largest energy use for New Zealand homes and the largest source of emissions. This paper models the "average" energy use by home based vehicles, which is about 1.8 vehicles.

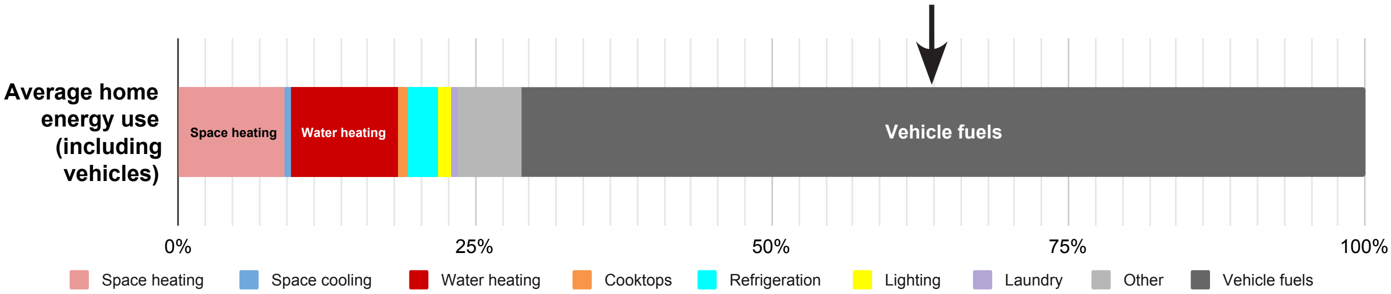


Figure 24 - Proportional energy use in an average New Zealand home when vehicle fuels are included.

As New Zealanders transition their vehicles to electric, much of their charging will likely come from the home as it is often the lowest cost and most convenient place to charge. Instead of petrol stations being the primary source of energy for vehicles, home electricity likely will be, joining the transport and residential sectors which are often viewed separately. This sector-coupling is an important consideration because it increases the home's electricity use, and means that the home's electricity supply will be the source of emissions reduction for those vehicles. For example, a home buying additional solar panels to charge vehicles is eliminating transport emissions through rooftop solar. This is especially important in the New Zealand context of the grid being mostly renewable, and rooftop solar sometimes being seen as having only a small impact on emissions reductions. When seen in the context of meeting the added energy needs to transition vehicles, it can reduce emissions and support the energy system.

Electric vehicles are substantially more efficient at converting energy into motion, with about four times greater efficiency than fossil fuel vehicles to go the same distance. In a petrol vehicle only about 16%–25% of the energy in petrol is turned into motion.[1] Most of this energy is lost as waste. In an electric vehicle 87%–91% of the electricity it receives is converted into motion at the wheels.[2] This efficiency difference enables significant driving cost savings with electric vehicles, and the largest saving comes from maximising how much the vehicle is charged from home solar.

Vehicle comparison in New Zealand homes. Costs & emissions per vehicle.

Sources: Rewiring Aotearoa Analysis. EECA End Use Energy Flows. EPA MPG Fuel Economy. MBIE Energy Prices 2023.

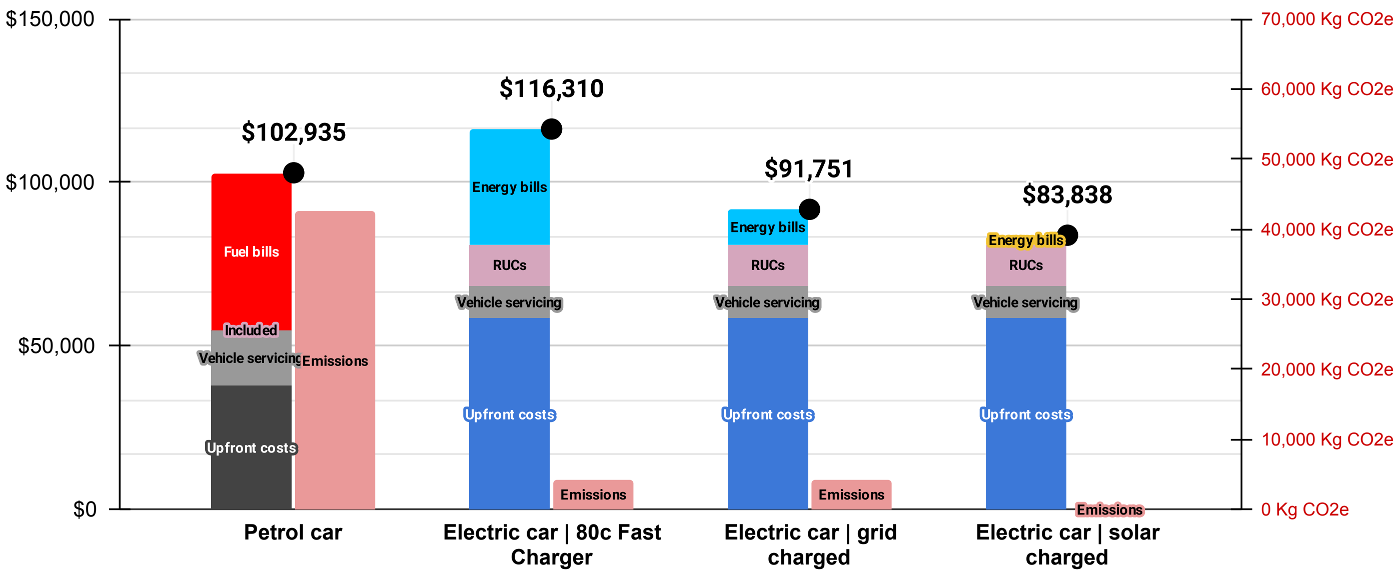


Figure 25 - Upfront and operating costs comparison of petrol vehicles and electric vehicles with different charging options. Emissions are shown in light red.

1 https://www.fueleconomy.gov/feg/atv.shtml
2 https://www.fueleconomy.gov/feg/atv-ev.shtml

Energy efficiency

Every vehicle has a different level of energy efficiency which is impacted by not only the fuel type, but also the vehicle's aerodynamics, drive train efficiency, weight and more. Electric vehicles are significantly more efficient than their fossil fuel counterparts of the same weight, size and shape. This is because electric vehicles have far less energy waste. They do not have the same thermodynamic losses as combustion vehicles which lose most of their energy. As discussed earlier, the majority of energy in petrol does not actually get turned into motion at the wheels, as around 79% is wasted. A striking example of this is in the chart below which compares a range of different electric vehicles and similar petrol vehicles. Even a large electric pickup truck is still far more efficient than a small petrol hatchback. This demonstrates the substantial difference in energy efficiency between electric and internal combustion vehicles.

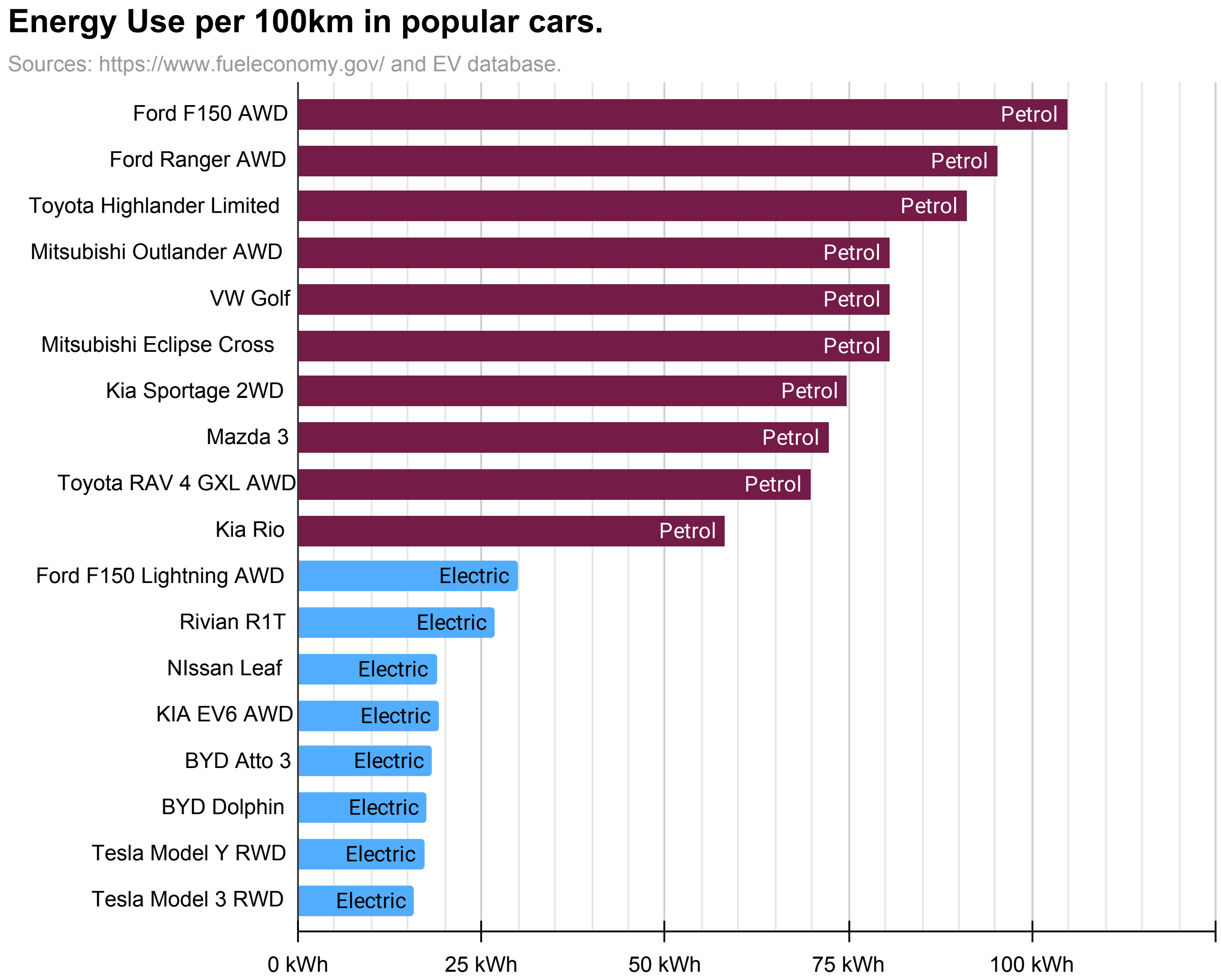


Figure 26 - Energy use per 100km for different models of vehicle. Petrol vehicles are shown in maroon, electric vehicles in blue.

Operating cost comparison

The four-times greater efficiency of electric vehicles leads to significant savings in operational costs. It is worth remembering that every person drives different distances each year, so the operational costs will vary. The further a vehicle drives, the better the economics stack up for electric vehicles because the cost of operation is so much lower, and the cost of fossil fuels so much higher. People who drive more than average are likely to be able to purchase an EV much sooner than those who drive less than average, because the fuel savings will be higher and therefore justify the higher upfront cost of an electric vehicle faster - it will have a shorter payback period. Electric vehicles are in general easier to maintain and therefore have lower servicing costs.[1]

The cost of charging has a significant impact on the driving cost of electric vehicles, as can be seen in the chart below. By far the lowest cost way to charge an electric vehicle is with rooftop solar. Electric vehicles with a longer range will benefit from this more. Given that the range of electric vehicles now covers more than the distance travelled during the average driving week, it is possible for owners to charge their vehicles on weekends during the day. Workplace solar chargers also offer opportunity for low cost charging. The difference is stark between fast chargers and charging from home solar or on normal grid rates. Maximising the amount of time a car can be charged at normal grid rates, or even better from rooftop solar, will maximise the cost of living savings for homes.

Yearly driving cost comparison in New Zealand. Electric vehicle and petrol vehicle.

Sources: Rewiring Aotearoa Analysis. EECA End Use Energy Flows. EPA MPG Fuel Economy. SEANZ. MBIE Energy Prices & QSDEP 2023.

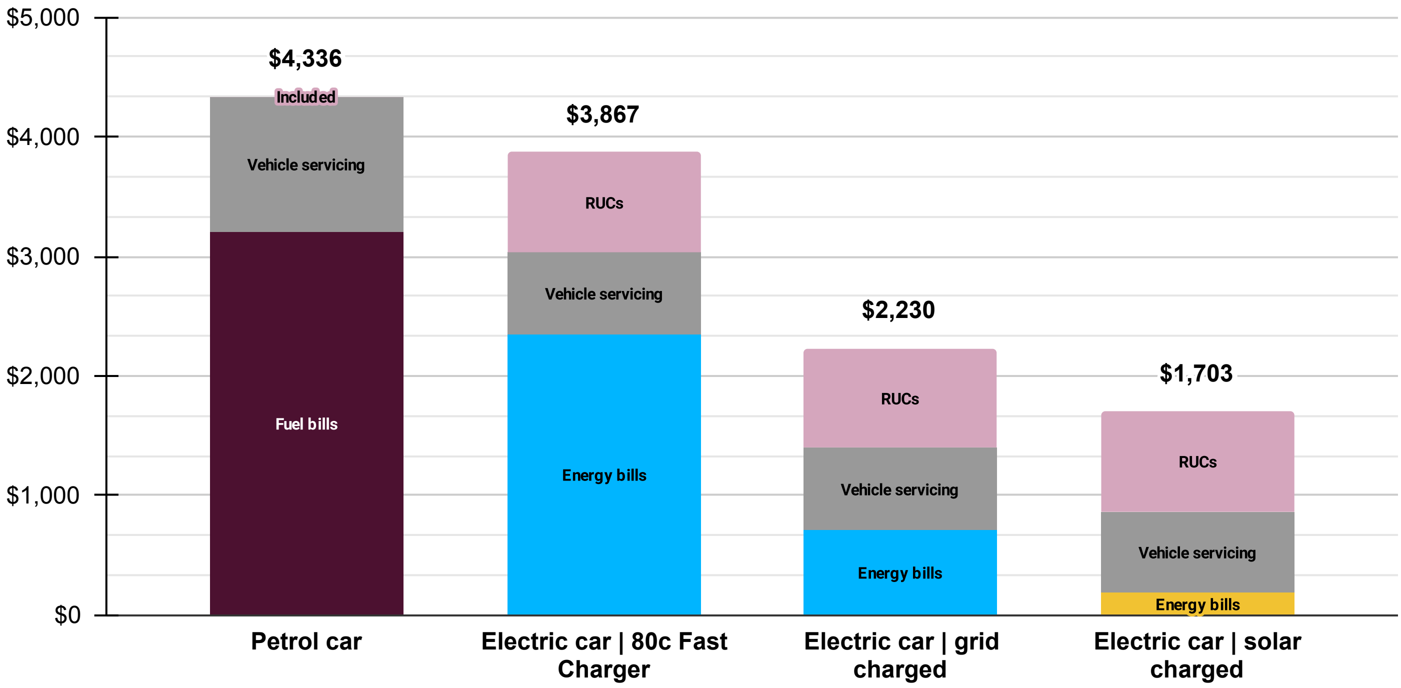


Figure 27 - Average annual operating/driving costs of different types of vehicles. For electric vehicles, this includes charging with different charging options.

1 Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains" (Argonne National Laboratory report ANL/ESD-21/4 July 2021) https://publications.anl.gov/anlpubs/2021/05/167399.pdf

Upfront costs

Electric vehicles vary in cost significantly depending on how premium the vehicle is, as do non-electric vehicles. Electric vehicles are still more expensive in the showroom than internal combustion engine vehicles on average. Below we show the upfront costs of many electric vehicles on sale in New Zealand in comparison to similar internal combustion engine vehicles. The cost of electric vehicles has been declining and is predicted to reach cost parity in the showroom with their fossil fuel counterparts around 2026[1] – with total cost tipping point including operational costs coming before that.

Due to the simpler overall components of an electric vehicle, it is predicted that with economies of scale they will eventually fall below significantly below an equivalent sized fossil fuel vehicle. This is in part because electric vehicles have fewer moving parts and are less complex in many ways than a fossil fuel vehicle.

Below is a comparison of upfront costs in New Zealand for a range of different electric and petrol vehicles.

New car price comparison across selection of electric and petrol vehicles

Sources: Manufacturer websites (NZ based) accessed Feb 2024.

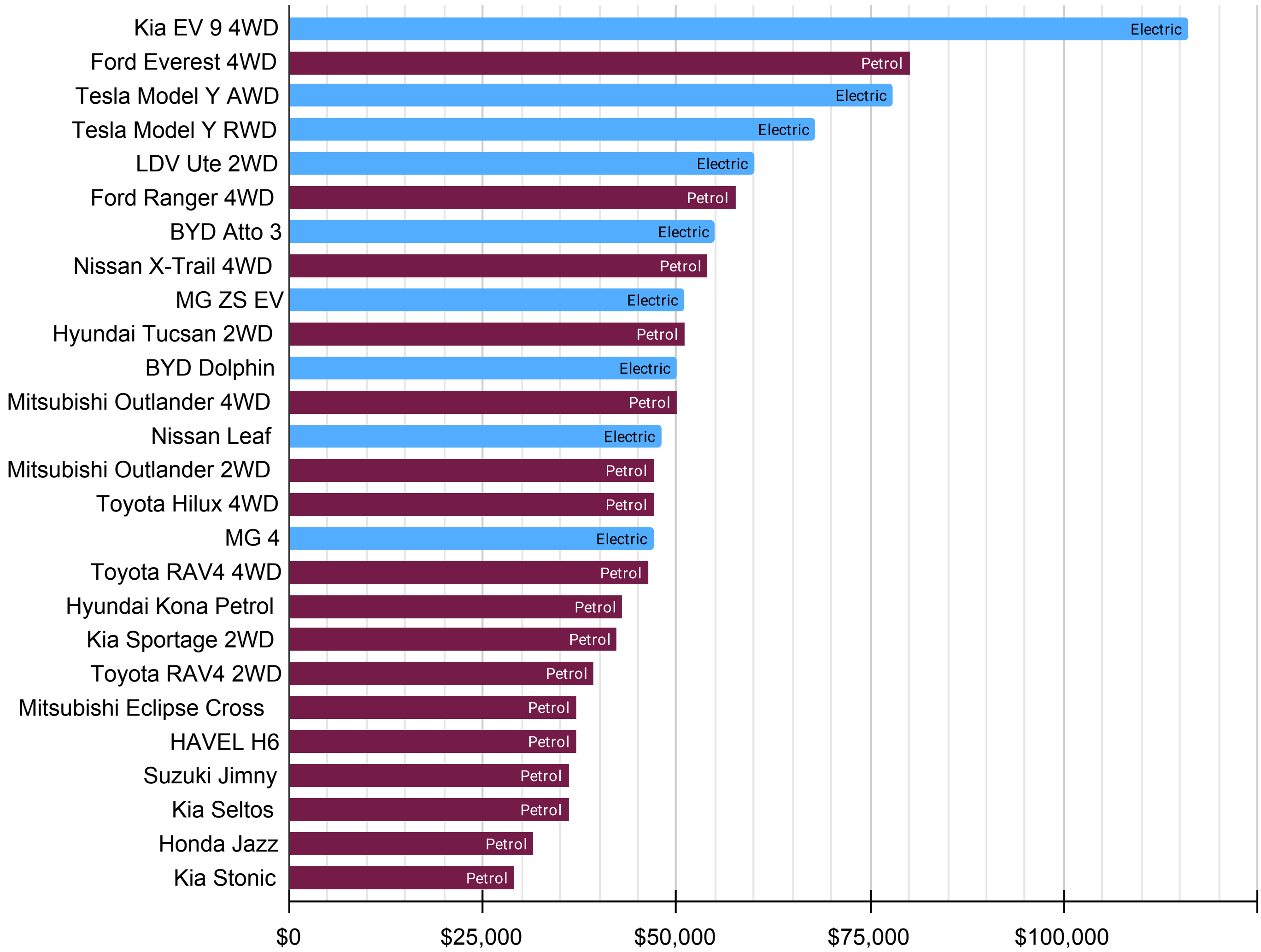


Figure 28 - Comparison of new car prices for a range of electric (blue) and petrol (maroon) vehicles. Note there are many more cars than this on the market, this is a selection of popular petrol/diesel vehicles and similar electric vehicles. There are more premium (and expensive) electric vehicles and also more premium petrol vehicles not in this list (e.g. this list does not include vehicle offerings from Audi, Volvo, BMW etc). For the household model an average price is calculated to compare new petrol and new electric vehicles. This is explained in more detail in the methodology, the goal was for the price to be representative of the cost difference to swap from a petrol car to a similar electric car.

1 https://www.transportenvironment.org/wp-content/uploads/2021/08/2021_05_05_Electric_vehicle_price_parity_and_adoption_in_Europe_Final.pdf

Upfront and operating costs

The total costs for EVs demonstrate the value of charging with solar. Over 15 years an EV charged from solar is lower than the cost of a petrol equivalent vehicle. If charged with the grid, it is still lower, but if charged only with fast chargers the total cost is higher. Note real world driving will likely involve a mix of charging options. For people that drive more than the average amount, an EV will likely make economic sense much faster than for people who drive less than average. If people can purchase an EV for a similar cost to the petrol car they would have purchased, then the economics will easily stack up.

More considerations go into car purchases than economics, and with that costs can vary considerably. For this comparison, we are using new vehicle costs on both sides, and it is worth nothing that a significant portion of car purchases are also second hand. The "difference" in cost between the fossil fuel vehicle and the electric vehicle is the main figure being evaluated, which also applies to second hand vehicles. For example, if a second hand petrol vehicle is $20,000 and a second hand electric vehicle $40,000, the question is still if the operating costs recovery from the electric vehicle can pay back that difference in upfront cost.

Service costs change this picture even more, with EVs having lower overall service costs. Perhaps the most important consideration in this picture is that EVs are expected to significantly drop in price between now and 2030, which will make a significant difference to the economic picture of EV ownership. It's clear today, EV's can already be lower cost investments over time than petrol vehicles even when the electric vehicle is higher cost upfront.

Driving cost comparison in New Zealand. Electric vehicle and petrol vehicle over 15 years.

Sources: Rewiring Aotearoa Analysis. EECA End Use Energy Flows. EPA MPG Fuel Economy. SEANZ. MBIE Energy Prices & QSDEP 2023.

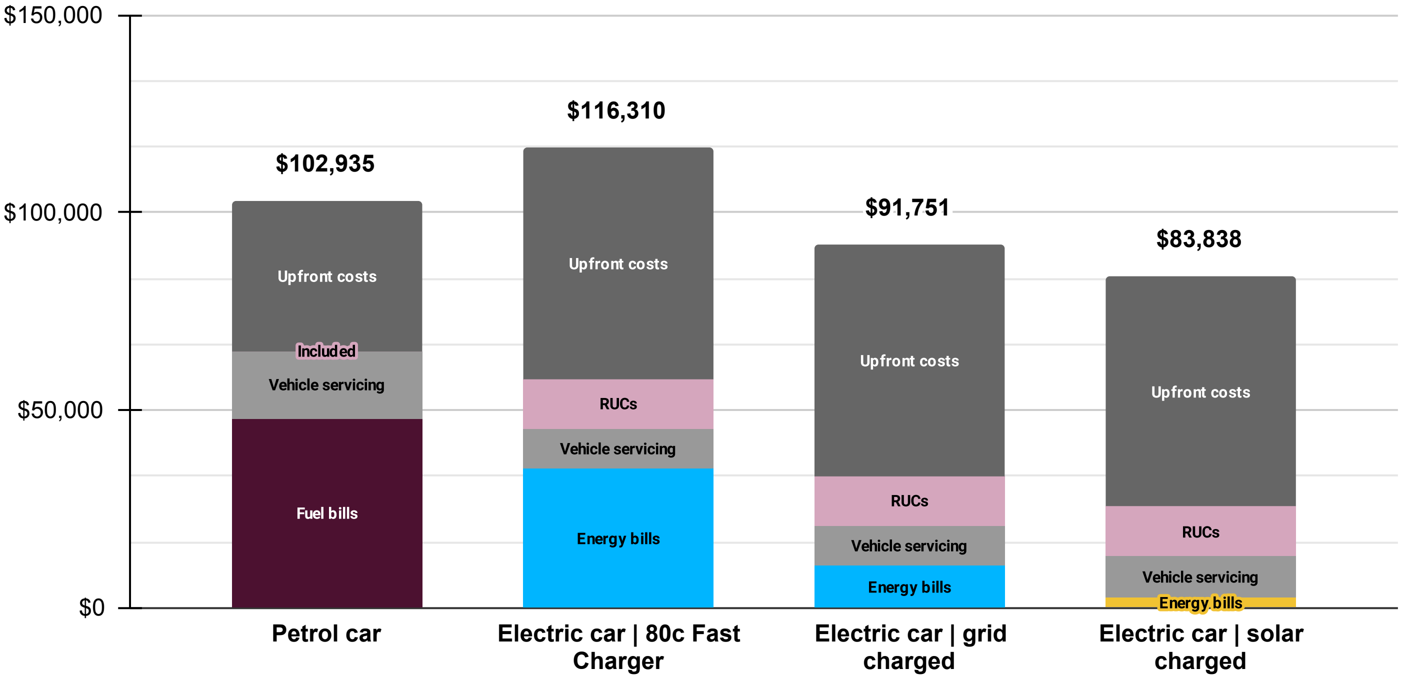


Figure 29 - Upfront and operating costs of petrol vehicles compared to electric vehicles with different charging methods over 15 year vehicle lifetime.

Operating emissions over lifetime

Over 15 years, switching to an electric vehicle can save over 42,000 kg of emissions. If the vehicle is charged with the current New Zealand grid it can save around 38,000 kg. As the grid becomes more renewable this only gets better, and charging with solar and/or batteries enables electric vehicle charging to be virtually zero operating emissions today. It is worth noting all manufactured products also contain embedded/embodied emissions, which are emissions from the materials and processes used to make the product. This is especially apparent in electric vehicles which require significant amounts of battery materials. This has been studied in detail, and it is clear that over their operational lifetime electric vehicles have significantly lower emissions than their fossil fuel counterparts. [1]

Petrol and Electric Vehicle emissions comparison with average New Zealand driving.

Sources: Rewiring Aotearoa Analysis. EECA End Use Energy Flows. EPA MPG Fuel Economy.

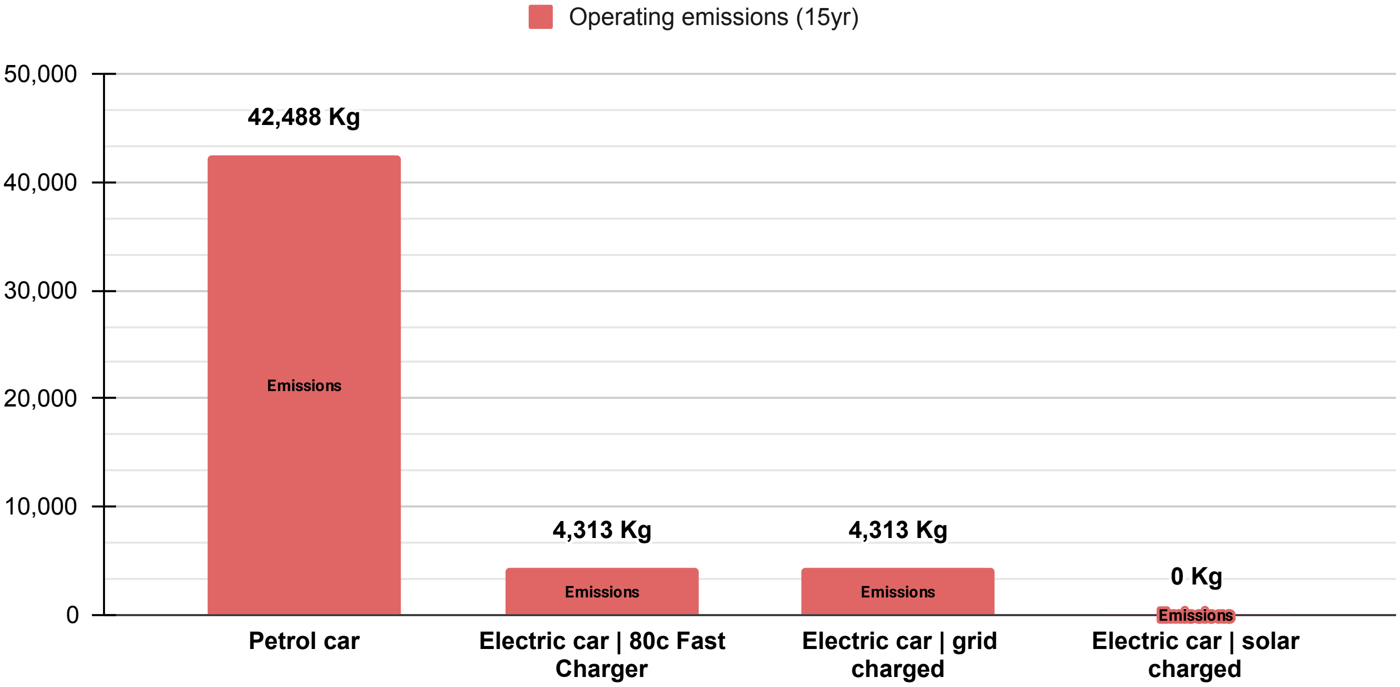


Figure 30 - Emissions over the lifetime of a petrol or electric vehicle, including emissions for different charging methods

1 European Federation for Transport and Environment, 2022, How clean are electric cars? https://www.transportenvironment.org/discover/how-clean-are-electric-cars/

Section 2.2

Rooftop Solar

Rooftop solar is the lowest cost energy for New Zealand homes

Rooftop solar in New Zealand is the lowest cost delivered energy available to homes, at less than half of average grid electricity costs. This is demonstrated in the chart below which shows the comparison of average electricity costs between the grid and solar installations. Seasonal variations, fixed cost variations, and fluctuating wholesale prices add nuance to this picture, but the point it conveys is clear: rooftop solar is the lowest cost energy available to New Zealand homes and is likely only to extend this lead into the future as costs fall with economies of scale. The capacity factor used here is 15%, and it's worth noting in some parts of New Zealand this can be both lower and higher, which will change solar economics though in most cases is unlikely to change them significantly and solar is likely to remain the lowest cost energy source available.

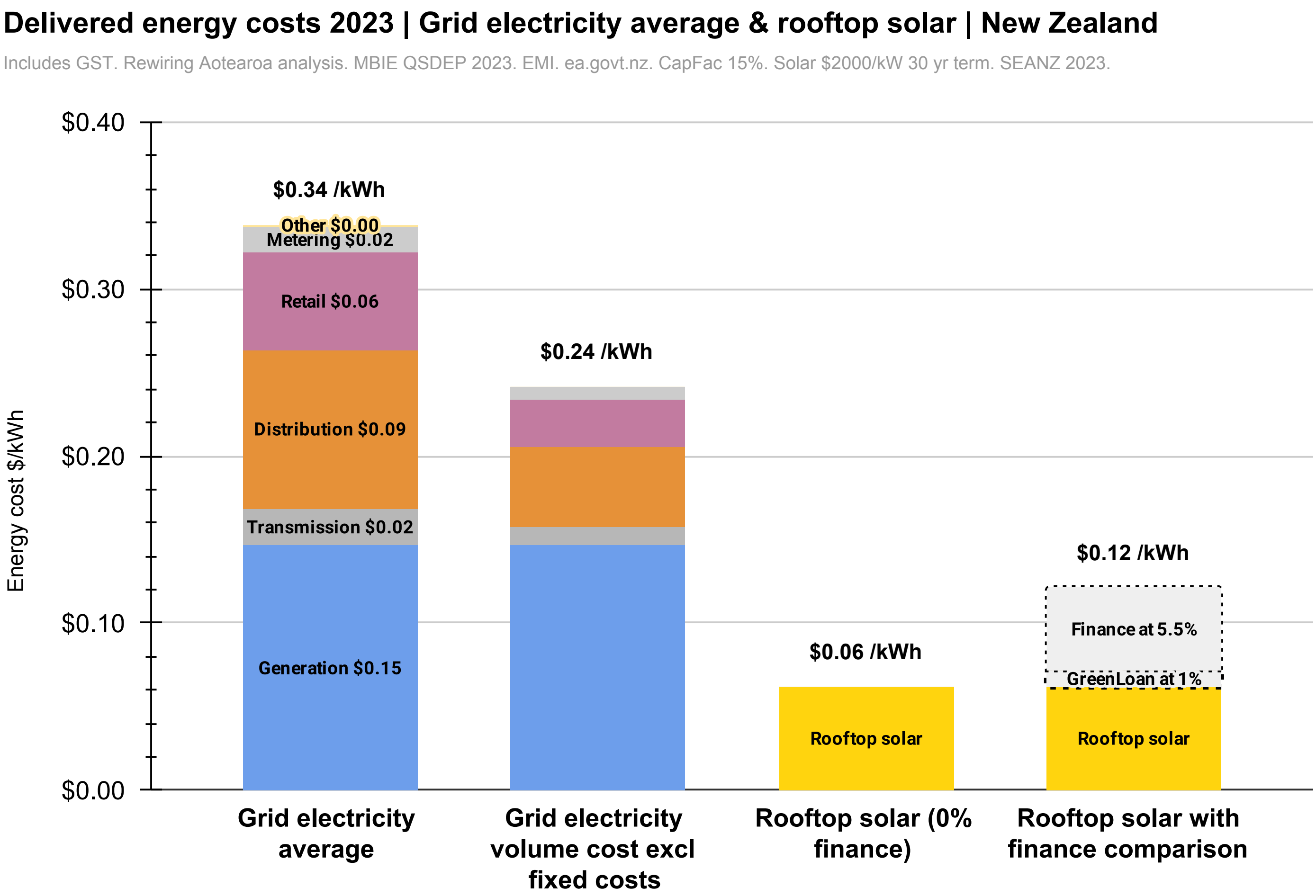


Figure 31 - Delivered electricity costs for grid electricity, and rooftop solar with finance costs included. Solar capital cost $2000/kW and a 30 year finance term.

As vehicles and homes electrify, double to triple the current renewable electricity load will likely need to be delivered to homes. The lowest cost way to produce much of this additional energy is likely to generate as much as is feasible from rooftop solar on homes, businesses and farms. This has the simultaneous benefit of increased resilience for New Zealand communities, and locking in cost-of-living savings for homes and operating cost savings for businesses.

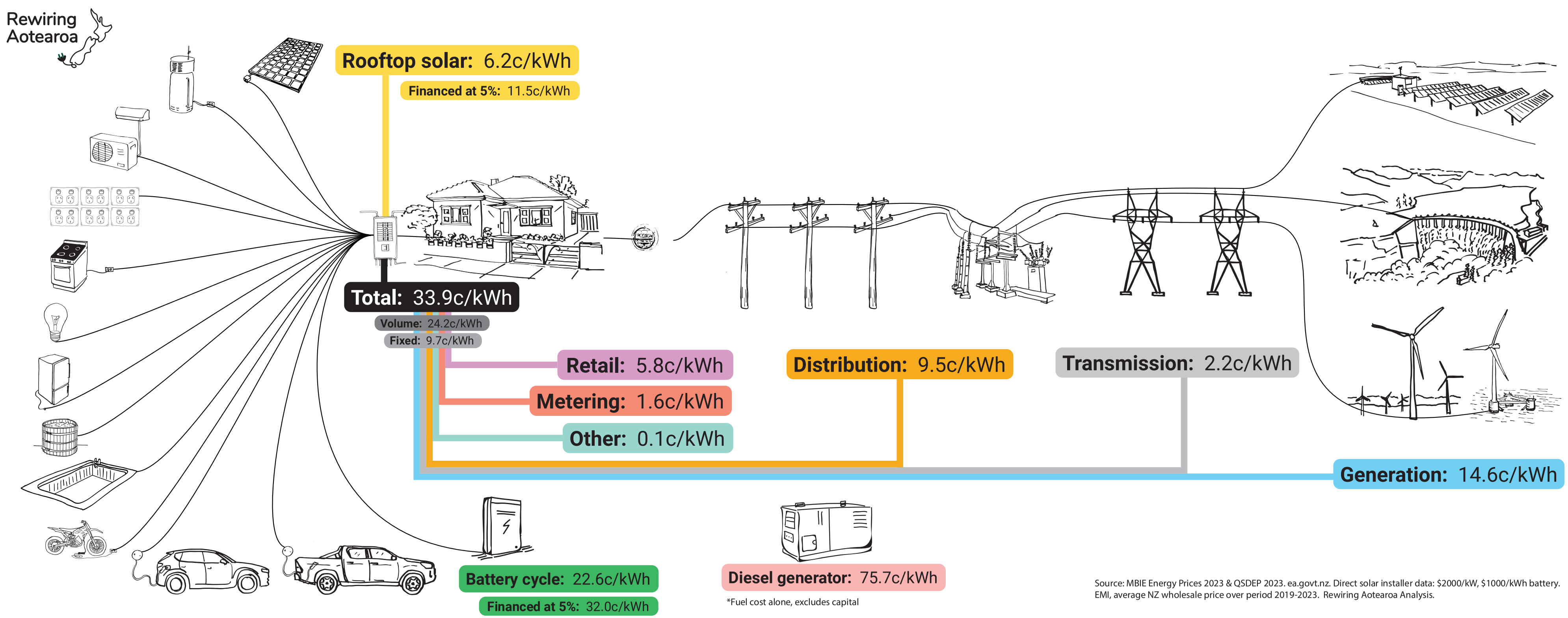


Figure 32 - Delivered electricity costs breakdown for grid electricity, rooftop solar, battery cycles and diesel generators.

How solar is financed will make a big difference for many homes

The availability of suitable solar finance products will make a significant difference to the economics of rooftop solar for homes and the ability for low-income homes to have access to the cost of living benefits of electrification. Multiple loan products are on the market today - typically to homeowners - offering low interest green loans that can be used for solar. Often these products do not cover the full warranted lifetime of the solar panels, and therefore require an increase in costs for the home for a short period in exchange for higher savings when the solar is paid off early.

Loan products that cover the warranted lifetime of solar panels could significantly improve access to low cost energy for New Zealand homes. Similarly, enabling rooftop solar access to renters could deliver significant cost of living savings on energy. When purchasing solar outright, Net Present Value (NPV) should be taken into account, and also the forward price of grid electricity which has risen historically. This is an important consideration because purchasing solar locks in the delivered energy cost of that solar for 30 years for the home, whereas most energy prices have risen in an inflationary manner over the past 30 years and are expected to continue to do so.

Flattening energy prices

Financed rooftop solar helps flatten energy prices for homes. Historically fossil fuel prices have risen in an inflationary manner, and so have the costs to consumers of grid electricity. When purchasing a solar installation, a home is buying 30 years of energy upfront that will output from the solar panels over their lifetime. When financed, this turns into a flat repayment cost for the energy provided. This is demonstrated in the chart below with the black line, solar being purchased in 2023 and the repayments going forward. Batteries experience a similar flat cost over their lifetime, where a home is purchasing years of energy storage that is paid off over time.

New Zealand delivered energy cost per kWh, historic and forecast.

Rewiring Aotearoa Analysis. StatsNZ Quarterly CPI History 2023. MBIE Energy Prices & QSDEP 2023. SEANZ 2023 Solar data. NREL forecast. Micah Ziegler and Jessika Trancik (2021) historic battery pricing and Our World in Data historic solar pricing adjusted to NZ prices.

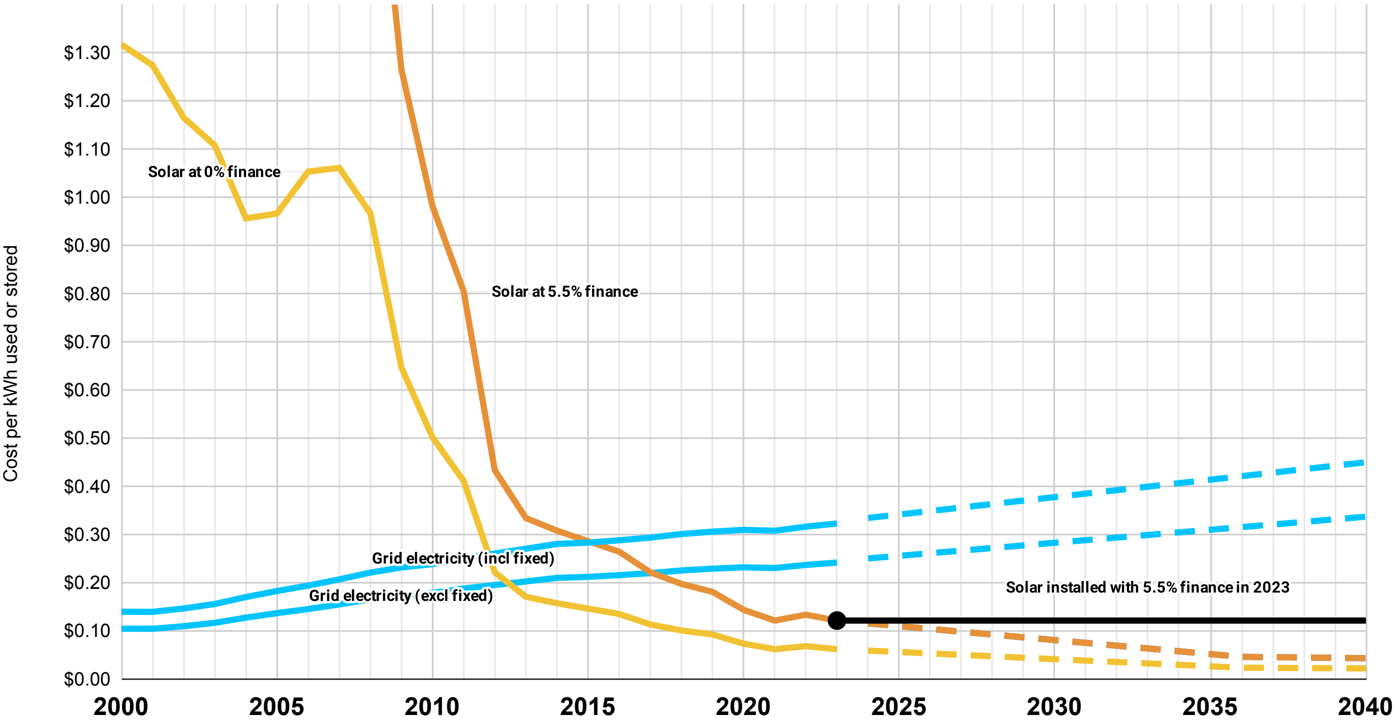


Figure 33 - Solar and grid electricity costs compared historically and with future price forecasts. The black line shows the flat repayments for solar financed in 2023 at a fixed interest rate of 5.5%. With rooftop solar and batteries, homes are purchasing many years of energy upfront, finance turns this into flat stable repayments in contrast to energy prices which have historically risen in an inflationary manner. Historic solar prices estimated based on international module cost curves indexed to current New Zealand solar prices. Future solar prices based on NREL Advanced forecast adjusted to New Zealand solar prices. Today's grid prices based on MBIE and EMI price data, historic and forecast based on electricity Consumer Price Index (CPI).

Rooftop solar vs large scale solar - delivered energy costs

It is important to understand the end costs to the consumer when looking at the lowest cost energy system, and the lowest cost-of-living option for households. Large scale or grid-scale solar is often more efficient than rooftop solar - it can generate energy at lower cost because of installations that track the sun - but by the time that energy reaches many households it is more expensive than a household installing its own solar. There are multiple reasons for this, one being the additional costs a consumer pays for energy coming through their meter, which includes transmission and distribution costs and retailer costs. Line losses and generation profit margin also contribute.

This paper is not meant to be an exhaustive comparison of grid-scale and rooftop solar. Both will likely be required at scale to deliver a zero-emissions energy system. However, maximising the deployment at scale of rooftop solar for homes is likely to deliver the lowest cost of living, more resilient communities, and a lower cost energy system for New Zealanders.

Costs are expected to fall in the short and long term

New Zealand's rooftop solar is still not as cheap as Australia where solar is currently installed for about half the cost of New Zealand.[1] Australia's solar uptake is a global success story, delivering the cheapest home energy in human history.[2] However, New Zealand solar will likely continue to get more affordable both in the short term and long term.[3] [4]

We still need the grid

This paper in no way suggests that homes should go "off grid". Keeping homes on the grid is likely to lead to a significantly lower cost and more robust energy system. It's important to consider the additional electricity needed as we transition off gas and petrol/diesel to electricity. While this will be an overall reduction in primary energy, it will require an increase in electricity. Rooftop solar can play a large role in providing additional zero-emissions electricity for a low cost to consumers. Batteries can support solar, but grid electricity should still be an essential part of the energy mix in balancing a system with large levels of localised rooftop solar and storage. It is likely to be vital that pricing mechanisms encourage customers to stay on the grid as the falling costs of solar and storage makes it economically easier for homes to choose to go off grid. Customers leaving the grid will not only increase the cost of grid electricity for everyone else on the grid, raising equity concerns, it will also waste the value to the system these resources can provide to lower system costs. We should design a grid that encourages and works in harmony with customer resources, recognising they will be a large part of the energy system as homes act in their own economic interest and install solar and batteries.

1 https://www.greentechmedia.com/articles/read/how-to-halve-the-cost-of-residential-solar-in-the-us
2 https://www.nytimes.com/2022/06/08/opinion/environment/defense-production-act-solar-power-australia.html
3 https://www.abc.net.au/news/science/2023-02-16/solar-panel-prices-fall-decade-installation-rooftop-renewables/101966764
4 https://www.pv-magazine.com/2023/08/23/solar-module-prices-continue-to-fall/

Section 2.3

Home Batteries

Home batteries are approaching a tipping point

Home batteries are approaching the tipping point where they make economic sense for the majority of homes. Batteries in New Zealand are being installed for $700 - $1300 /kWh. Over a 15 year lifetime of cycling (charging and discharging) once per day, this amounts to about 17 cents - 28 cents per kWh (including degradation). With the average New Zealand home paying about 33 cents per kWh for grid electricity, or about 24 cents after fixed costs, the costs of batteries are starting to drop below this point. If a battery can be financed at a low interest rate - currently made available in green loans by many banks - then it is likely already affordable today for many homes.

Batteries are dropping in price fast,[1] and predicted to drop even further with wholesale battery pack prices approaching $100 USD/kWh[2] before they are put into products. An eye-opening example of this is the cost of home batteries compared to electric vehicle batteries. While home batteries can cost over $1000/kWh, a long range BYD Atto 3 can be purchased in New Zealand for $59,990, with a 60kWh battery in it. This makes it virtually a battery at $1,000/kWh - with a free car attached. Some of these battery economies of scale are expected to be realised in home batteries too. As batteries drop in price, they become economical for more and more homes, which enables them to install more solar, and to enhance their energy resilience.

New Zealand battery costs per kWh cycle, historic and forecast.

Rewiring Aotearoa Analysis. StatsNZ Quarterly CPI History 2023. MBIE Energy Prices & QSDEP 2023. SEANZ 2023 Solar data. NREL forecast. Micah Ziegler and Jessika Trancik (2021) historic battery pricing and Our World in Data historic solar pricing adjusted to NZ prices.

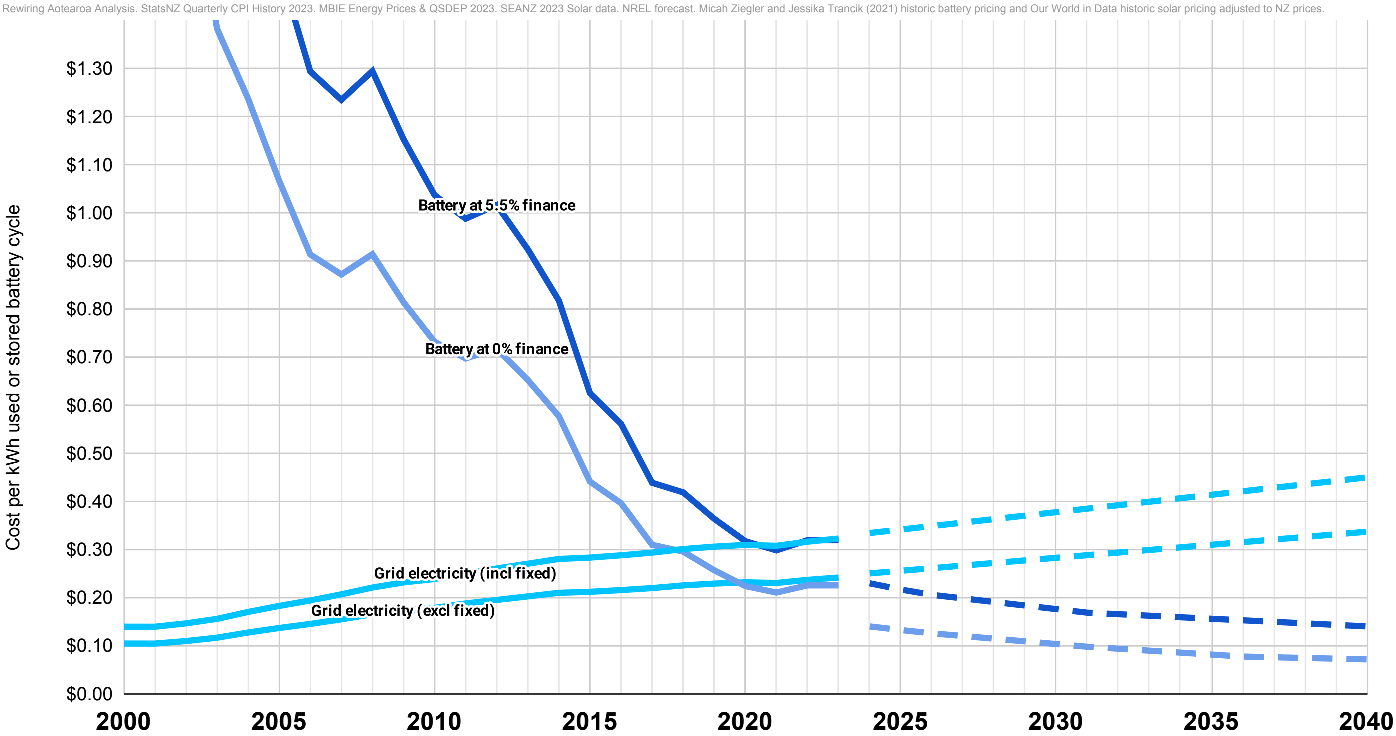


Figure 34 - Battery cycle costs per kWh when financed at 5.5% or 0%, historic and forecast comparing to grid electricity volume costs. It should be noted that homes do not need to store 100% of their energy, only a portion of it for later use, therefore the cost of a solar and battery energy system only needs part of the energy needs to be met by battery cycles. Additionally, batteries can store during peak or high cost periods when electricity costs are higher than average. What this shows is that battery costs are around the tipping point where they become lower cost than grid electricity. In many cases today they are past the tipping point, and they are expected to drop rapidly over the next few years with economies of scale.

1 https://ourworldindata.org/battery-price-decline
2 https://source.benchmarkminerals.com/article/global-cell-prices-fall-below-100-kwh-for-first-time-in-two-years

Resilience: People don't just buy batteries for economics

New Zealand homes and communities are impacted by and at risk from natural disasters. This was emphasised in 2023 with the severe flooding of the North Island in January,[1] noted as a 1-in-200 year event, followed merely weeks later by Cyclone Gabrielle,[2] reported as the costliest cyclone in recorded history for the southern hemisphere. Cyclone Gabrielle resulted in widespread power cuts and damages. New Zealand's earthquake risk adds further emphasis to the need for a resilient energy system. The 2011 Christchurch earthquake killed 185 people and was New Zealand's costliest natural disaster. The earthquake caused significant damage to infrastructure that left thousands of homes without power. [3]

There are more reasons than just economics for homes to purchase batteries that can provide them with backup power in an emergency. Rural communities also have less grid redundancy, meaning they are more affected by planned maintenance outages. As prices of solar power and batteries drop, New Zealand communities stand to benefit significantly from not only the cost savings but also the added resilience local batteries can provide.

Modern electricity pricing makes batteries more economic for homes

Today, few electricity consumers in New Zealand get to share in the benefits that consumer/customer energy resources (CER) – such as solar, batteries and smart electric appliances including EV charging – can provide to the electricity system. Boston Consulting Group's (BCG) *The Future is Electric* report suggested that every MW of demand (equivalent to 1,000 heat pumps, or the charging of 140 EVs) that can be smartly managed to avoid periods of high demand will save around $1.5m of generation, distribution and transmission infrastructure costs.[4] Similarly, Sapere Research Group advised the Electricity Authority (EA) that smart deployment of CER could create economic benefits of nearly $7b by 2050.[5]

New electricity pricing being rolled out by distribution networks in Australia is rewarding consumers for their ability to contribute to the energy system, and in doing so making battery economics better for homes.[6] [7] [8] Two-way tariffs provide a higher reward for homes which can feed in battery power at peak times to lower network peaks and therefore reduce infrastructure needs. These are different to conventional solar feed-in-tariffs which are well known. These reverse distribution tariffs range from about NZD 15-28 cents / kWh. This then gets added to the price of wholesale electricity (including the feed-in-tariff) to provide a reward to homes that is higher than the cycle cost of the battery. As New Zealand adopts more cost reflective pricing in its electricity market, the justification for households to buy batteries will likely only increase further.

Example: battery storage potential

Considering batteries are becoming economic for many homes today, and add additional value like resilience, it's important to contextualise how much potential there is for homes to contribute significantly to the energy system. Homes which install a 10kWh battery can virtually eliminate their peak load usage entirely. If 80% of homes had a battery install alongside their rooftop solar, residential peak loads would likely be entirely reshaped for the better and infrastructure utilisation and resilience increased significantly. As combined solar and battery prices reach lower costs than consumer grid peak pricing, reducing peak loads becomes virtually free, in that the home can reduce their peak load with no additional cost because the battery is economic in itself.

We should also not underestimate the capability and scale of Vehicle-To-Grid, or Vehicle-To-Home, where an electric car battery shares energy back into the grid or home. The electric cars parked in our future driveways could back up our homes for over a week if needed. Assuming 1.8 vehicles per home, and an average battery size of 75kWh per vehicle, they represent around 250GWh of storage. Even if only half that was utilised, it would provide more overnight storage capacity than all of New Zealand's hydroelectric storage could provide.

1 https://en.wikipedia.org/wiki/2023_Auckland_Anniversary_Weekend_floods
2 https://en.wikipedia.org/wiki/Cyclone_Gabrielle
3 https://www.stuff.co.nz/national/christchurch-earthquake/4734825/Power-restored-to-most-households
4 https://www.bcg.com/publications/2022/climate-change-in-new-zealand
5 https://www.ea.govt.nz/assets/dms-assets/28/Cost-benefit-analysis-of-distributed-energy-resources-in-New-Zealand-Sapere-Research-Group-final-13September.pdf
6 https://onestepoffthegrid.com.au/sun-tax-trial-turns-home-battery-into-money-making-machine-for-this-household/
7 https://www.endeavourenergy.com.au/__data/assets/pdf_file/0021/54273/Endeavour-Energy-Tariff-Structure-Statement-January-2023.pdf
8 https://www.sapowernetworks.com.au/public/download.jsp?id=320663

Section 2.4

Economies of scale

Renewable energy technologies continue to drop in price. It is vital to take this into account when planning for and building out the nations energy system. Energy-economy modelling has historically underestimated the rate of decline in prices for renewable technologies. For solar PV, wind, and batteries, the rates of cost improvement have been close to 10% per year. Costs have dropped exponentially while installed capacity has increased exponentially.[1]

It's not magic. Economies of scale have been seen time and time again.

When understanding the falling prices of rooftop solar, batteries, heat pumps, and electric vehicles, it is important to understand the historical context of technology development. As a technology increases in adoption and the scale of manufacturing increases, prices often fall significantly. This is known as the *learning curve* or *experience curve*, where the cost of producing a technology reduces as a function of cumulative experience in terms of units produced.[2] This is especially relevant for mass-produced technologies that are relatively simple to assemble and do not involve significant customisation, such as solar panels, heat pumps and electric vehicles.[3] The chart below illustrates this for the Ford Model T manufacturing between 1909 and 1923, and the next chart demonstrates the similar trend of solar cells in more recent years. These price drops are seen across many technologies, computers, batteries, electric vehicles and more.

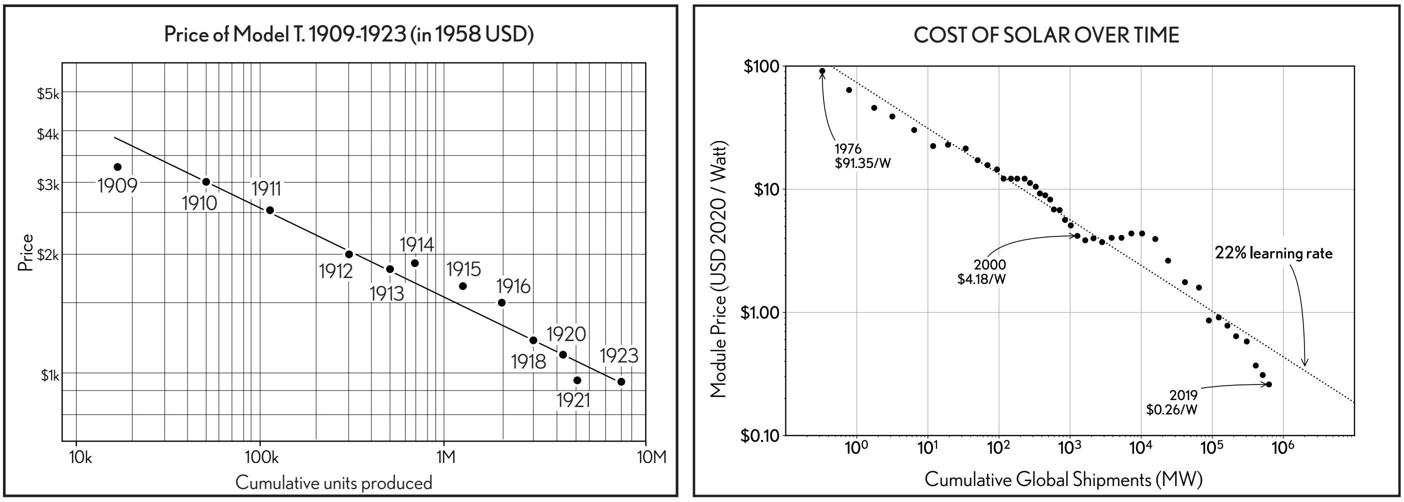


Figure 35 - Learning curves showing the cost trajectories for the Ford Model T (left) and solar power (right). From Electrify, Saul Griffith. MIT Press.

1 Way, R., Ives, M. C., Mealy, P., & Farmer, J. D. (2022). Empirically grounded technology forecasts and the energy transition. Joule, 6(9), 2057-2082. https://www.cell.com/joule/fulltext/S2542-4351(22)00410-X
2 Grubb et al. (2021). The New Economics of Innovation and Transition: Evaluating Opportunities and Risks. EEIST. https://eeist.co.uk/eeist-reports/the-new-economics-of-innovation-and-transition-evaluating-opportunities-and-risks/
3 Malhotra, A., & Schmidt, T. S. (2020). Accelerating low-carbon innovation. Joule, 4(11), 2259-2267.

Economies of scale in New Zealand's energy context

The chart below shows the combined cost of rooftop solar and 50% battery storage, or storing half of the energy needed throughout a day. This is compared to the historic and forecast grid electricity costs. It demonstrates the pace at which customer energy resources have dropped in price over time as their scale of production increases globally.

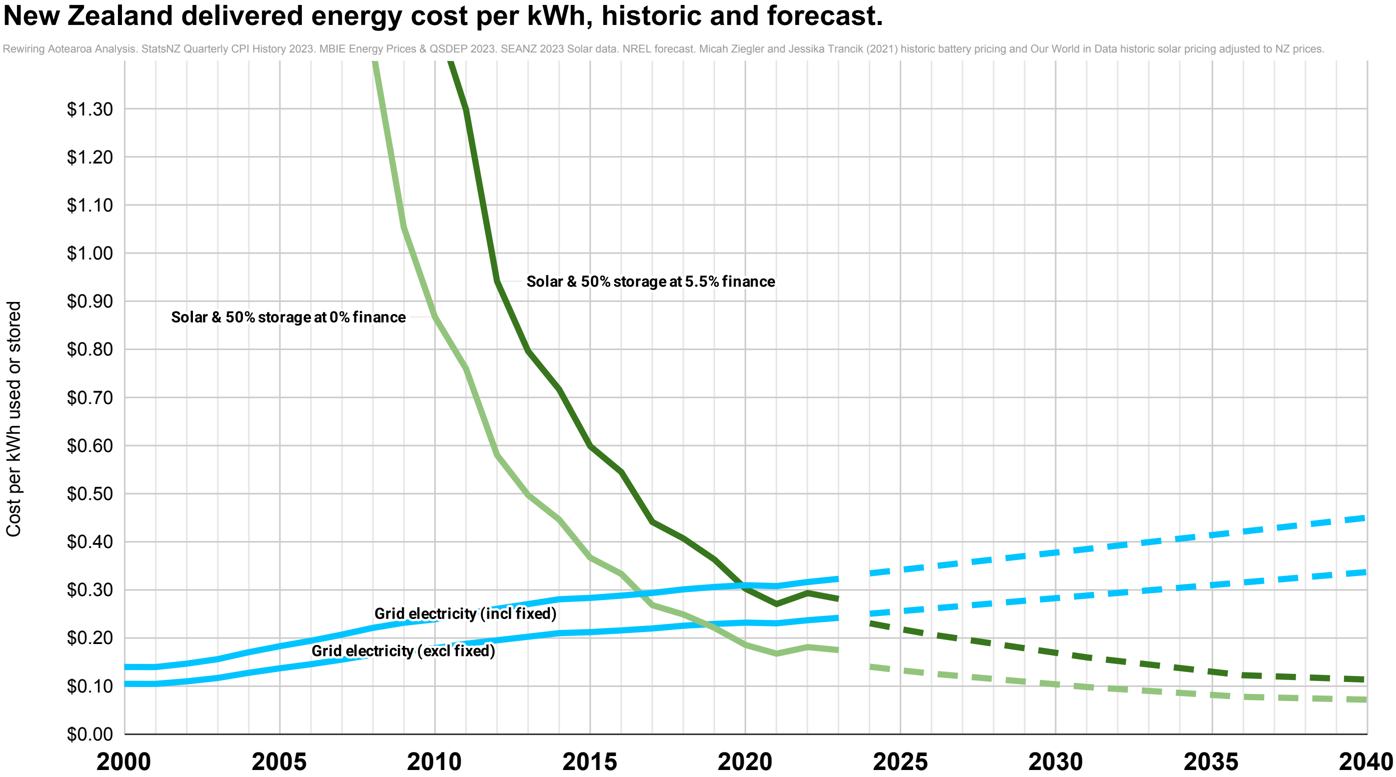


Figure 36 - Delivered electricity cost comparison, historic and forecast.

These trends are important to consider in the planning and build out of national energy infrastructure. We are already at the point where locally generated electricity is lower cost than conventional long distance electricity, and we will soon be at the point where storing energy locally is also lower cost. With both of these costs continuing to drop significantly into the future. Solar and wind are both variable energy sources, and as such benefit greatly from a grid connection that can balance out the highs and lows of production. They also benefit from being connected geographically to take advantage of different weather conditions in different regions. New Zealand could benefit greatly from designing an energy system that utilises as much local energy as feasible, while using its significant renewable grid resources to support that local energy where and when it's needed. We should not underestimate how much local energy can be deployed into the system over the coming years as consumers (homes and businesses) act in their own economic self interest by installing their own solar and batteries for cost savings and resilience.

Section 2.5

Full Household Electrification

Looking at the full household electrification picture adds further context to the size of opportunity for New Zealand homes. Much of what we already use in homes is electric: fridges, lights, computers, smart phones, washing machines etc. Lowering the cost of electricity for homes improves their cost of living significantly. Electrification the rest of the machines (appliances and vehicles) in homes is a recipe for near zero home energy emissions and significant cost of living savings.

Efficiency

Firstly, energy efficiency should be explored. An electrified home can provide all the same comfort at less than half the energy use. This is a significant difference considering how much focus is often put on conventional efficiency or energy saving measures. These are important, yet the efficiency gains through electrification are in general far larger and come at a lower cost.

Energy use comparison per day in New Zealand homes.

Sources: Residential Baseline Study 2021. EECA Energy End Use Database. EPA MPG. Rewiring Aotearoa Analysis.

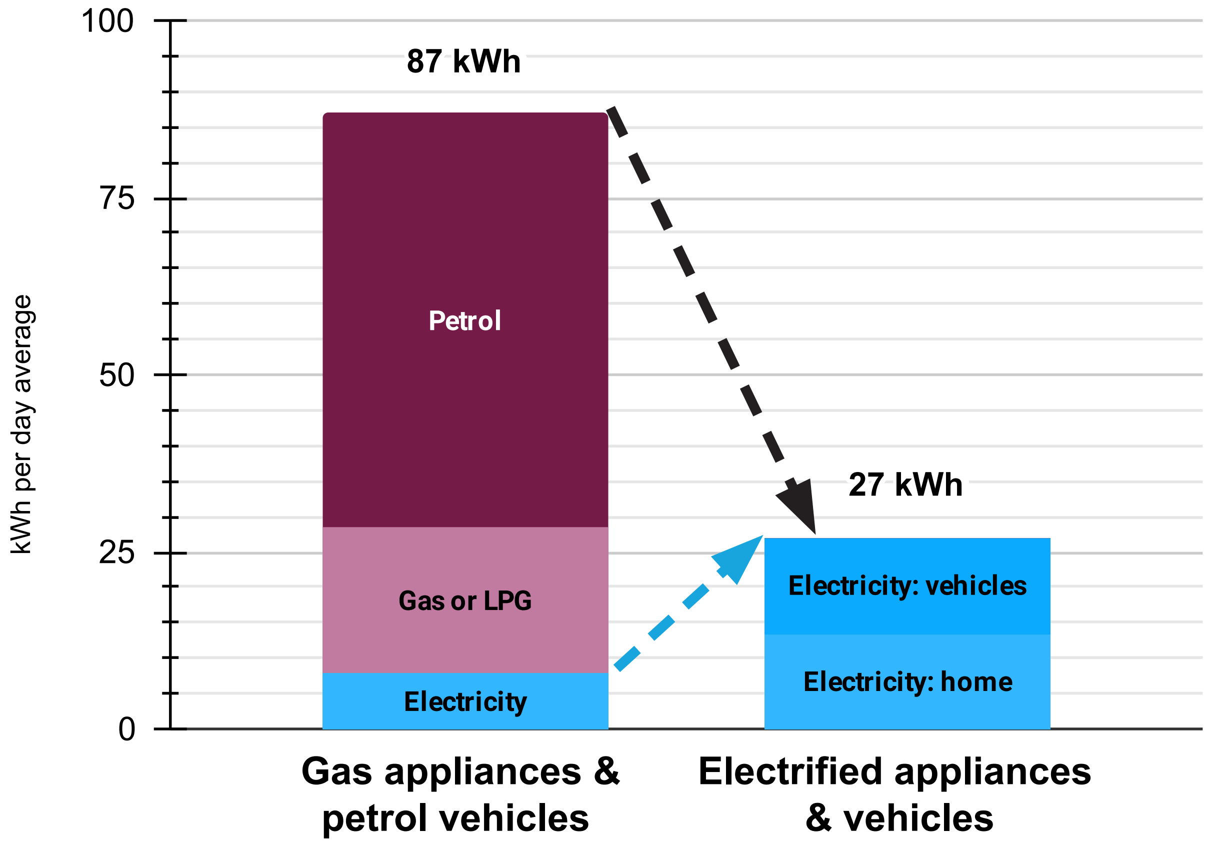


Figure 37 - Energy use comparison. On the left is the energy use of a home that uses gas for space heating, water heating, and cooking, petrol vehicles, and electricity for other appliances. On the right is the energy use of an electrified home. The substantial energy reduction is caused by the thermodynamic efficiency of electric machines. Note: many homes have a mix of electric, gas, LPG, wood, diesel machines. Each home will have a unique usage profile, yet it is clear across all of these that electrification provides significant efficiency gains.

Upfront and operating costs over 15 years

In this section, we compare the full operating and capital costs of electrified homes compared to gas or LPG appliances and petrol vehicles. Purchasing electric vehicles and electric appliances is often more costly upfront, but significantly lower cost to operate, paying themselves back over time. These items have been explored individually earlier in this paper, and here they come together with the homes other energy usage (refrigeration, lighting, TV, etc) to form the full picture of an electrified home versus a fossil fuel home.

It should be acknowledged that every home is different, and will have different levels of energy use and different types of appliances. In many homes, only some of the appliances are gas or LPG, or maybe the home is already electric but doesn't yet have solar and a battery. In this full home example, we compare a home which has gas/LPG space heating, gas/LPG water heating, gas/LPG cooking, and petrol vehicles. The home still uses electricity already with other appliances. Further, this comparison is for the "average" homes energy needs, with 2.8 people and 1.8 vehicles. Larger homes will generally have higher operational costs and therefore larger savings from electrification. Smaller homes with low energy use will generally save less, as their energy bills are lower and the upfront costs required for appliances remain similar.

We model two types of electrified homes. One with electrified appliances and vehicles using only New Zealand's grid electricity, the other with a solar and battery installation supported by the grid. The solar is 7kW, and the battery 7kWh. The solar home still consumes electricity from the grid.

We model 15 years of energy bills for all energy types, with forward prices based on a linear trend from the associated fuel in the consumer price index.

New Zealand home energy comparison. LPG/Gas appliances and petrol vehicles versus electrified.

Sources: Rewiring Aotearoa Analysis. Residential Baseline Study 2021. EECA Energy End Use Database. MBIE Energy Prices 2023. 15 year lifetime. Average home has 2.8 people and 1.8 vehicles.

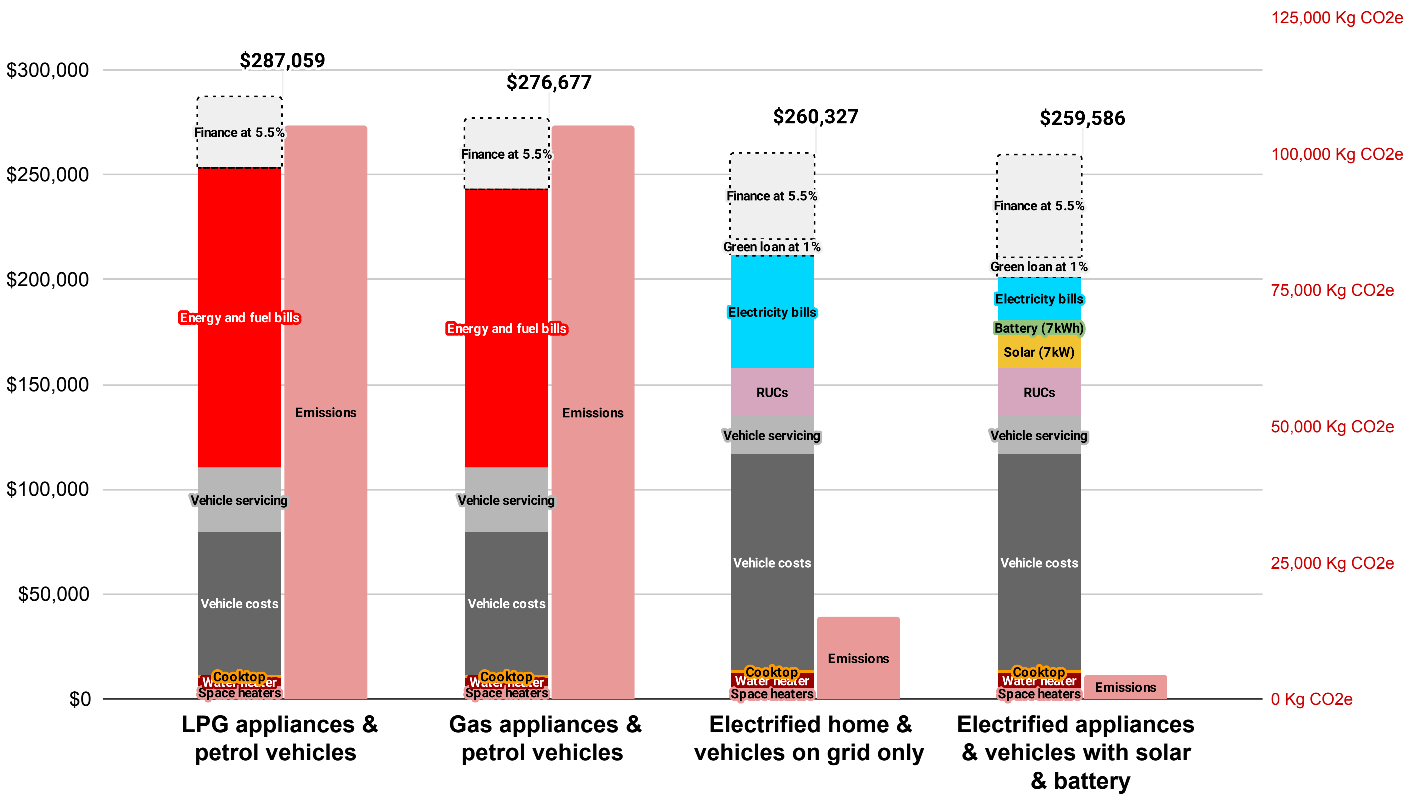


Figure 38 - Total energy bills and purchasing costs comparison over a 15 year period including emissions on the right axis. Comparing a home with gas/LPG appliances and petrol vehicles to an electrified home with electrified appliances and electric vehicles. Two bars on the left are for LPG and gas homes with petrol vehicles; two bars on the right are for a grid-only powered electrified home, and a solar, battery, and grid supported home (on the far right).

Electrification gets even better with economies of scale.

The prices of electric vehicles, solar, and batteries are falling worldwide. Taking this into account is important when we look at both the future of the energy system and the future of household energy choices. Below we look at the total cost to electrify combined with the forecast price drops across these technologies, and how this impacts the economics of electrification going forward for homes. As can be seen, electrification gets cheaper by the year. Many households can likely electrify today and save money, and any that aren't yet economically able to justify electrification likely soon will be as prices fall.

New Zealand home energy and vehicle comparison. Today and with forecast price drops in electrification.

Sources: Rewiring Aotearoa Analysis. Residential Baseline Study 2021. EECA Energy End Use Database. MBIE Energy Prices 2023. Average home has 2.8 people and 1.8 vehicles.

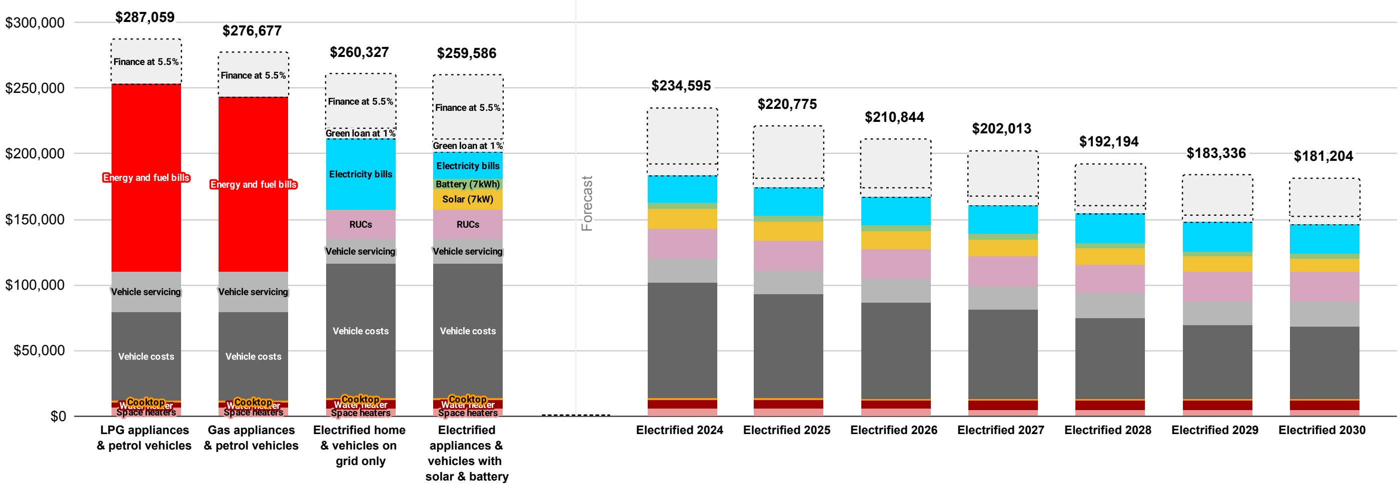


Figure 39 - Same as Figure 38 but with total costs estimated for conversions to electric, solar and battery installations done in future years with forecast drops in price of electric vehicles, solar, batteries, and heat pumps. All of which are forecast to drop in price with economies of scale over the coming years.

This can perhaps be better expressed as savings based on which year the home is electrified. In this example, we compare the savings over 15 years against an average of the Gas and LPG homes. The first light green bar at 5.5% finance, and the second darker green bar at 1% finance like a green loan.

Forecast savings from electrification compared to average Gas or LPG home.

Rewiring Aotearoa Analysis. Savings from an electrified home with solar and battery compared to the average Gas/LPG home.

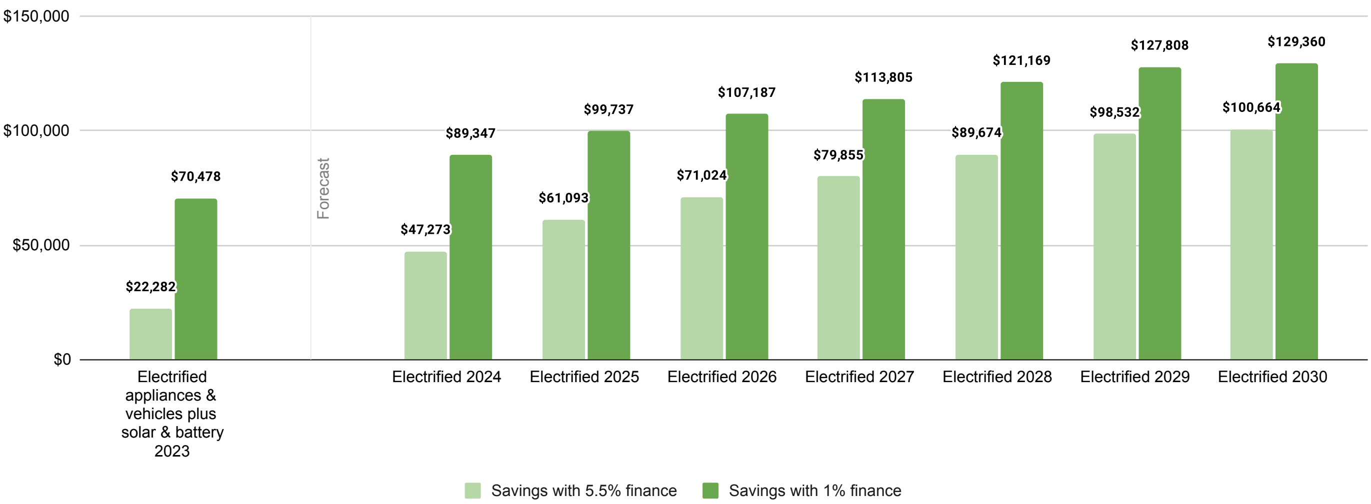


Figure 40 - 15 year lifetime savings for households who convert from gas/LPG and petrol vehicles to fully electric with solar and battery based on the year in which they convert. Forecast forward with predicted economies of scale.

Annualised economics of electrification

Here we split the charts from the previous page into year-by-year costs, to help contextualise them with household energy bill savings on a yearly basis. These charts include the capital cost paid for appliances, vehicles, solar and battery paid for over a 15 year lifetime.

New Zealand home energy comparison. LPG/Gas appliances and petrol vehicles versus electrified, annualised.

Sources: Rewiring Aotearoa Analysis. Residential Baseline Study 2021. EECA Energy End Use Database. MBIE Energy Prices 2023. 15 year lifetime and finance term. Average home has 2.8 people and 1.8 vehicles.

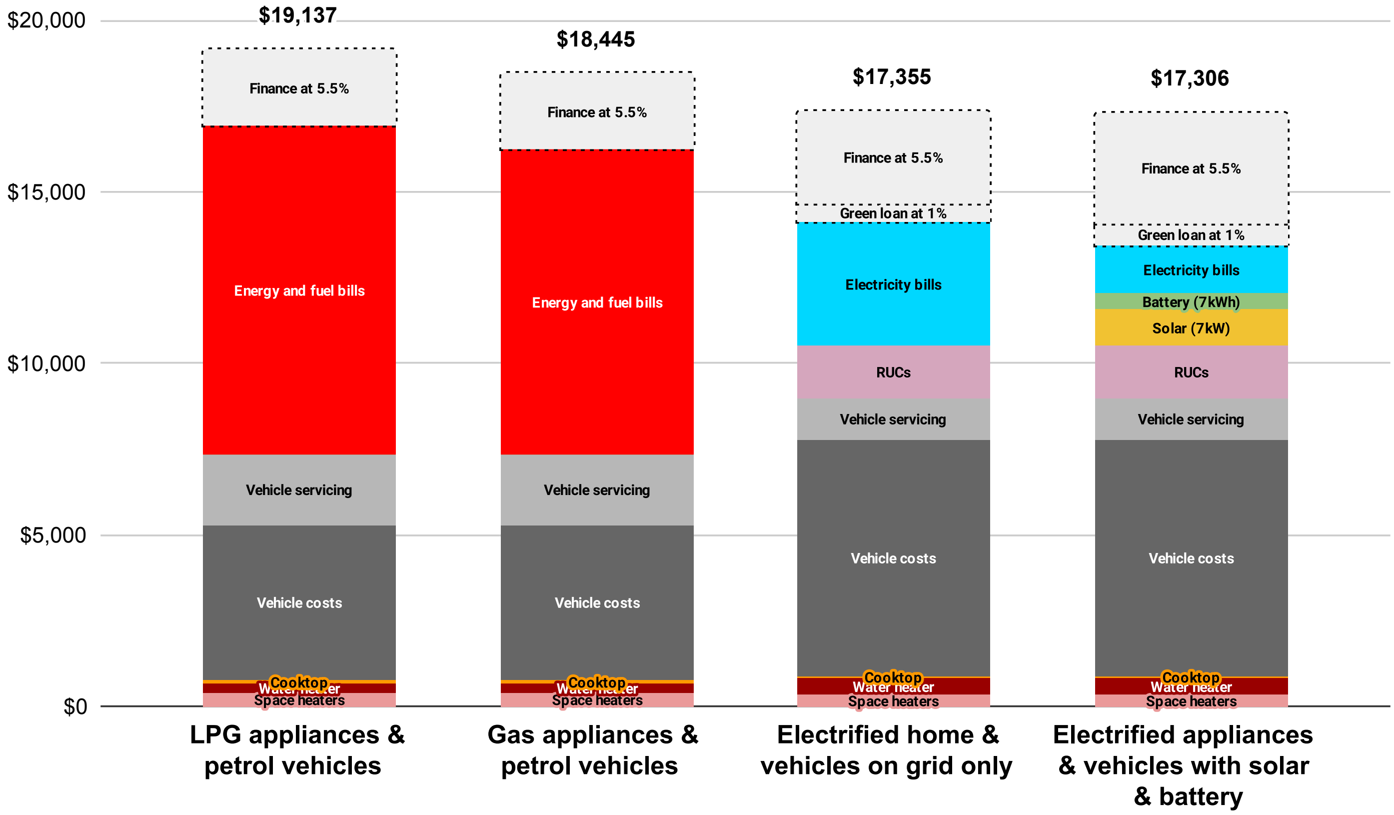


Figure 41 - Annual energy and capital costs for homes with LPG or gas appliances and petrol vehicles, compared to homes with electric appliances and vehicles fully powered by the grid or by solar, batteries and the grid.

Forecast savings from electrification compared to average Gas or LPG home, annualised.

Rewiring Aotearoa Analysis. Savings from an electrified home with solar and battery compared to the average Gas/LPG home.

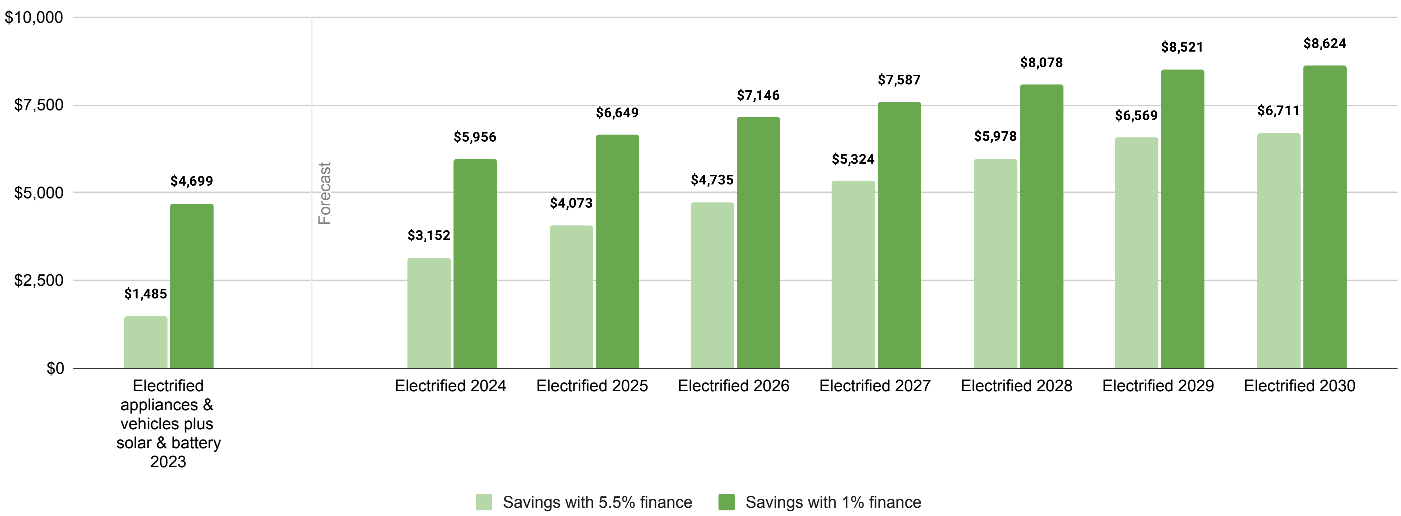


Figure 42 - Average annual savings for households that convert from gas/LPG and petrol vehicles to fully electric with solar and battery based on the year in which they convert. Forecast forward with predicted economies of scale. This savings chart is based on the electrified solar home compared against an average of the gas/LPG home.

Emissions comparison

Here we compare the 15 year operational emissions of different home types in New Zealand with average energy use. Including a home with LPG appliances and petrol vehicles, a home with gas appliances and petrol vehicles, and two electrified homes one using the grid only, and another using solar, battery and the grid.

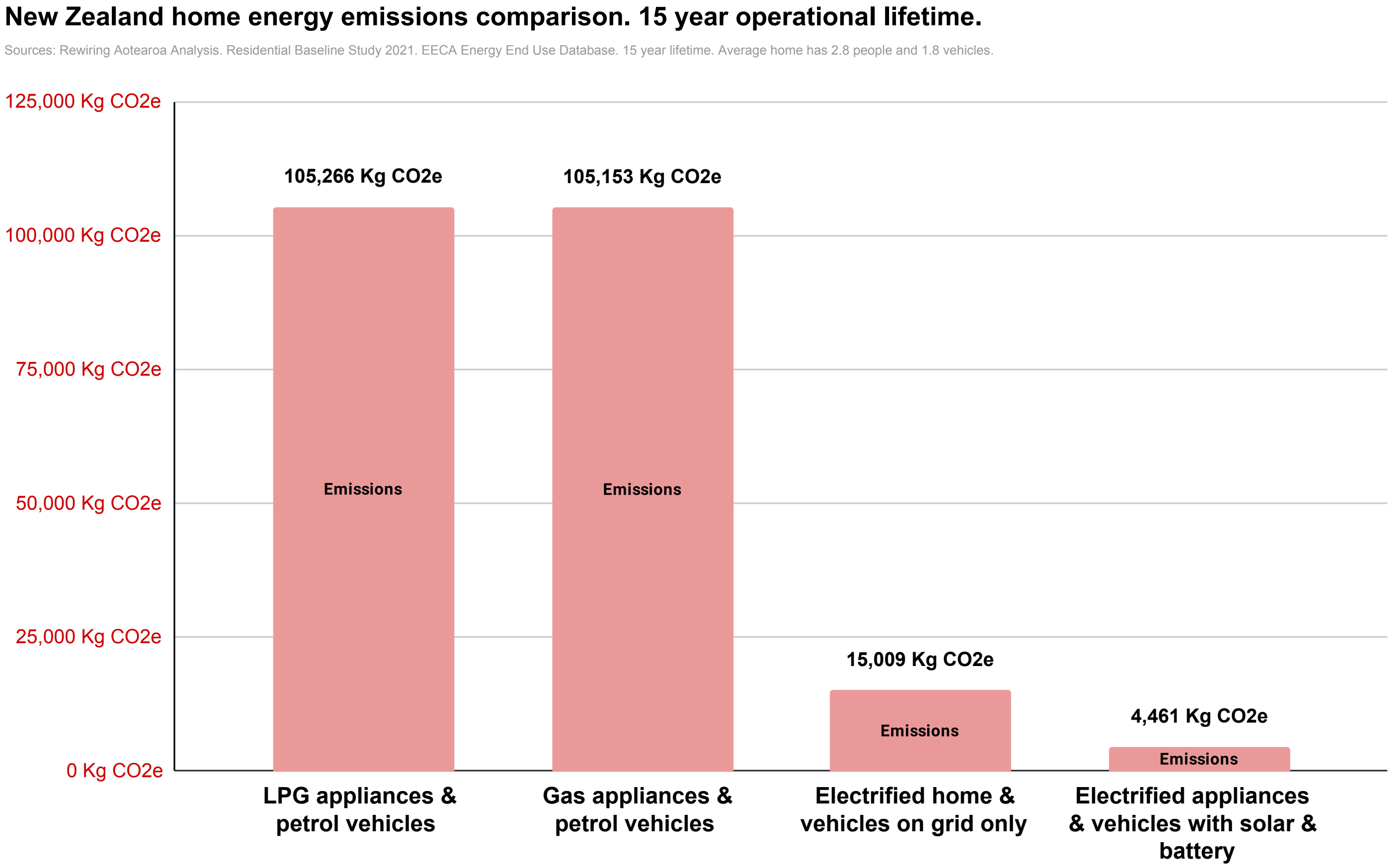


Figure 43 - Emissions comparison, average home energy use and driving, comparing gas/LPG home with petrol vehicles to an electrified home using grid electricity only, and an electrified home using grid electricity, solar, and battery. 15 year operational lifetime of emissions.

Section 2.6

Comparison Scenarios

Energy usage is different in every home. Energy use is impacted by occupancy, location/climate, types of available energy sources, behaviour, condition of the home, sunshine hours (solar production) and more.

To acknowledge and demonstrate this, in this section we model the electrification economics for four different regions across New Zealand to compare them to the average. Auckland, Wellington, Christchurch, and Dunedin.

The variables for each region are listed in Table 1 below:

Location	Space heating energy	Space heaters installed	Solar capacity factor
Auckland	74%	1	15.50%
Wellington	173%	3	14.90%
Christchurch	124%	2	14.30%
Dunedin	198%	3	12.50%
Average	100%	2	15%

Table 1 - Energy variables used to model different regions in the comparison scenarios.

In each region, we also model four different energy use scenarios to show the economic variation that homes have based on the amount of energy they use and amount of vehicles they have at the home. This includes comparing a home with no vehicles / appliances only. The energy use variable is used for both appliances (which relates to home occupancy, amount of hot water use etc) and vehicles (which relates to kilometres driven or efficiency of vehicles). The four energy use scenarios we do for each location are shown in Table 2 below.

Energy scenario	Cars per home	Energy use (across appliances and vehicles)	Solar capacity factor
A	0	100%	15.50%
B	1	50%	14.90%
C	2	100%	14.30%
D	3	200%	12.50%
Average	1.8	100%	15%

Table 2 - Variables used to model different energy use scenarios for each location.

Average New Zealand home energy use

To start we compare the four energy scenarios for the "average" home energy use in New Zealand, which is a home with about 2.8 people and 1.8 vehicles, that drives about 11,000km per vehicle per year. This is a baseline to compare against the other location based scenarios around New Zealand which we compare next.

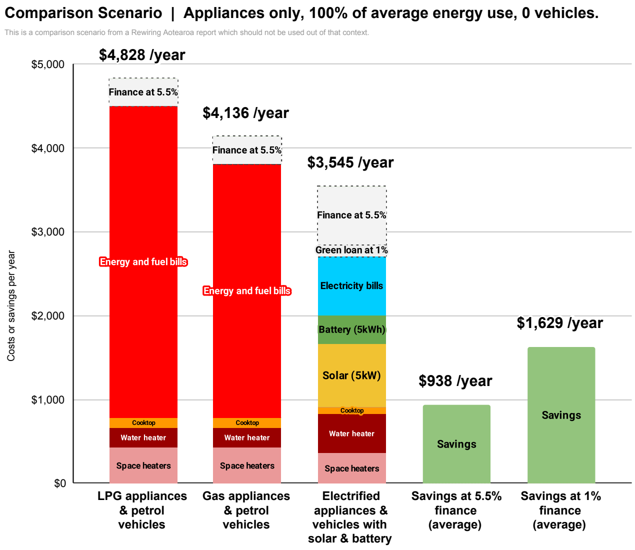


Figure 44 - Scenario A. Comparison scenario with average energy use for New Zealand homes, appliances only, no vehicles. Smaller 5kW solar system and 5kWh battery.

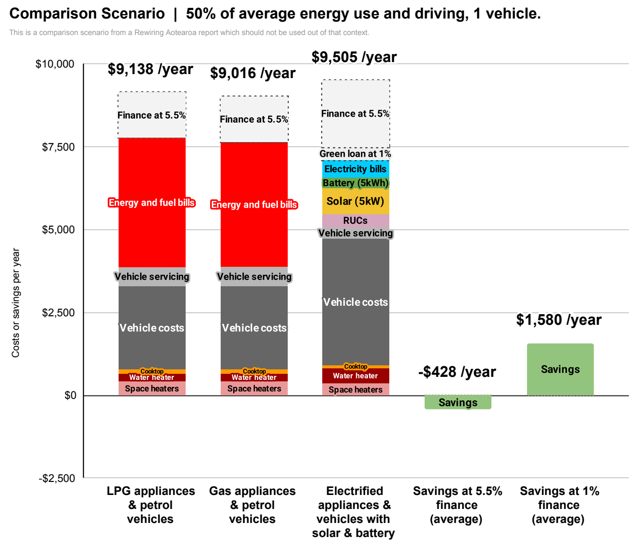


Figure 45 - Scenario B. Comparison scenario with 50% of average New Zealand energy use and 50% of average driving, with 1 vehicle. Smaller 5kW solar system and 5kWh battery.

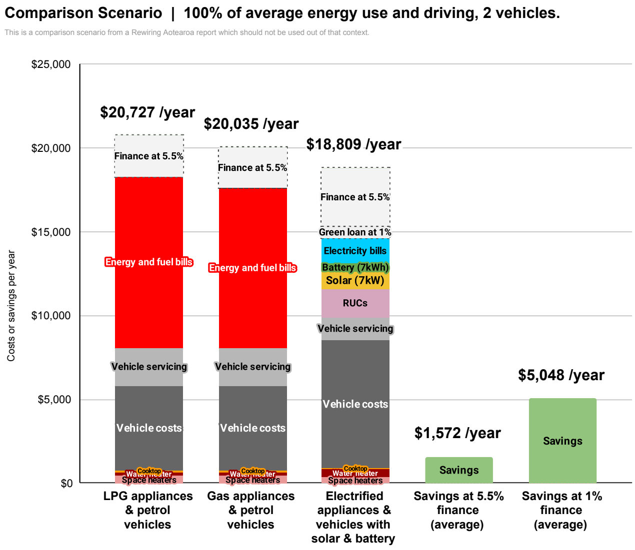


Figure 46 - Scenario C. Comparison scenario with 100% of average New Zealand energy use and 100% of average driving, with 2 vehicles.

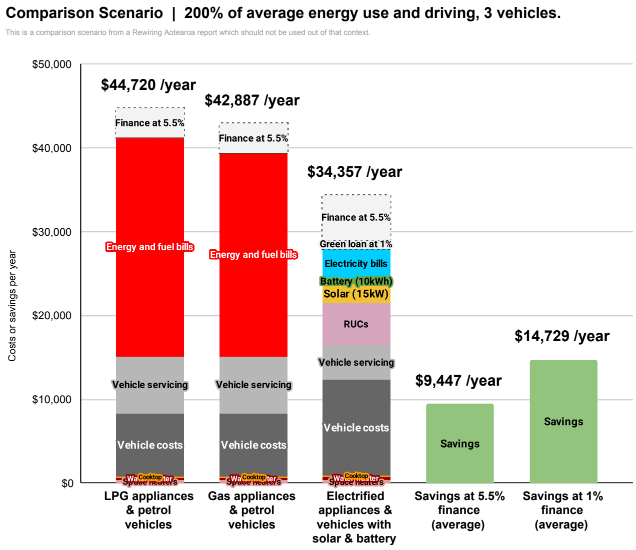


Figure 47 - Scenario D. Comparison scenario with 200% of average New Zealand energy use and 200% of average driving, with 3 vehicles. Larger 15kW solar system and 10kWh battery.

Auckland comparison scenarios

Auckland Comparison | Appliances only, 100% of average energy use, 0 vehicles.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

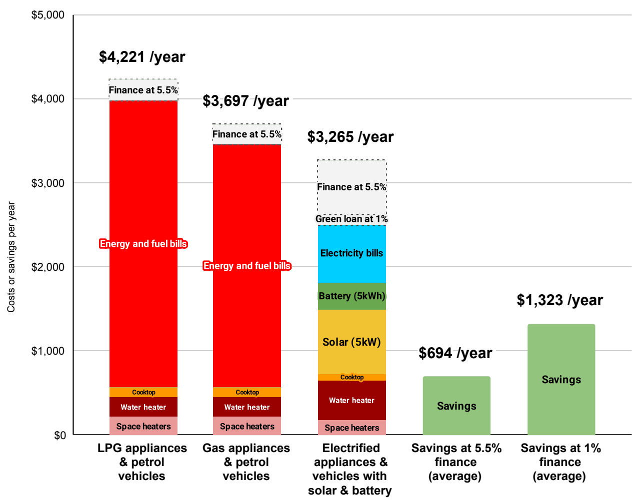


Figure 48 - Scenario A. Comparison scenario for Auckland with average energy use, appliances only, no vehicles. Smaller 5kW solar system and 5kWh battery.

Auckland Comparison | 50% of average energy use and driving, 1 vehicle.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

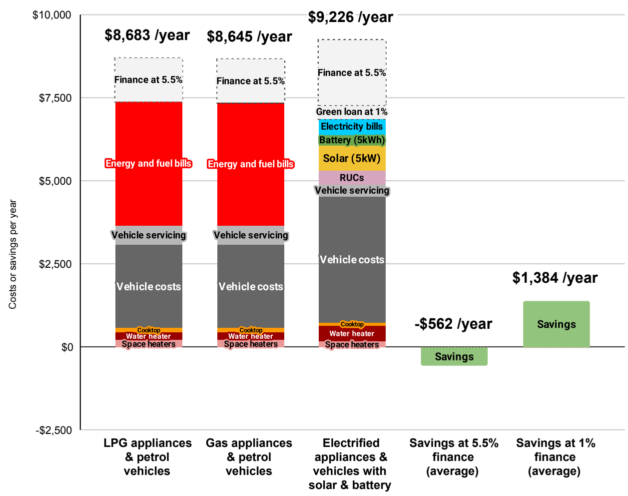


Figure 49 - Scenario B. Comparison scenario for Auckland with 50% of average energy use and 50% of average driving, with 1 vehicle. Smaller 5kW solar system and 5kWh battery.

Auckland Comparison | 100% of average energy use and driving, 2 vehicles.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

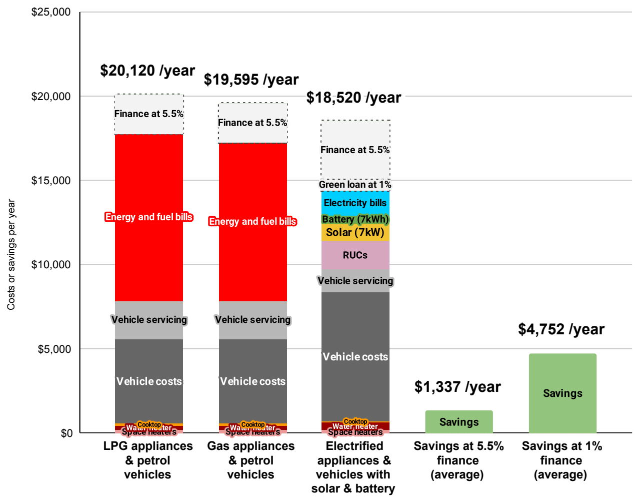


Figure 50 - Scenario C. Comparison scenario for Auckland with 100% of average energy use and 100% of average driving, with 2 vehicles.

Auckland Comparison | 200% of average energy use and driving, 3 vehicles.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

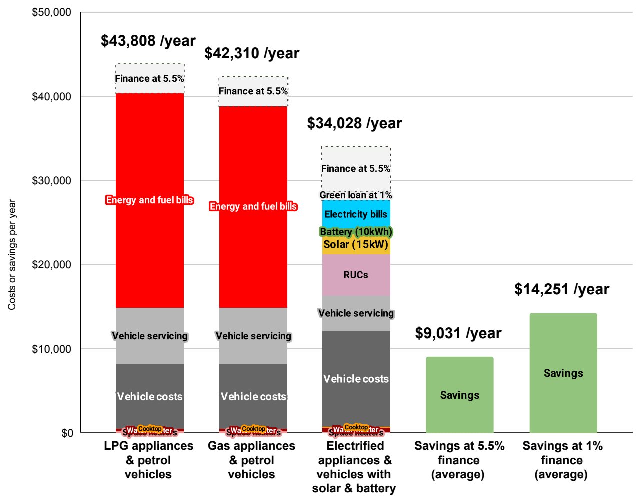


Figure 51 - Scenario D. Comparison scenario for Auckland with 200% of average energy use and 200% of average driving, with 3 vehicles. Larger 15kW solar system and 10kWh battery.

Wellington comparison scenarios

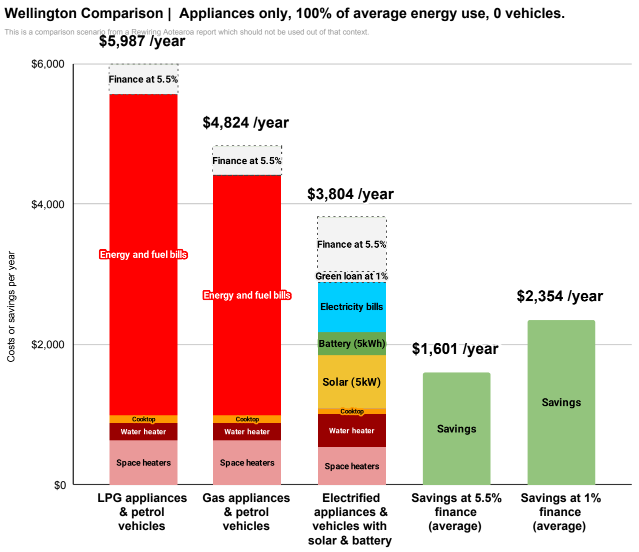


Figure 52 - Scenario A. Comparison scenario for Wellington with average energy use, appliances only, no vehicles. Smaller 5kW solar system and 5kWh battery.

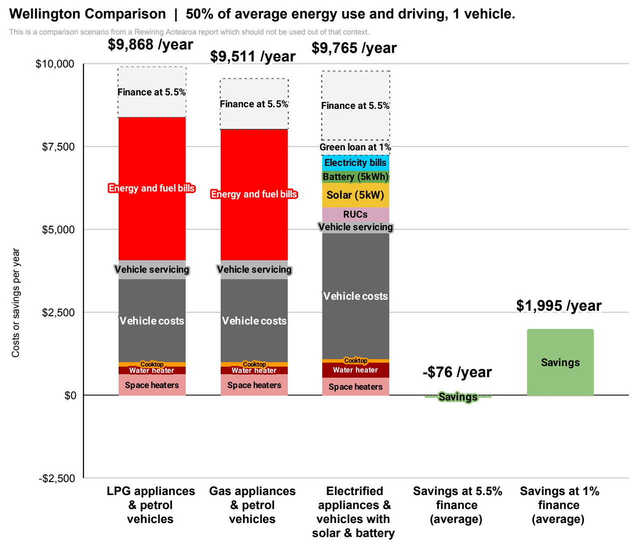


Figure 53 - Scenario B. Comparison scenario for Wellington with 50% of average energy use and 50% of average driving, with 1 vehicle. Smaller 5kW solar system and 5kWh battery.

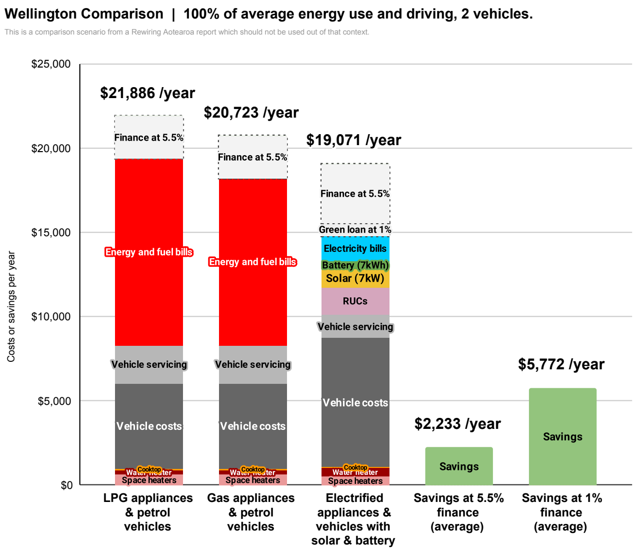


Figure 54 - Scenario C. Comparison scenario for Wellington with 100% of average energy use and 100% of average driving, with 2 vehicles.

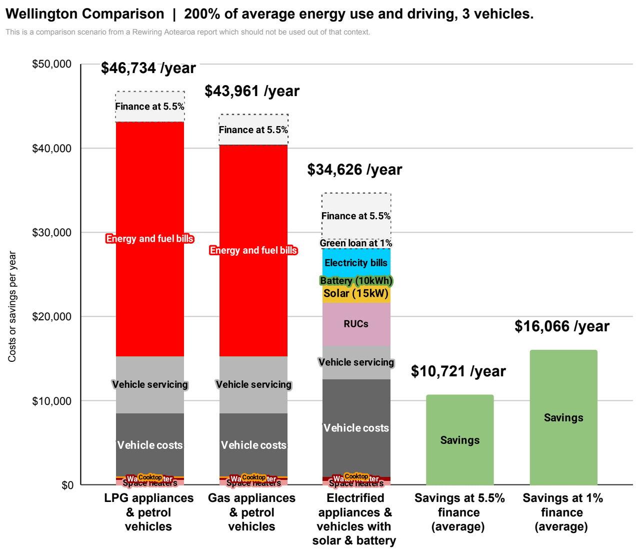


Figure 55 - Scenario D. Comparison scenario for Wellington with 200% of average energy use and 200% of average driving, with 3 vehicles. Larger 15kW solar system and 10kWh battery.

Christchurch comparison scenarios

Christchurch Comparison | Appliances only, 100% of average energy use, 0 vehicles.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

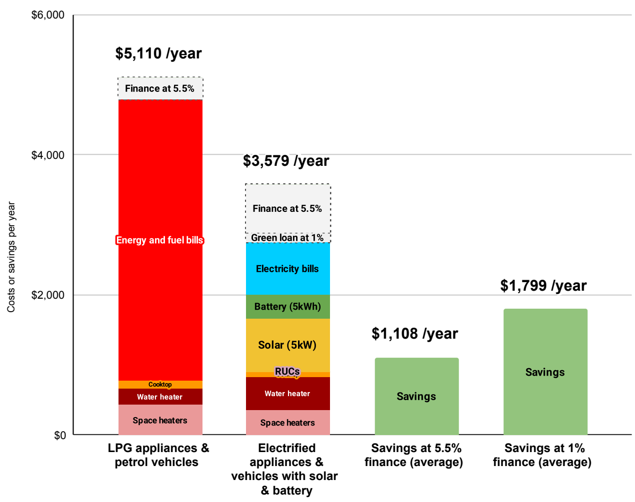


Figure 56 - Scenario A. Comparison scenario for Christchurch with average energy use, appliances only, no vehicles. Smaller 5kW solar system and 5kWh battery.

Christchurch Comparison | 50% of average energy use and driving, 1 vehicle.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

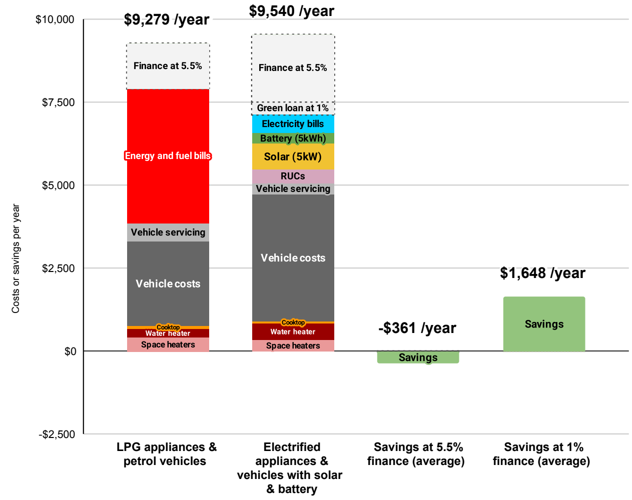


Figure 57 - Scenario B. Comparison scenario for Christchurch with 50% of average energy use and 50% of average driving, with 1 vehicle. Smaller 5kW solar system and 5kWh battery.

Christchurch Comparison | 100% of average energy use and driving, 2 vehicles.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

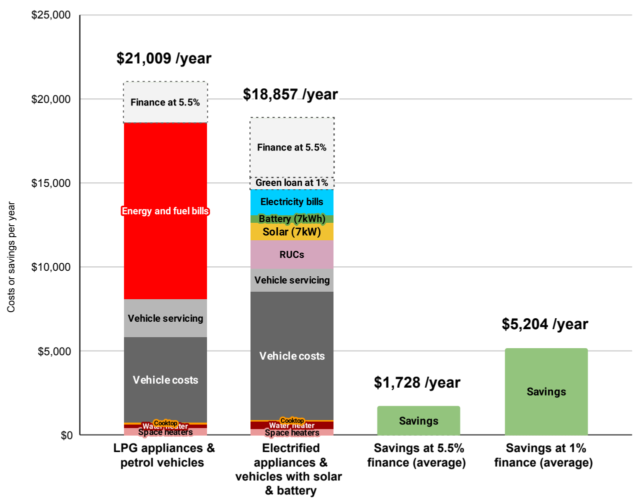


Figure 58 - Scenario C. Comparison scenario for Christchurch with 100% of average energy use and 100% of average driving, with 2 vehicles.

Christchurch Comparison | 200% of average energy use and driving, 3 vehicles.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

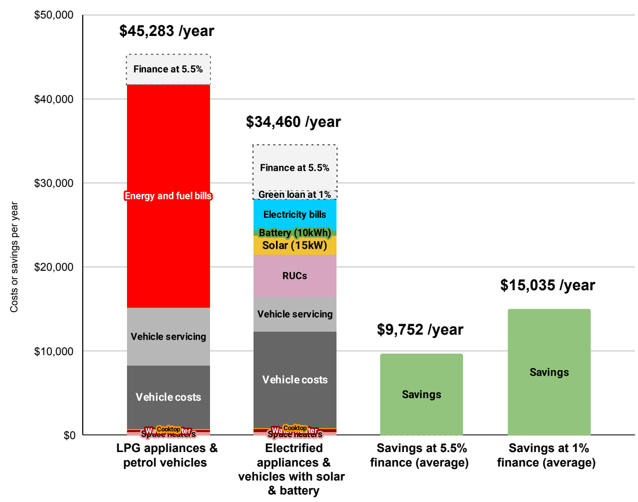


Figure 59 - Scenario D. Comparison scenario for Christchurch with 200% of average energy use and 200% of average driving, with 3 vehicles. Larger 15kW solar system and 10kWh battery.

Dunedin comparison scenarios

Dunedin Comparison | Appliances only, 100% of average energy use, 0 vehicles.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

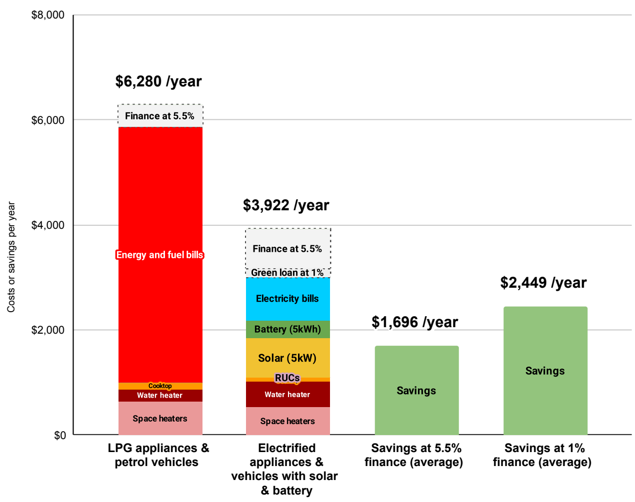


Figure 60 - Scenario A. Comparison scenario for Dunedin with average energy use, appliances only, no vehicles. Smaller 5kW solar system and 5kWh battery.

Dunedin Comparison | 50% of average energy use and driving, 1 vehicle.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

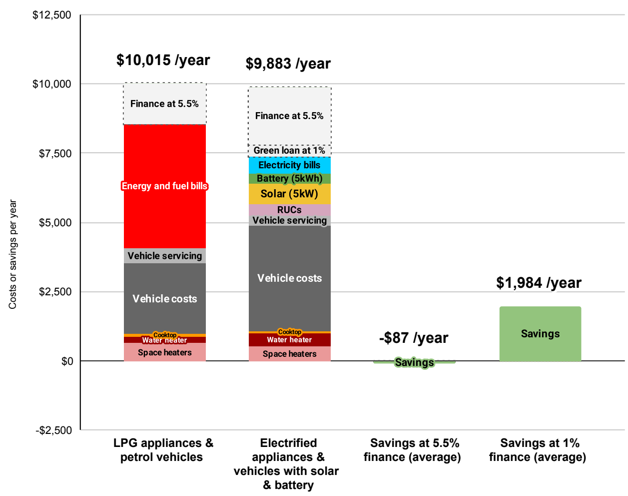


Figure 61 - Scenario B. Comparison scenario for Dunedin with 50% of average energy use and 50% of average driving, with 1 vehicle. Smaller 5kW solar system and 5kWh battery.

Dunedin Comparison | 100% of average energy use and driving, 2 vehicles.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

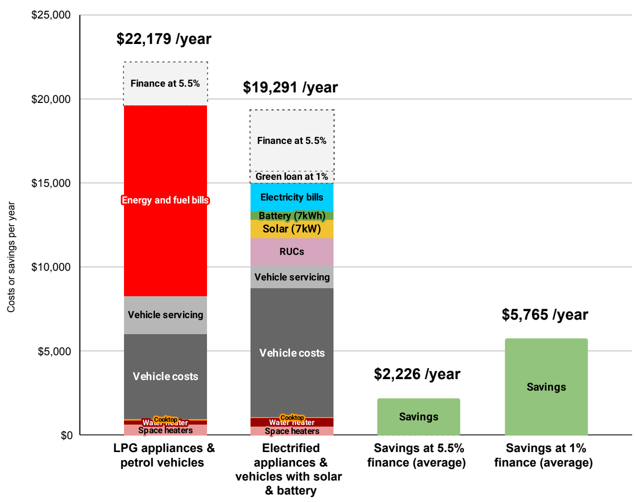


Figure 62 - Scenario C. Comparison scenario for Dunedin with 100% of average energy use and 100% of average driving, with 2 vehicles.

Dunedin Comparison | 200% of average energy use and driving, 3 vehicles.

This is a comparison scenario from a Rewiring Aotearoa report which should not be used out of that context.

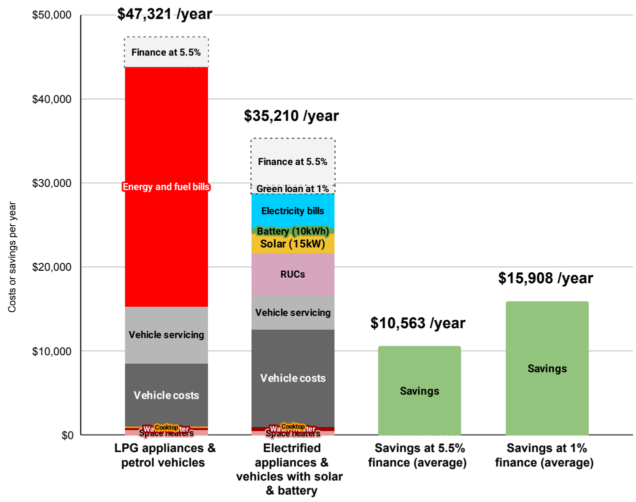


Figure 63 - Scenario D. Comparison scenario for Dunedin with 200% of average energy use and 200% of average driving, with 3 vehicles. Larger 15kW solar system and 10kWh battery.

Appendix

Methodology, sources, and assumptions

Emissions

We first disaggregated New Zealand's territorial emissions into trade emissions and domestic use emissions. To do this, for each line item in the National Greenhouse Gas Inventory (noting that in some cases where line items were very small, we included aggregated categories rather than every single entry), we estimated the amount of emissions that went into export products. The remainder were attributed to domestic use emissions. For example, we found that 95% of dairy products are exported (https://www.environmentguide.org.nz/activities/agriculture/), therefore we allocated 95% of dairy emissions to export emissions. A full list of the sources used to calculate this is available below.

We then broke down domestic use emissions into four broad categories Household, Industrial, Commercial and Agriculture energy, industrial processes and waste. This disaggregation reflects four major economic categories for New Zealand. The categorisation allows us to better understand where the key opportunities for decarbonisation are and where those decisions are made.

We separated Agriculture from Commercial and Industrial to reflect its prominence in the economic and political landscape. Agriculture energy, industrial processes and waste were separated from livestock emissions (which were included in Household for domestic use), to show where the decarbonisation decisions can be made. For example, it is a household's choice to eat meat, but it is the farm's choice to use diesel machinery. The Industrial category includes construction and manufacturing.

The disaggregation into these four categories was done through a literature survey and data analysis to discover the source of emissions. For example, for freight emissions, we used the most recent freight demand study that breaks down the proportion of total freight taken up by various high-level products (https://www.transport.govt.nz/assets/Uploads/Report/NFDS3-Final-Report-Oct2019-Rev1.pdf). The full list of sources is available below.

Energy

https://www.mbie.govt.nz/dmsdocument/23550-energy-in-new-zealand-2022-pdf

https://www.mbie.govt.nz/assets/Data-Files/Energy/nz-energy-quarterly-and-energy-in-nz/oil.xlsx

https://www.aucklandcouncil.govt.nz/ResourceConsentDocuments/18DIS60376538%20AppH%20EIA.pdf

Aluminium export ratio from https://nzas.co.nz/

https://www.eeca.govt.nz/insights/energys-role-in-climate-change/renewable-energy/biomass/ assumed remainder is agricultural burn off

Transport and Industrial

https://www.transport.govt.nz/assets/Uploads/Freight-and-supply-chain-issues-paper-full-version.pdf

https://www.transport.govt.nz/assets/Uploads/Report/NFDS3-Final-Report-Oct2019-Rev1.pdf

https://www.transport.govt.nz/statistics-and-insights/fleet-statistics/sheet/2021-annual-fleet-statistics#:https://www.nzta.govt.nz/assets/resources/travel-planning-toolkit/docs/resource-1-

facts-and-figures.pdf

https://www.nzta.govt.nz/vehicles/how-the-motor-vehicle-register-affects-you/motor-vehicle-registrations-dashboard-and-open-data/

Agriculture

https://www.environmentguide.org.nz/activities/agriculture/

https://www.mia.co.nz/assets/MIA-Publications/Meat-in-focus.pdf

https://www.mpi.govt.nz/forestry/forest-industry-and-workforce/forestry-wood-processing-data/wood-processing-data/

https://www.mpi.govt.nz/dmsdocument/33457-The-New-Zealand-Food-and-Fibre-Sector-A-Situational-Analysis-Report

https://www.mpi.govt.nz/dmsdocument/54517-Situation-and-Outlook-for-Primary-Industries-SOPI-December-2022

Waste

https://environment.govt.nz/assets/publications/Waste/Waste-and-resource-recovery-infrastructure-and-services-stocktake-Project-summary-report.pdf

Energy use

We derive average household energy use across different appliances through the Australian and New Zealand Residential Baseline Study 2021, published November 2022. https://www.energyrating.gov.au/industry-information/publications/report-2021-residential-baseline-study-australia-and-new-zealand-2000-2040

We then use energy factors / coefficient of performance across each appliance type to calculate the base energy requirements needed by a home depending on what appliances it uses.

Heat pump space heating Coefficient Of Performance (COP) is sourced from EECA and a COP of 3.5 is used for the average heat pump. Space heating energy factors for other appliances are sourced from the Warm Homes Technical Report published by the Ministry For The Environment November 2005. environment.govt.nz/assets/Publications/Files/warm-homes-heating-options-phase1.pdf

Water heating energy factors are sourced from the US Department of Energy - Energy Star ratings scheme. https://www.energystar.gov/products/water_heaters/residential_water_heaters_key_product_criteria. Electric Resistive Tank water heating is assumed at 90%, and Heat Pump water heaters are assumed at 315% which is based upon the 10% tank losses combined with the EECA 350% heat pump efficiency for space heating.

Cooktop efficiency is sourced from the Frontier Energy Residential Cooktop Performance and Energy Comparison Study Report # 501318071-R0. Published July 2019. https://cao-94612.s3.amazonaws.com/documents/Induction-Range-Final-Report-July-2019.pdf

Electric oven efficiency is assumed at 95%, and gas/LPG oven 90%.

We derive average vehicle energy use through the EECA energy end use database https://www.eeca.govt.nz/insights/data-tools/energy-end-use-database/ for 2019. The amount of vehicles per home is sourced from the Census 2018 and number of vehicle types (light passenger and light commercial) is sourced from the Motor Vehicle Association historic sales data. https://www.mia.org.nz/Sales-Data/Vehicle-Sales#oss.

We then use energy factors from the US Department of Energy fuel economy database to calculate the different energy requirements across vehicle types. fueleconomy.gov. For electric vehicles this includes charging losses. To calculate the average efficiency difference between an electric and ICE vehicle we use a comparison of popular vehicles both ICE and Electric and their EPA MPG combined rating. Where EPA data is not available for some electric vehicles in New Zealand (e.g. BYD), we use the EVDB real range energy consumption estimate. https://ev-database.org/car/1782/BYD-ATTO-3. Where the energy consumption is not available for any remaining vehicles through either of these methods (very few) we use manufacturer estimates provided in technical vehicle documentation or a comparative vehicle. The average MPG for an ICE vehicle used is 27.4, the average MPG for an electric vehicle used is 116.8.

Energy Prices

Most energy prices used come from the average of the most recent 4 quarters of the MBIE Energy Prices data. https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-prices/ Where data is not provided (e.g. Wood) an online comparison of prices is used.

The electricity price is calculated using data from MBIE Energy Prices and QSDEP 2023. We split electricity pricing into a volume cost per kWh and a fixed cost per kWh.

Electricity fixed costs vary by energy use in the home, ConsumerNZ estimates $1.89 per day, or $689 per year. https://www.consumer.org.nz/articles/home-heating-costs, which is what we use for the full household model.

Gas fixed costs are estimated at: $587 (ConsumerNZ). LPG fixed costs are estimated at: $139 (ConsumerNZ).

For individual appliance operating cost comparisons fixed costs are excluded for electricity because all homes pay this cost whether or not they choose gas appliances or electric appliances. This is because many items in homes are already electric (lighting, refrigeration, etc). For full household cost comparisons electricity fixed costs are included. Gas and LPG fixed costs are included in the full household comparison, and are proportionally included in appliance comparisons based on the average energy use proportions of that appliance. This is perhaps conservative as many homes have one or two gas appliances and not necessarily three or more. A home with only gas cooking will be paying the entire gas fixed cost just for the cooking, though the way it is shown is just the proportion of the fixed cost for the gas use by the cooktop, which is a fraction of that used by water heating or space heating with gas.

Electricity volume cost per kWh is 24.2 cents. Ripple control off peak is 18.0 cents per kWh.

Gas volume cost per kWh is 11.0 cents.

LPG volume cost per kWh is 18.9 cents.

Petrol is $2.59 per litre or 27.4 cents per kWh.

Diesel is $2.21 per litre or 20.6 cents per kWh.

Wood is 11.3 cents per kWh, or $4.4 per Kg, or $150 per cubic metre.

Costs in forward years are calculated using the consumer price index for each item. Energy costs for product comparisons use the average energy price over 15 years from the date of purchase.

Solar and battery

Solar prices are estimated at $2000/kW using a combination of 2023 data from SEANZ and direct surveys from installers. For full household calculations we use an example 9kW installation. Assuming 0.5% degradation per year over a 30 year lifetime. Inverter replacement costs are assumed at $2500. The solar capacity factor assumption is 15%.

We assume 50% of appliance energy needs and 50% of vehicle energy needs can be met during the solar window. Water heating which is near a third of average household loads can be moved almost entirely into the solar window. Other appliances like space heaters can only be moved a small amount, with significant energy needs being met outside the solar window. We consider this to be a conservative estimate of the load shifting possible by homes. For example, with new electric vehicles having more range than a week or even two weeks of driving, homes could choose to charge near 100% from solar on weekends or if they are at home during sunlight hours any time during the week. The other electricity consumption is assumed at full grid electricity costs, which we also consider to be conservative as households often have access to low cost electric vehicle charging rates during off peak periods.

All households remain connected to the grid, consume grid electricity and pay for grid fixed costs and volume costs for the amount of electricity used. The solar export feed-in-tariff is assumed at 12 cents per kWh. Note the primary electrified comparison home in the model also has a battery, however the battery export feed-in-tariff is assumed the same as the solar feed-in-tariff. This is considered conservative, as the battery can feed in at peak times when electricity prices are significantly higher, and where some EDBs and retailers provide higher reward for peak feed-in.

For individual appliance comparisons we calculate a cost/kWh for solar based on the above example installation. This is then applied for the portion of the appliance energy use that could be feasibly powered during the solar window and the rest of the energy comes from the grid.

Battery costs are assumed at $1000/kW, from multiple surveys of 2023 installation costs in New Zealand direct from battery installers, in addition to comparison of available online prices for batteries in New Zealand. Battery cycle costs are calculated over a 15 year, 5475 cycle life. Degradation is assumed at 60% after the 15th year with an accelerating degradation curve from the first year of use. We assume round trip efficiency of 95%.

Appliance and vehicle prices

Appliance prices come from a comparison of over 100 different quotes for appliance costs, sourced both online and direct from installers. An average capital cost and average install cost is used for each individual appliance. The scope of the appliance cost comparison aims to compare products that are not the cheapest possible product, nor the most premium, as appliance costs can vary significantly. The aim of the comparison was to create an assumed common cost for each option, in the middle of the cost spectrum.

Appliance installation specific costing is scarce, and we acknowledge the need for detailed work to be done in the area of obtaining these “soft costs” or installation costs of devices. Installation costs also vary significantly between installers, creating further complexity. This paper uses installation costs that are the result of real quotes from both online and direct installer provided quotes, but a detailed analysis of the impact of different household conditions and installation costs across different appliances would be valuable for emissions reduction and energy system planning in New Zealand.

Heat pump costs are $3800 per device, and $1050 per device installation.

Gas flued heater costs are $3200 per device, and $1250 per device installation.

LPG flued heater costs are $3300 per device, and $1250 per device installation.

Resistance bar heater costs are $300 per device and $0 for installation as they plug in at the wall.

Wood fire costs are $2900 for the fire, $1050 for the flue, and $1000 for installation.

Gas instant water heaters are $1400, and $2180 for installation.

LPG instant water heaters are $1400, and $2180 for installation.

Heat pump water heaters are $4700, and $2320 for installation.

Resistance water heaters are $2000, and $2000 for installation.

Gas and LPG cooktops are $1000, and $700 for installation.

Induction cooktops are $1400, and $1300 for installation.

Resistance cooktops are $900, and $300 for installation.

Vehicle prices are based on a comparison of popular New Zealand petrol vehicles and their prices, compared alongside an alternative similar EV option and its price. Using pricing data from vehicle manufacturer websites accessed November 2023 - January 2024. Clean car rebate not included as the rebate has been phased out in 2024.

The average new price used for ICE vehicles is $37,900 and the average new price used for EV's is $56,300. One $2000 EV charger per home is also added onto the costs of a new EV. RUCs are included on electric vehicles at 11,000km per year, $76 per 1000km.

Vehicle maintenance costs are derived from Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains" (Argonne National Laboratory report ANL/ESD-21/4 July 2021) https://publications.anl.gov/anlpubs/2021/05/167399.pdf FIGURE ES-4 adjusted to New Zealand currency and based on 12000km per year.

Finance rates, terms and lifetimes

The primary finance rate used to compare homes is 5.5%, assumed from the 10 year historic residential mortgage interest rate data from The Reserve Bank of New Zealand. https://www.rbnz.govt.nz/statistics/series/exchange-and-interest-rates/new-residential-mortgage-standard-interest-rates. A secondary rate of 1% is also compared for the electrified home as there are multiple "green loan" products currently available from major banks in New Zealand that offer interest rates of 0% and 1%. The term used for the finance is 15 years, with acknowledgement that some homes may pay this off faster and reduce total spending on finance. The lifetime for appliances and vehicles is assumed at 15 years including solar which is conservative. Solar panels often have 25-30 year warranties, up to 40 years, and the assumption is that products will not die the moment the warranty ends. Batteries often have 10 year warranties for capacity, e.g. the Tesla Powerwall 2 with a 70% capacity warranty of 10 years, some have 15 year warranties. The assumption is that capacity will continue to increasingly degrade and the battery will still remain functional (at lower capacity) for 15 years. Electric vehicles often come with 8 year warranties (and/or around 160,000km) for the battery and drivetrain, and it is assumed the vehicles will last longer than their warranties as most cars significantly outlast their warranty (e.g. a 20 year old car did not have a 20 year warranty). Heat pumps, water heaters, and stovetops are assumed to last 15 years, noting that the quality of device impacts this lifetime and this study has purposely avoided choosing only the cheapest options as explain above, instead aiming for common expected pricing in the middle of the cost spectrum.

Price history and forecasts

Historic prices for electricity, gas, LPG, petrol, diesel, and wood are modelled using the quarterly consumer price index for the associated type of fuel for the past 40 years, with today's pricing as the basis. https://www.stats.govt.nz/indicators/consumers-price-index-cpi/. Future prices for each of these energy types is based on the linear trend of the CPI for the related energy category.

Solar price history is based on international solar price trends adjusted to current New Zealand solar prices. Nemet (2009); Farmer & Lafond (2016); International Renewable Energy Agency (IRENA). https://ourworldindata.org/grapher/solar-pv-prices. Future solar price forecasts are based on the National Renewable Energy Laboratory Residential PV Advanced cost forecast: https://atb.nrel.gov/electricity/2023/residential_pv#capital_expenditures_(capex) adjusted to New Zealand solar prices. With acknowledgement that forecasts have historically underestimated the speed at which renewable energy technology drops in price: https://www.cell.com/joule/fulltext/S2542-4351(22)00410-X.

Battery price history is based on Ziegler, M. S.; Trancik, J. E. Re-Examining Rates of Lithium-Ion Battery Technology Improvement and Cost Decline. Energy Environ. Sci. 2021, 14, 1635–1651. DOI: 10.1039/D0EE02681F https://pubs.rsc.org/en/content/articlelanding/2021/ee/d0ee02681f https://doi.org/10.7910/DVN/9FEJ7C adjusted to New Zealand battery prices. Forecast battery prices are based on the National Renewable Energy Laboratory Residential Battery Storage Advanced cost forecast: https://atb.nrel.gov/electricity/2023/residential_battery_storage which is adjusted to New Zealand battery prices and has the cost decline offset (delayed) by one year to represent delays in supply chain cost reductions reaching New Zealand consumers.

Electric vehicle price forecasts are based on an index derived from BloombergNEF "Hitting the EV inflection point" published May 2021: https://www.transportenvironment.org/wp-content/uploads/2021/08/2021_05_05_Electric_vehicle_price_parity_and_adoption_in_Europe_Final.pdf Adjusted to New Zealand EV prices today.

Embedded/embodied emissions

Embedded emissions are the carbon emissions associated with the production of vehicles and appliances (often called embedded or embodied emissions). It is important to consider embedded emissions when comparing electric and fossil fuel machines, as it enables a fuller understanding of the carbon footprint of our household choices.

Electric alternatives can have higher embedded emissions than their fossil fuel counterparts due to the extraction and processing of metals such as lithium for use in batteries. For example, although no emissions are produced from operating an EV (unlike Internal Combustion Engine (ICE) vehicles there are no 'tailpipe emissions'), there are emissions resulting from manufacturing the vehicle and battery. Over their lifetime electric vehicles and appliances are much less emissions-intensive than their fossil fuel equivalents.

Recent work from the European Federation for Transport and Environment[1] found that, on average, an EV produced in China has 12.3 tonnes CO2e of embedded emissions, made up of 6 tonnes for the vehicle and 6.3 tonnes for the battery. An EV with a battery built in Sweden has an average of 3.9 t CO2e in the battery production process thanks to the use of renewable or cleaner electricity during production. This same report estimated that 2 t CO2e could be avoided in the production of EVs through circular supply chains or via recycling. In contrast, an ICE vehicle embodies about 6.7 t CO2e, roughly 3-5 t less than an EV.

But over the lifetime of the vehicle, the large amount of tailpipe emissions from ICE vehicles quickly exceeds the extra embedded emissions in an EV. In New Zealand, an EV driving 11,000km a year and powered entirely by the NZ electrical grid will emit about 0.26 t CO2e, while an ICE (petrol) vehicle will emit around 2.58 t CO2e.[2] This means that, because of New Zealand's highly renewable grid, after approximately 2 years of use an EV has lower lifetime emissions than an ICE vehicle. Over the average 15 year life of a vehicle, an EV emits on average over 30 t CO2e less than an ICE vehicle.

1 European Federation for Transport and Environment, 2022, How clean are electric cars? https://www.transportenvironment.org/discover/how-clean-are-electric-cars/
2 Agrilink, 2022, New Zealand fuel and electricity total primary energy and life cycle greenhouse gas emission factors 2022. https://agrilink.co.nz/casestudy/life-cycle-assessment-nz-fuel-and-electricity/

EV emissions can be reduced even further if rooftop solar is used to charge the car. Charging through solar would reduce the operational emissions to zero, making the embedded emissions pay off time even shorter. Embedded emissions in solar panels are mostly a result of the production process. A 2022 study by Elementa Consulting and Willmott Dixon[1] estimated that solar panels have about 520-780 kg CO2e per kW of installed capacity. A 9 kW installation therefore contains about 4.7-7 t CO2e. According to work done by the Centre for Alternative Technology (the CAT Report), home batteries contain about 100 kg CO2e per kWh, so a 10 kWh setup will embody about 1 t CO2e.[2]

A large amount of these embedded emissions arise from energy use in the manufacturing process. The CAT Report found that home batteries could be made for just 60 kg per kWh, and a number of solar panel manufacturers have committed to 100% renewable energy. Chinese manufacturers Longi Solar Technology and JinkoSolar, the two largest solar panel manufacturers in the world, have both committed to 100% renewable energy. JinkoSolar recently achieved the goal and Longi expects to reach this target in 2028.[3] As the solar and battery manufacturing process decarbonises, the emissions payoff time will shorten further.

Unlike EVs, electric appliances, such as heat pumps, water heaters and cooktops, don't contain batteries and so generally have similar embedded emissions to their fossil fuelled counterparts.

A Canadian study published in 2020 compared the embedded and operational emissions of a house with a range of different appliance configurations. They determined the embedded emissions in 'mechanical systems' (covering heat pumps, water heating etc.) and found the same value for embedded emissions for the house with gas water and space heating as for the fully electrified version. However, as this report shows, fossil fuel appliances have significantly more emissions over their lifetime compared to electric equivalents.

The modelling in this report has shown that the average gas or LPG powered kiwi home with ICE vehicles can save about 6.7 t CO2e of emissions each year by electrifying and getting its electricity from a combination of the grid, solar and battery storage. The embedded emissions from installing solar and batteries are therefore paid off after around two years, with the electrified home saving around 100.7 t CO2e over a 15 year operational lifetime.

All viewed together, an electrified home powered by a combination of grid electricity, rooftop solar and battery storage is a much lower emissions option than a traditional fossil fueled household. The increased embedded emissions in rooftop solar, batteries and electric vehicles, are quickly overcome by avoided operational emissions. As technology improves and more production processes are decarbonised, we expect the embedded emissions in electric vehicles and machines to decrease even further.

1 Willmott Dixon, 2022, Whole life carbon of photovoltaic installations. https://www.willmottdixon.co.uk/asset/17094
2 Centre for Alternative Technology, Battery Storage. https://cat.org.uk/info-resources/free-information-service/energy/battery-storage/
3 https://www.there100.org/re100-members