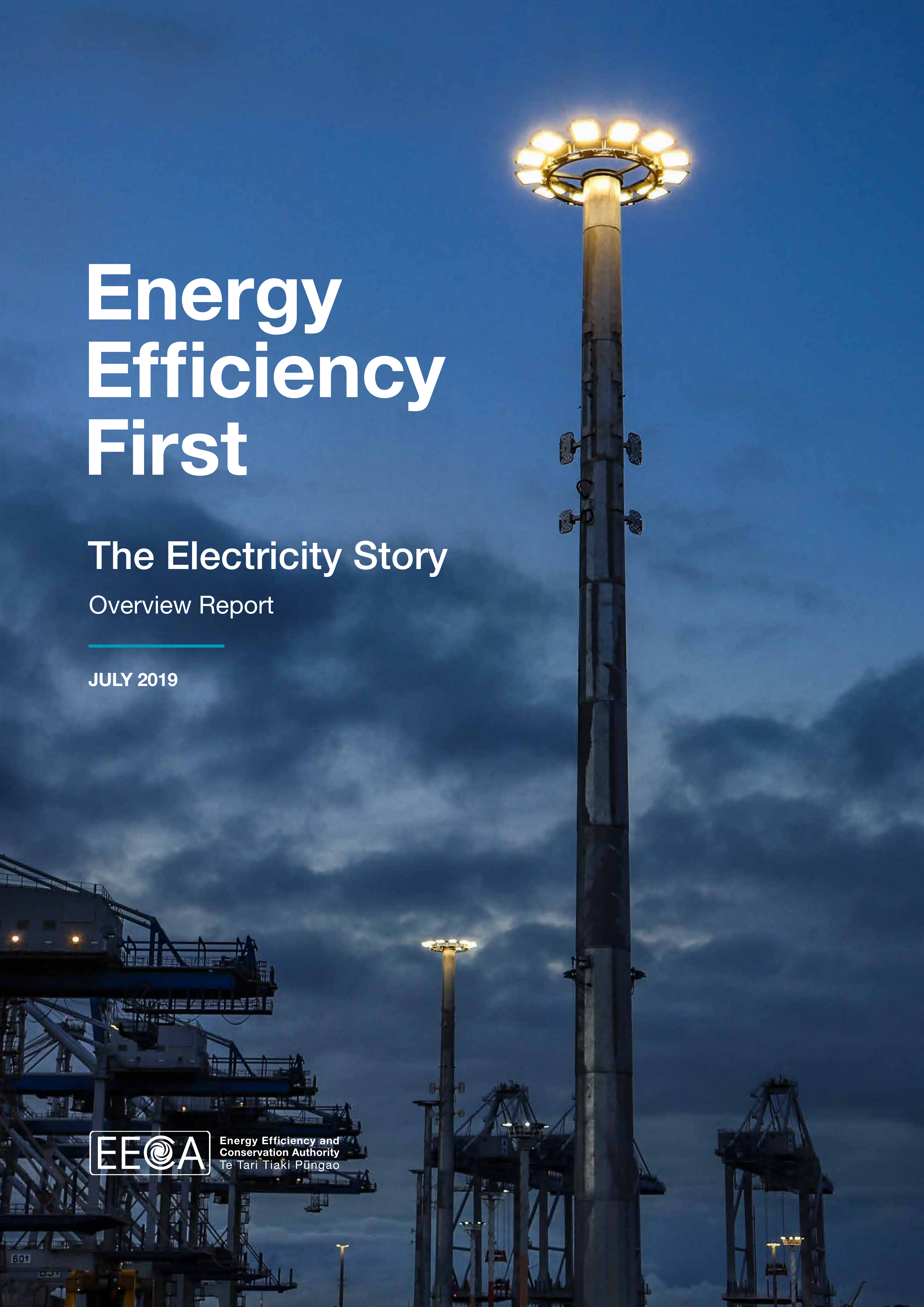


Energy Efficiency First

The Electricity Story

Overview Report

JULY 2019

EECA
Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

Executive summary

Energy efficiency can play an important role in reducing costs and emissions from energy use. This paper investigates the specific role that improving the energy efficiency of existing electrical demands can play in reducing costs and greenhouse gas emissions in New Zealand's energy system.

Decarbonising energy is a critical part of addressing the climate change problem

As the world grapples with the enormous challenge of climate change, a lower carbon energy system is key to reducing greenhouse gas (GHG) emissions. For many countries, especially those that rely on coal-fired power generation, cleaner electricity is critical to meeting their emissions targets. Conversely, New Zealand is one of only a few countries in the world where the majority of its electricity supply is generated from renewable and low-emission sources. New Zealand's biggest sources of emissions are currently agriculture, transport and industrial processing. However, emissions from electricity generation still contribute significantly to New Zealand's GHG emissions.

One of the pathways with high potential to reduce emissions in transport and industrial processing is electrification. However, electrification is much more effective at decarbonisation if the electricity supply is also decarbonised.

Decarbonising New Zealand's electricity system is a priority

The Government has prioritised the decarbonisation of the electricity sector, which currently relies on thermal generation to meet demand in all years. A key policy objective of the Government is to increase the supply of renewable electricity from the current levels of about 80–85% renewable, to 100% renewable by 2035[1].

The Government asked the Interim Climate Change Commission (ICCC) to provide advice on the costs and benefits of achieving this. Their report provides valuable insight into the challenges that reaching 100% renewable electricity may pose. New renewable generation is the default approach to reducing reliance on thermal generation, and this is evident in the ICCC's report. However, the ICCC's report also finds that the cost of decarbonising electricity by building new renewable generation is high.

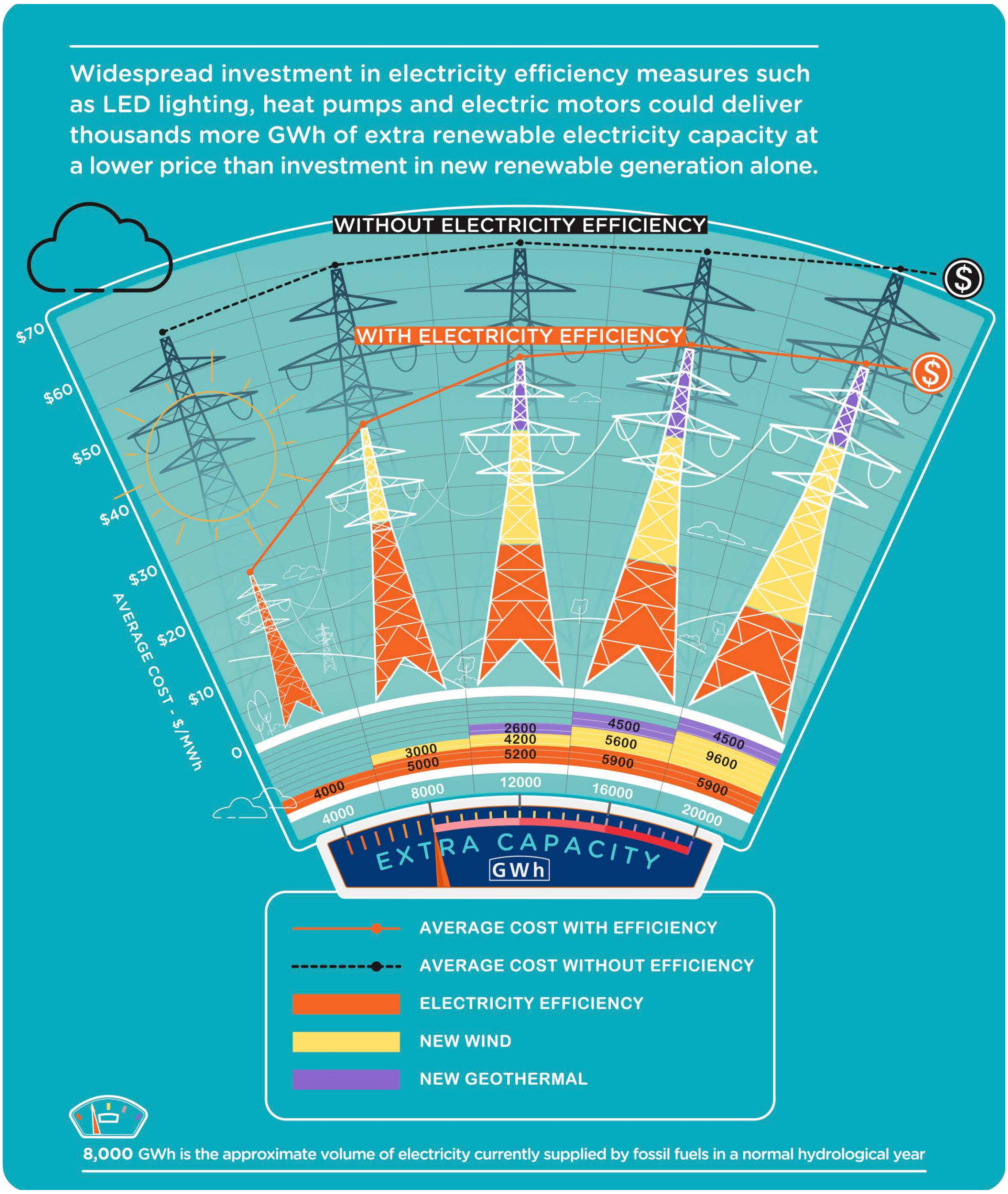
The Energy Efficiency and Conservation Authority (EECA) has worked alongside the ICCC to provide additional and complementary evidence of the benefits of energy efficient electrical technologies under any highly renewable scenario. Where possible, EECA has used data and assumptions consistent with the ICCC modelling, as well as our own internal information.

1 In a normal hydrological year

Electricity efficiency measures can play a key role in decarbonising electricity in New Zealand

Our research indicates that electricity efficiency measures can be deployed at a lower equivalent cost than new renewable generation, and that implementing these measures would make it easier to meet new demand arising from electrification. We also find that increased and accelerated uptake of electricity efficiency measures would reduce GHG emissions from electricity, but, for a range of reasons, these measures are often overlooked as a potential solution.

EECA has modelled a highly renewable New Zealand electricity system with and without energy efficiency measures and finds that overall costs and GHG emissions are lower with energy efficiency measures. These impacts are illustrated in the graphic below[2].This reduction in costs also translates into lower cost reductions of GHG emissions.



2 For more information refer to Energy Efficiency First: The Electricity Story
Figure 6, Page 16: LRMC of combined energy efficiency and generation projects

EECA has quantified the potential reduction in demand available from widespread deployment of key energy efficient electrical technologies, in particular LED lighting, heat pumps for water and space heating, and electric motors.

The research finds that the available cost-effective reduction in demand is around 4,000–5,000 GWh per year. This is approximately the same amount of electricity that would be required to charge one-third of New Zealand's light vehicle fleet if it were electric. It is also roughly equivalent to the annual output of around 1,200 MW of wind generation.

EECA's analysis finds that the average generation equivalent cost of implementing electricity efficiency measures is significantly lower than the cheapest currently available renewable generation technologies, with electricity efficiency measures costing $15–50/MWh compared to new generation at $60–75/MWh.

An optimal pathway to decarbonising New Zealand's electricity system must include investment in the energy efficiency of existing electrical demands

The electricity technologies considered are mature, readily available and are being adopted globally. Implementation times for switching to LEDs, heat-pumps or more efficient motors are short relative to building new renewable generation, which means that electricity efficiency measures could be deployed quickly, allowing emissions reductions to be achieved earlier. New Zealand's emissions target under the Paris Agreement is a reduction of total emissions between 2021 and 2030, so rapidly deployable interventions are especially valuable in meeting that target.

There is a great deal of experience with electricity efficiency interventions internationally, and in New Zealand, to help guide policies to accelerate adoption in New Zealand. It is not the role of this paper to propose policies. EECA wants to stimulate discussion about the potential to accelerate adoption of energy efficient electrical technologies because so far they are not being given the attention and priority they require.

Energy efficiency initiatives using mature and proven technologies can make a large, near-term, low-cost and low-risk contribution to achieving reductions in carbon dioxide emissions from energy.

> ***In combination with additional renewable generation, electricity efficiency measures can provide New Zealanders with affordable, low-emissions electricity and enable a transition to a low-emissions energy system, through electrification of transport and industrial heat.***

EECA's recommendation

Policy-makers and industry planners should ensure they devote appropriate investigation and investment to electricity efficiency measures alongside other decarbonisation activities. This requires placing a much higher priority on electricity efficiency than it currently receives.

1 Introduction

1.1 EECA's purpose and role

EECA promotes uptake of energy efficiency and renewable energy to improve the economic, environmental and social performance of energy and energy systems.

As part of its work, EECA gathers information from around the world about efficient and low-emission energy technologies, systems and policies, and evaluates their potential application and contribution to New Zealand's energy system.

Energy efficiency means using less energy to provide products and services. There are different pathways to energy efficiency. EECA's work includes changing behaviours that affect the purchase and use of goods and services, energy conservation, proper equipment maintenance, adoption of emerging technologies and optimising system efficiency.

1.2 The Energy Efficiency First electricity story

EECA also identifies and assesses options for using energy efficiency to decarbonise New Zealand's energy system. This paper focuses on the considerable potential to reduce electricity demand, and therefore carbon dioxide emissions, by accelerating adoption of mature energy efficient electric technologies, such as LED lighting and heat pumps.

The purpose of this paper is to stimulate discussion about the role energy efficiency should play in New Zealand's highly renewable, low-emissions electricity system.

We identify some near-term opportunities to improve the efficiency of existing electricity use.

The opportunities highlighted here:

- are implemented by investment decisions, rather than behaviour change
- have up-front costs which are repaid by reduced running costs over time
- permanently reduce energy use
- can be implemented through identified interventions, many of which have been shown to be effective in other countries

The paper examines New Zealand's circumstances, identifies economically attractive electricity efficiency opportunities and describes the economic and carbon reduction benefits available from implementing at scale.

1.3 Decarbonising New Zealand's economy

As the world grapples with the enormous challenge of climate change, a lower carbon energy system is critical for reducing GHG emissions. New Zealand has high emissions per capita so faces a big challenge to play its part in reducing climate risks.

As shown in Figure 1, New Zealand's biggest sources of emissions are agriculture, transport and industrial processing.

Agriculture contributes about half of New Zealand's GHG emissions. Methane production from ruminants is difficult to reduce and dairy and meat are important exports.

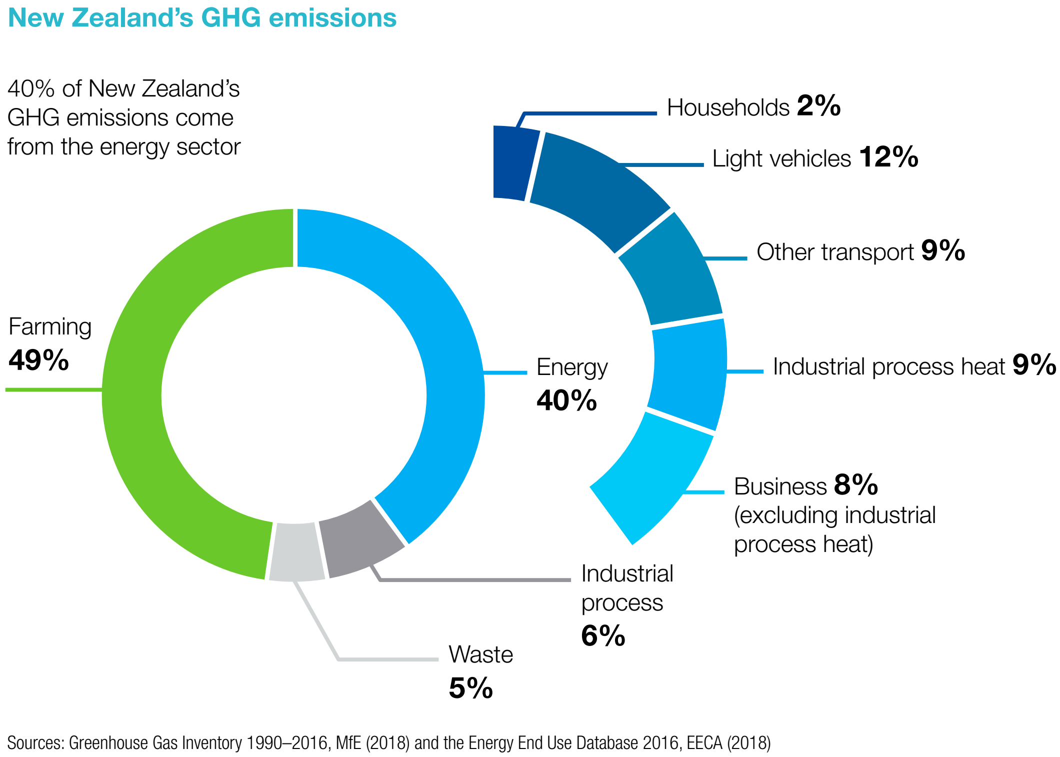


Figure 1: Breakdown of New Zealand's GHG emissions

The high contribution to emissions from agriculture suggests intense effort is required to reduce emissions from other parts of the economy, such as transport and industrial processing.

1.4 Decarbonisation through electrification

1.4.1 Transport and process heat provide big decarbonisation potential

In New Zealand, transport and process heat dwarf residential and business energy (non-process heat) use in terms of energy demand and GHG emissions because of the mixture of fuels used. Therefore, addressing these sectors is critical to achieving large-scale reduction in emissions from the energy sector.

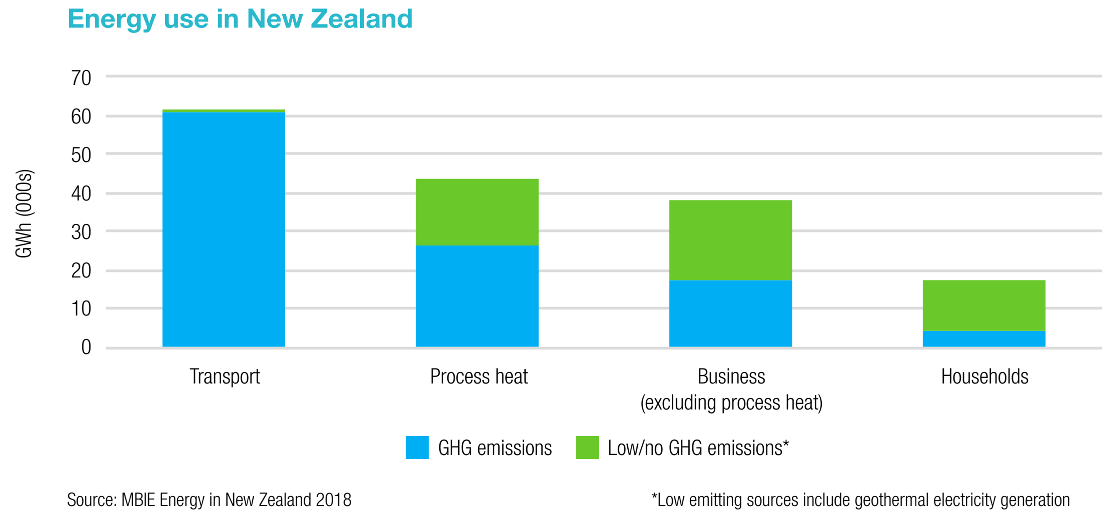


Figure 2: Composition of energy use in New Zealand

1.4.2 Electric technologies for transport and some types of heat will increase demand for electricity

Current transport fuel needs are met almost exclusively by fossil fuels, meaning transport is both a large energy consumer and a large source of emissions. Electric vehicles (EVs) are emerging as an important solution for decarbonising transport systems. At present, the upfront costs for EVs (purchase/lease) are higher than costs for incumbent fossil technologies. These costs, however, are falling, with EVs expected to be available at the same or lower prices than equivalent conventional vehicles between 2024 and 2029[3].

3 Reference https://bnef.turtl.co/story/evo2018?teaser=true. “The upfront cost of EVs will become competitive on an unsubsidized basis starting in 2024. By 2029, most segments reach parity as battery prices continue to fall.”

Electric motors are much more efficient at converting energy into motion than the internal combustion engines (ICEs) that dominate the current transport fleet, as shown in Figure 3.

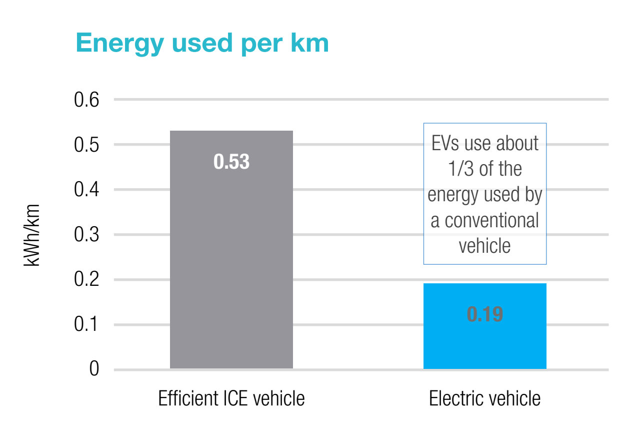


Figure 3: Energy used per kilometre of ICEs and EVs

Process heat is the next largest sector for energy demand after transport, with fossil fuels, primarily gas and coal, supplying the majority of process heat. Some process heat can be decarbonised through conversion to electrically powered heat pumps[4].

Heat pumps transfer low temperature heat from the source to the target while efficiently increasing the temperature. Heat from a low temperature source such as air is absorbed by the heat pump's working fluid, which is usually a refrigerant such as ammonia. Electricity is then used to compress the working fluid, which increases its temperature to the target level. The useful heat is then discharged to the target via a heat exchanger (for example as hot water for process or cleaning needs, or as warm air for space heating).

Heat pump economics are more situation specific, but costs are also falling as their performance improves.

The implication of advances in EV and heat pump technologies and costs is that large, economic, emissions reduction opportunities from these sources are likely to be available within a few years, with corresponding increases in electricity demand.

1.4.3 Default solution for meeting increased demand is new renewable generation

With uptake of electrification, the demand on New Zealand's electricity system will grow, requiring more supply. Solutions for increasing electricity supply have been focused primarily on building more renewable generation such as onshore wind and geothermal. Some studies have also estimated a high uptake of solar photo voltaic (PV), based on expected cost reductions, particularly for large-scale, 'utility' installations. So far, the potential for widespread uptake of efficient electricity technologies to help offset increased electricity demand has largely been ignored.

4 For more about process heat, refer to the PHINZ issues paper at https://www.mbie.govt.nz/dmsdocument/4292-process-heat-in-new-zealand-opportunities-and-barriers-to-lowering-emissions

1.5 Decarbonising the New Zealand electricity system

1.5.1 Low-emissions renewable electricity

New Zealand generates 80–85% of its electricity from renewable sources, making it one of the lowest emissions electricity systems in the world.

However, the remaining 15–20% of New Zealand's electricity is generated by burning fossil fuels, resulting in carbon dioxide emissions of 4–5 million tonnes per year, around 5–6% of New Zealand's total.

Decarbonisation through electrification is most effective when the electricity supply is low-emissions, which means that increases in renewable capacity are needed in line with increasing demand.

The Government has a policy objective to increase low-emission renewable generation to 100% in a normal hydrological year and has tasked the ICCC with providing advice on achieving that.

Emerging and developing energy technologies are available to increase production of low-emission electricity and the costs of many of these technologies, especially wind and solar, are reducing rapidly. New Zealand has the potential to deploy enough low-emissions electricity generation capacity to displace all the existing thermal generation under normal conditions and meet new demands, although, as we will discuss later in the paper, this comes at a significant cost.

1.5.2 Winter peaks and hydrology

Peak demand for electricity in New Zealand is during winter, when temperatures are colder and nights are longer.

Around 60% of New Zealand's electricity is generated by hydro turbines using water stored in dams, which are replenished by rainfall. If there is a shortage of rainfall before or during winter, there is a risk of insufficient generation capacity to provide for the winter demand.

As an isolated island nation that cannot draw on supply from a connected country as other nations sometimes do, New Zealand needs a system that can manage peaks without outside help.

1.5.3 Potential for electricity efficiency to reduce emissions

EECA's analysis demonstrates there is an opportunity for energy efficient electricity technologies to substitute for some thermal generation, thereby helping reduce New Zealand's greenhouse gas emissions as well as electricity costs for consumers.

> ***New Zealand energy consumers have a greater opportunity to improve the efficiency of energy use than those in many other countries because New Zealanders do not use energy very efficiently now.***

Buildings and houses often perform poorly, requiring extra heating, and that is often supplied using inefficient appliances. A preference for market solutions over regulation has seen products available and standards lag the rest of the developed world, where regulatory and other interventions have been more common. A tendency to under-invest in new equipment means New Zealand is holding onto older, less efficient equipment for longer.

EECA has identified low-cost opportunities for electricity efficiency that collectively comprise an estimated 10–12% of current electricity demand. Adopting those opportunities could happen rapidly, and quickly lock in emissions reductions.

The remainder of this paper describes how adoption of electricity efficient opportunities would benefit New Zealand and provides an introduction into how interventions could progress the opportunities.

1.5.4 The ICCC is providing advice on 100% renewable electricity

The Government tasked the ICCC with advising on the costs, benefits and practicalities of achieving 100% renewable electricity by 2035. EECA contributed specialist input into the ICCC advice and supports the conclusions reached.

The ICCC has provided its advice to Government on this topic and its key findings are that:

- There is large potential for energy efficiency and carbon reduction from EVs and process heat via electrification.
- Demand for electricity can be expected to increase as a result of this electrification.
- A highly renewable electricity system is feasible and should be expected.

1.5.5 EECA complements and extends the ICCC position

The ICCC included a realistic uptake of electricity efficiency in its modelling, based on current policies. EECA's work presented here looks at a more aggressive pursuit of electricity efficiency, and comes up with an additional and complementary view to the scenarios developed by the ICCC.

2 Electricity efficiency can make a valuable contribution

Efforts to reduce New Zealand's reliance on thermal electricity supply and consequential emissions should not be solely focused on building new renewable generation. EECA analysis indicates that there are opportunities for readily deployable electricity efficiency measures that would result in substantial reductions in New Zealand's thermal generation, and the resulting emissions.

Progressing electricity efficiency opportunities widely across New Zealand's sectors would reduce the demand for electricity. The resulting reduction in generation would come almost exclusively from thermal generation[5], due to its higher variable cost, which is driven by the costs of coal and gas. As the use of thermal generation reduces, so too would GHG emissions.

The energy efficient solutions would also cost less than building new renewable capacity. Although there are long-term electricity cost savings from these solutions, the upfront costs are a barrier to uptake of the technologies. This and other barriers can be overcome with interventions such as regulation, incentives or information provision, the costs of which would need to be taken into account in policy analysis. While we have not estimated the potential cost of interventions in our analysis, we expect total costs will be less than the cost of building new renewable capacity.

2.1 Modelling of energy efficient technologies

There are several mature and cost-effective energy efficient technologies that can provide reductions in energy demand, and emissions, but these have not yet been fully adopted in New Zealand.

> ***Three technologies are prominent in our modelling: LED lights, heat pumps for water and space heating, and more efficient electric motors.***
>
> ***All these energy efficient technologies provide the same or better functionality as the less efficient technologies they replace; meaning the energy needs of users can be met with less electricity.***

Substituting existing, less efficient technologies with more efficient electrical technologies would deliver a material reduction in emissions from thermal generation.

New Zealand lags behind other advanced economies in the implementation of efficient technologies, partly because it has done less to encourage adoption.

Energy efficiency is usually expressed as energy savings or percentages, costs of savings per unit, or payback periods. For this research it is necessary to compare energy efficiency opportunities with new renewable generation, in which case the most useful measure is the generation equivalent cost. EECA has drawn on its own research into economic energy efficiency opportunities to estimate the expected savings and capital implementation costs for different technologies and sectors.

EECA's approach uses a model to work out the rationally optimal uptake of technologies based on the relative economics of each technology. Some constraints are applied within the model to limit the rate of change of technology to realistic levels.

5 Reducing thermal generation in normal years will alter the economics of owning and building thermal plant. It is expected that thermal plant (or some yet to be discovered alternative) will be needed to provide security of supply during periods where renewable output is less than normal (dry years). It is not clear at this stage what provisions may be needed to ensure dry year support plant remains available.

For each end use and subsector, current energy service demand forms the baseline. This energy service demand is then modelled as being met by the most efficient economic technology available. Modelled technology uptake can then be used to derive total capital costs and energy savings figures. Sector technology capital costs ($M) are determined using a per unit capex value multiplied by the overall uptake figure.

Annual energy volume savings (GWh) are calculated by multiplying the technology uptake by the percentage efficiency improvement and the usage factor over a year.

In order to compare energy efficient technologies to new generation, a 'Generation equivalent cost' is calculated by dividing the upfront capital cost by the discounted energy savings over the expected life of the technology to give a cost in $/MWh. These estimates are shown in Appendix 1.

To further explain our results, we look at commercial lighting.

Current electricity consumption for commercial lighting is estimated by EECA's energy end use database (EEUD) at 8,024 TJ, or 2,228 GWh.

Upgrading to LED lighting is expected to deliver 46% savings on average (most commercial lighting is fluorescent tubes).

EECA's model calculates that it would be economic to upgrade 100% of commercial lighting load to LEDs. This would give savings of 46% times 2,200 GWh, or 1,035 GWh and annual consumption after upgrade of 1,182 GWh.

Commercial lighting is assumed to be in use 50% of the time on average. Using this capacity factor we can calculate the total input load as 270 MW.

EECA estimates the capital cost of upgrading at $500 per input kilowatt. Multiplying this by the total input load we get a capital cost to upgrade of $135M.

To calculate the generation equivalent cost we divide the capital cost by the discounted energy savings over 10 years, which gives us a generation equivalent cost of $13.40.

2.1.1 Lighting – LED lights

LED lights use an electronic circuit to produce the same amount of light as resistive filament lamps or fluorescent discharge tubes but use much less energy. The efficiency gain is because a much larger proportion of the electricity is turned into light rather than heat. The lamps cost more to purchase but they also last a lot longer.

Table 1 below shows the potential electricity savings if LED lights were adopted in all situations where they are currently economic.

Sector	Capex estimate ($M)	GWh saved	Generation equivalent cost ($/MWh)
Commercial	135	1,035	$13.40
Primary	10	75	$13.40
Industrial	20	152	$13.40
Residential	371	741	$51.60
Total	**536**	**2,003**	

Table 1: Demand reduction and costs of LED lights for different sectors

The calculated generation equivalent cost for business lighting is around $13 per MWh, several times lower than the cost of the current best generation alternative.

Residential lights are used a lot less on average, so the generation equivalent cost is higher.

Where generation equivalent costs are below both the current average wholesale cost and the estimated near term cost of new generation, there should be a national economic benefit arising from the uptake of LED lighting, on the basis that the net cost to the economy of meeting demand for lighting will be lower overall.

2.1.2 Water and space heating – heat pumps

Heat pumps are energy efficient and cost effective for many applications. Heat pumps can be used for water heating and space heating. Section 1.4.2 provides a brief explanation of how heat pumps work.

Table 2 below shows estimated capital costs and electricity savings if heat pumps were deployed in all economic situations in different sectors as replacements for existing electrical heaters.

Sector	Capex estimate ($M)	GWh saved	Generation equivalent cost ($/MWh)
Water heating			
Commercial	189	637	$25.80
Primary	112	379	$25.80
Total water heating	301	1,016	-
Space heating			
Commercial	315	920	$29.80
Industrial	30	87	$29.80
Residential	345	753	$62.15
Total space heating	690	1,760	-
Total heating	**991**	**2,776**	**-**

Table 2: Demand reduction and costs of heat pumps for water and space heating for different sectors

The calculated generation equivalent cost for business water heating is around $26 per MWh, less than half the cost for the current best generation alternative. Similarly, the calculated generation equivalent cost for business space heating is around $30 per MWh, around half the current best generation alternative. As with LED lights, there is an expected national economic benefit arising from the uptake of heat pumps, on the basis that the net cost to the economy of meeting demand for heating will be lower overall.

Residential space heating is slightly more expensive than new renewable generation on an equivalent basis, because residential heating is used a lot less on average; however, the generation equivalent cost is still comparable to most current generation options. There are additional benefits from improving the efficiency of residential space heating, such as reducing winter peak demands.

2.1.3 Motive power – electric motor with variable speed drive (VSD)

Motors used across the commercial, industrial and primary sectors are big energy consumers. Large gains can be realised through installation of higher efficiency motors with variable speed drives (VSDs). Advances in motor technology, largely driven by European Union (EU) efficiency regulations, mean that newer motors use a lot less energy than their older equivalents.

A VSD increases the efficiency of a motor by allowing it to operate at the ideal speed for the load required, usually without gearboxes or similar devices. That reduces wasted energy and increases process precision.

High efficiency electric motors with VSD are now readily available and can be swapped directly for older, less efficient equivalents.

Table 3 below shows the potential electricity savings if high-efficiency electric motors with VSD were rolled out comprehensively across different sectors.

Sector	Capex estimate ($M)	GWh saved	Generation equivalent cost ($/MWh)
Industrial	178	773	$31.30
Commercial	44	190	$31.30
Primary	13	54	$32.20
Total	**235**	**1,017**	

Table 3: Demand reduction and costs of electric motors with VSD to New Zealand across sectors

The calculated generation equivalent cost for high efficiency motors is around $31 per MWh, around half the cost of the current best generation alternative. As with LED lights, there is expected to be a national economic benefit arising from the uptake of electric motors with VSD, especially from the industrial sector.

2.2 Some electricity efficiency opportunities are cheaper than the lowest cost renewables

EECA has assessed the potential for electricity efficiency measures to contribute to New Zealand's future electricity system. The work compares new renewable generation projects and energy efficiency projects, examining their long run marginal cost (LRMC) and electricity generation potential. LRMC is an estimate of the cost of generating electricity per unit. It includes capital and finance costs plus fixed and variable operating costs. These costs are added up over the expected life of the plant and divided by the total expected production from it. LRMC is calculated on a discounted cash flow basis and is expressed as dollars per megawatt-hour ($/MWh).

Figure 4 shows an estimated[6] LRMC curve for renewable generation projects in New Zealand. LRMC cost curves can be used to understand the economic potential of different generation options and to anticipate the likely sequence of generation builds.

The lowest cost generation options are wind and geothermal projects, with estimated LRMCs of between $60 and $75 per MWh. There is around 12,000–15,000 GWh of potential generation capacity in that cost range, more than enough to meet foreseeable electricity needs for the next 10–15 years.

6 Derived from Lazard LCOE v12 and MBIE EGDS 2016.

LRMC of new generation projects

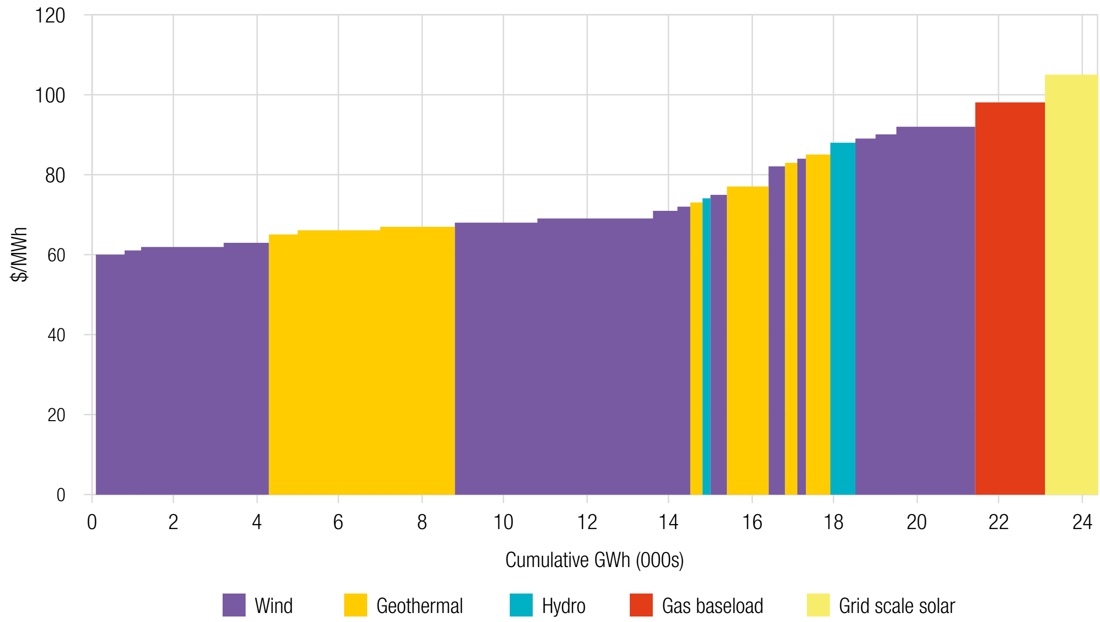


Figure 4: Long run marginal cost (LRMC) of new renewable generation projects

Our analysis described in Section 2.1 has been used to derive an equivalent cost curve for electricity efficiency options, shown in Figure 5.

The electricity cost curve shows more than 6,000 GWh of electricity energy efficiency options are available at a reasonably competitive cost, with around 4,500 GWh of those being substantially lower cost than the cheapest new renewable generation. The lowest-cost options are all in the business sectors, and include upgrading existing lighting to LEDs, upgrading electric water and space heating to heat pumps and updating existing electric motors to more efficient versions with VSDs. These low-cost electric energy efficiency options would allow replacement of 4,500 GWh or around half of existing mean year thermal generation at a cost that would be lower than the cost of replacing the same amount of thermal generation with new wind farms.

Equivalent LRMC of energy efficient technologies

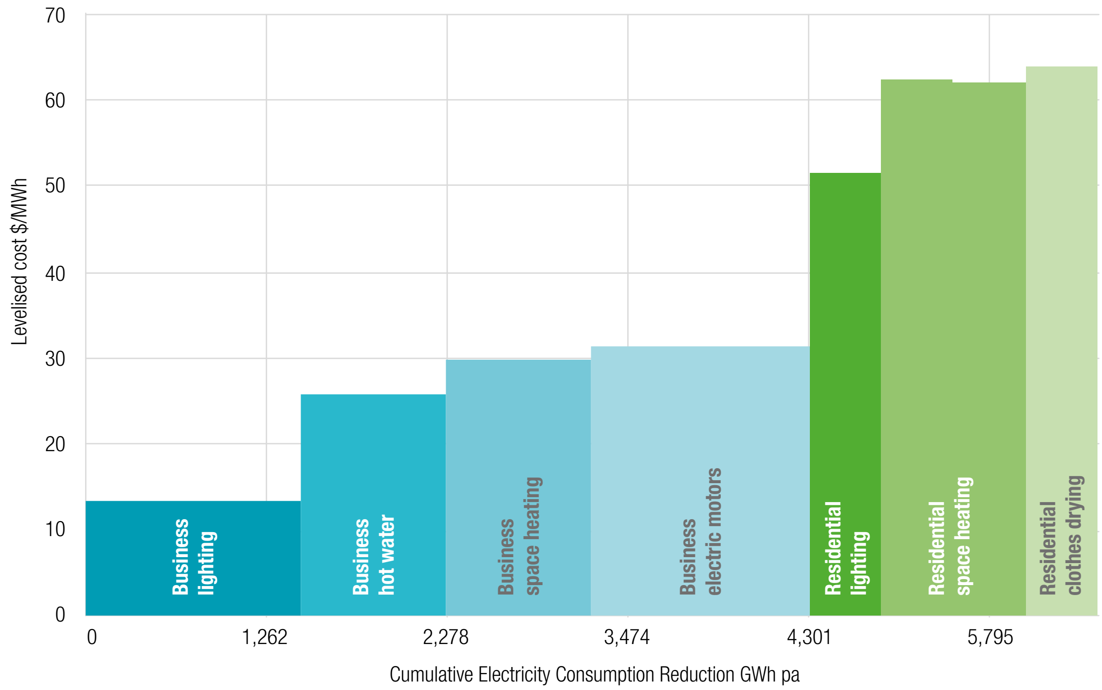


Figure 5: Equivalent LRMC of energy efficient technologies

Figure 6 combines the LRMC estimates for new generation with those for energy efficiency to create a single compound supply curve. The grey line shows the cost of meeting a given level of supply with generation alone (from Figure 4). The combined curve shows that a mixture of generation and energy efficiency resources can be deployed to achieve a given thermal emissions reduction or demand satisfaction target at a lower overall cost than either approach alone.

LRMC of combined energy efficiency and generation projects

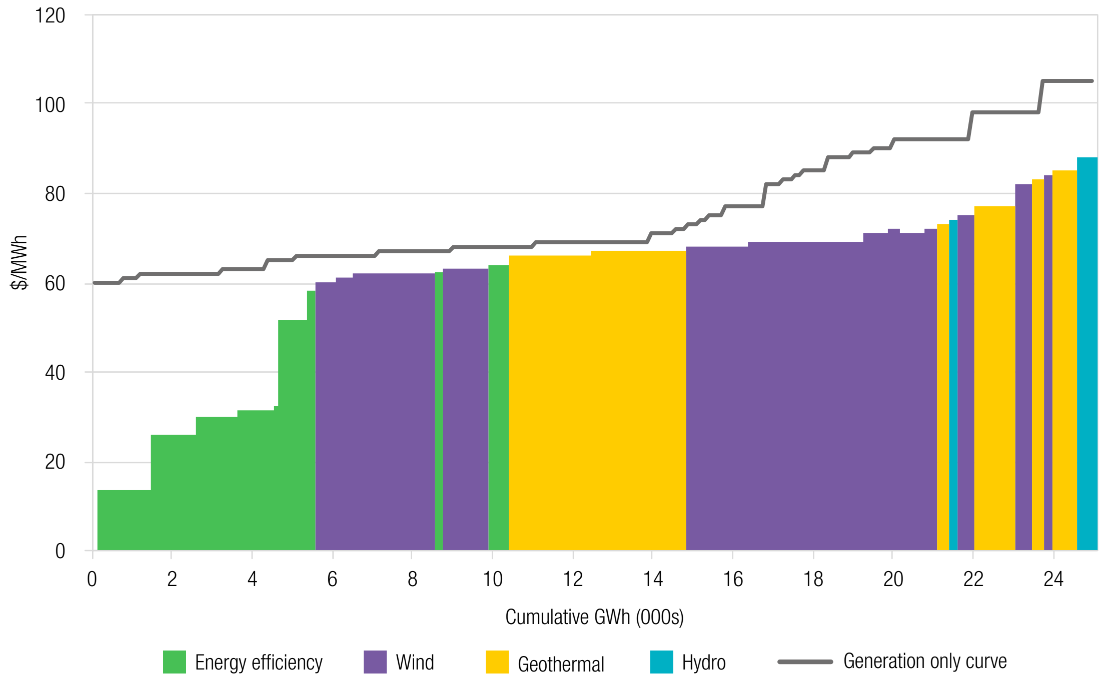


Figure 6: LRMC of combined energy efficiency and new renewable generation

3 Modelling shows that using electricity more efficiently is effective at reducing thermal generation emissions in the New Zealand context

Investing in energy efficient technology will provide a cheaper means of substituting for thermal generation and lowering greenhouse gas emissions than new renewable generation.

Analysis based on LRMC in Section 2 provides an indication of how the electricity market will work on average. However, hydro inflows and wind generation can be highly variable, and actual market operations have daily and seasonal variability that must be managed.

To get an accurate picture of the impact of energy efficiency on the electricity system, and for thermal generation quantities, requires detailed modelling.

EECA has used a market simulation tool, EMarket, from an energy services provider, Energy Link. The tool is purpose built for the New Zealand electricity industry and includes the complete set of 86 years of hydro inflow data and robust methods of valuing and scheduling hydro and other resources. Its detailed demand model enables estimation of the effects of deploying the electricity efficiency opportunities.

Three scenarios for New Zealand's electricity system were developed, modelled and compared with the base case[7], using the EMarket tool.

These scenarios included the addition of new renewable generation only and a 'hybrid' approach which deployed energy efficiency in combination with new renewable generation:

1. **Thermal restricted to peaking only scenario** – offer prices for existing thermal plants were increased to a multiple of short run marginal cost (SRMC) to reflect a 'peaking only' operating mode. Enough new renewable generation was added to limit thermal generation to less than 50 GWh per year on average.
2. **99% renewable scenario**[8] – uses the peaking only scenario as a base, with additional renewable generation capacity reduced to allow average annual thermal generation of ~400 GWh, reflecting 1% of average demand and achieve the 99% scenario target.
3. **Hybrid scenario** – seeks to find the optimum balance between new renewable generation and energy efficiency to achieve close to 100% renewable electricity. The model includes a 4,100 GWh decrease in demand, based on the assumption that the low-cost energy efficient solutions are fully deployed.

All scenarios retain thermal generation and use it for peaking and dry year cover, which results in reduced hours of operation, less fuel used and reduced carbon emissions. As shown in Table 4, thermal generation in dry years is generally 1,000–2,000 GWh higher than the mean across the years, reflecting the underlying hydro inflow variability which varies from around 22,000–27,000 GWh with a mean of 24,500 GWh.

7 The base case consists of existing demand and generation capacity for the 2017 year, modelled across a full set of 86 hydro inflow years.
8 Note, this should not be seen as a recommended or optimal target. 99% renewable is just a scenario chosen to represent a very highly renewable scenario that is less than 100% renewable.

Scenario	Base case	Peak thermal only	99% renewable	Hybrid
Average thermal generation (GWh)	6,057	37	352	189
Maximum thermal generation (GWh)	8,148	385	1,835	1,332
Inflow year of maximum thermal generation	1,975	1,931	1,970	1,970

Table 4: Average and maximum thermal generation across modelled scenarios

All scenarios were modelled across the full range of historical hydro inflows. Security of supply assessed as annual shortfall quantities was similar or better than the current system as shown in Table 5 below.

Scenario	Base case	Peak thermal only	99% renewable	Hybrid
Average shortfall (GWh)	2.3	0.0	0.02	0.0
Maximum shortfall (GWh)	125.0	0.0	1.54	0.0
Inflow year of maximum shortfall	1,931	NA	1,968	NA

Table 5: Average and maximum shortfall across modelled scenarios

The base demand for the analysis is 2017 and has been chosen because it is a known quantity, as is the level of technology uptake. Using 2017 as a base year avoids the potential for double counting the impact of energy efficiency when considered as part of future demand volumes. However, we note that the results are not perfectly transferable into reality (for example, absolute reductions in annual demand are unlikely to occur due to the impact of electrification).

3.1 Reducing New Zealand's current reliance on thermal generation

Figure 7 illustrates the modelled annual generation from each electricity source for each scenario, based on the 2017 demand assumptions.

All three scenarios have a large decrease in reliance on thermal generation compared with the base case. The volume of thermal generation decreases from an annual average of 6,057 GWh in the base case, to 301 GWh in the hybrid model, a reduction of 5,756 GWh. That means that in the three scenarios, thermal moves from a baseload role to being used essentially only during dry year and peak periods.

The hybrid scenario achieves a similar decrease in thermal generation as the 99% renewable scenario, but does this by adding much less new renewable generation. A breakdown of modelled decreased demand, increased renewable generation and reduction of thermal reliance is outlined in Table 6.

Scenario	Peak thermal only	99% renewable	Hybrid with EE
Renewable generation added (average annual GWh)	7,243	6,722	2,313
Energy efficiency demand reduction (GWh)	NA	NA	4,100
Total effective capacity addition (GWh)	**7,243**	**6,722**	**6,413**
Average annual thermal reduction (GWh)	6,020	5,705	5,756

Table 6: Shifts in electricity generation sources and demand across modelled scenarios

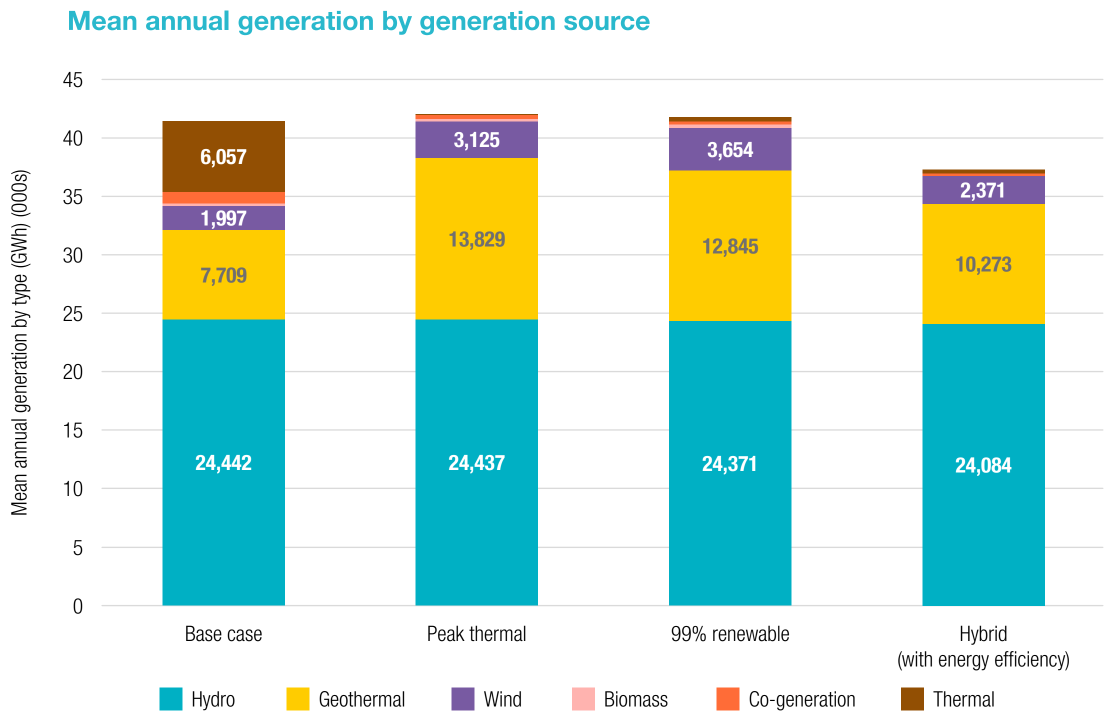


Figure 7: Mean annual generation by scenario and type

3.2 Reducing New Zealand's GHG emissions

Figure 8 shows modelled GHG emissions for each scenario according to electricity source. Across all scenarios, average GHG emissions decrease sharply due to the reduction in thermal generation, and to roughly comparable levels.

The hybrid scenario presents the lowest level of GHG emissions with a decrease in GHG emissions of 70% relative to the base case.

This average annual reduction across all scenarios of 2.7 MT per year is roughly equivalent to 15% of the estimated 20 MT per year reduction required between 2021 and 2030 by New Zealand's commitment in the Paris Agreement.

The Paris Agreement establishes a cumulative obligation over the period 2021 to 2030. Therefore, emissions reductions that can be implemented earlier will have greater value as they will count towards the Paris target for a greater proportion of the commitment period. Energy efficiency measures can potentially be deployed more rapidly than new renewable generation, both due to economics (Section 2) and implementation requirements such as consenting, construction and transmission connections.

Geothermal emissions increase across the three scenarios as new geothermal generation is added. There is less generation of new geothermal emissions in the 'hybrid' scenario as the amount of new renewable generation needed is less, due to the reduced demand for electricity.

Average annual GHG emissions for each scenario

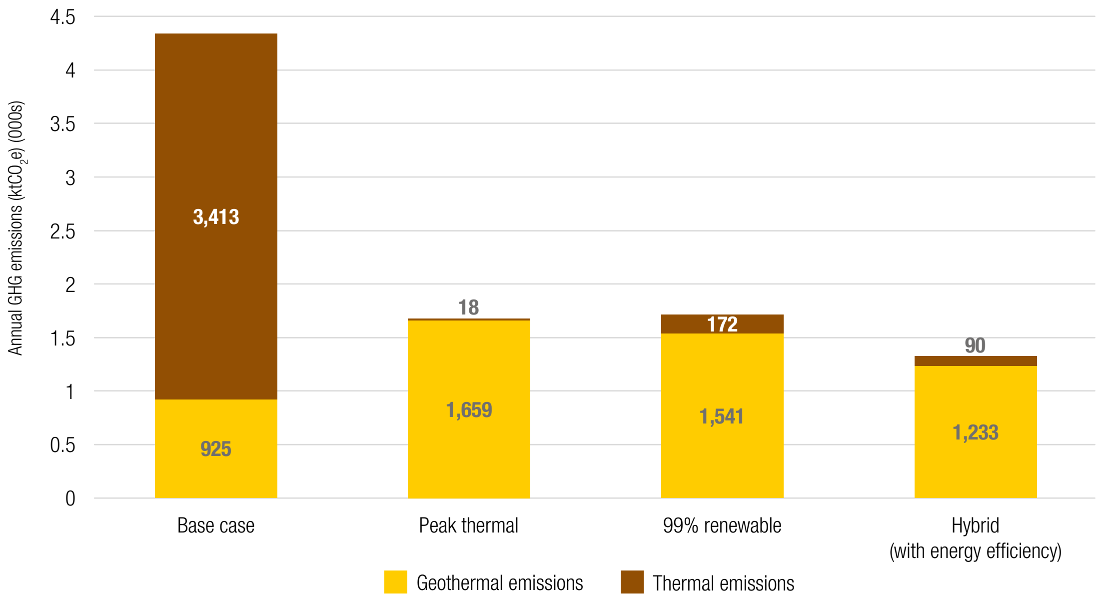


Figure 8: Mean annual GHG emissions for each scenario

3.3 Reducing the cost of electricity

When considering alternative electricity system scenarios, the minimisation of costs and cost increases is important to avoid creating problems for existing consumers and deterring future electrification.

3.3.1 Estimating system costs

The measure chosen for this study was total system cost, which includes estimated generation, transmission and distribution costs. Total system cost is a measure of the overall economic cost of generating and supplying electricity. Changes in total system cost are a good measure of the national benefit or cost.

Existing and new generation plant and energy efficiency investments are treated on a long run cost basis, with the exception of thermal generation which is treated as a sunk asset due to the low likelihood of replacement and valued on a short run cost (variable costs only) basis.

Key assumptions are given in the table below:

Item	Value	Basis (source)
Carbon Price	NZD $25/t$CO_2$e	Current NZETS price (CommTrade)
Cost of capital/ finance cost	5% per annum	Estimated weighed average cost of capital for New Zealand businesses
Transmission cost	NZD $990 million per year	2017 Transpower maximum allowable revenue (Commerce Commission)
Distribution cost	NZD $2,521 million per year	2017 total EDB revenue (Commerce Commission)

Table 7: Key assumptions used in estimating system cost

It is assumed that all system costs are fully recovered from consumers. This assumption is needed to ensure that estimates of cost are sustainable. If costs are not fully recovered then the system may not be sustainable in that configuration, and parties may retire assets or change business models, leading to a new equilibrium. Using a fully recovered cost shortcuts the process of seeking full market equilibrium prices using, for example, Nash-Cournot methods, which are computationally intensive and sensitive to input assumption errors.

For most scenarios, the total system cost increases, reflecting the additional costs of new capacity and to some extent the need for 'overbuild' to ensure security of supply. However, in the hybrid scenario, total system costs fall. The decrease is partly because demand has reduced, but primarily because the modelled LRMC of energy efficiency is lower than the fuel-dominated variable cost of the thermal generation it replaces.

An additional benefit of deploying energy efficient technologies is the reduction in demand during peak periods.

> ***This reduction is expected to result in lower transmission and distribution costs, and may also make it easier to maintain security of supply, all of which contribute to lower costs.***

3.3.2 Estimating system costs on a per unit basis

A useful way of looking at cost is on a per unit basis, as shown in Figure 9. Unit cost is the total system cost divided by the MWh supplied. For the hybrid scenario, which includes energy efficiency measures, the MWh figure used is the base demand rather than the MWh supplied, on the basis that the energy efficient technologies supply the same service and hence the same value to the consumer, despite the reduction in demand quantity.

Of the three scenarios, the 'hybrid' scenario is the only one that has a fall in per unit costs relative to the base case cost of the current system. This scenario estimates system costs that are $8/MWh lower than the next best low-emissions scenario.

To quantify the additional value of energy efficiency in this case, if the $8/MWh reduction in system costs is multiplied by the total system demand over 10 years[9], a total benefit of around $2.3 billion results.

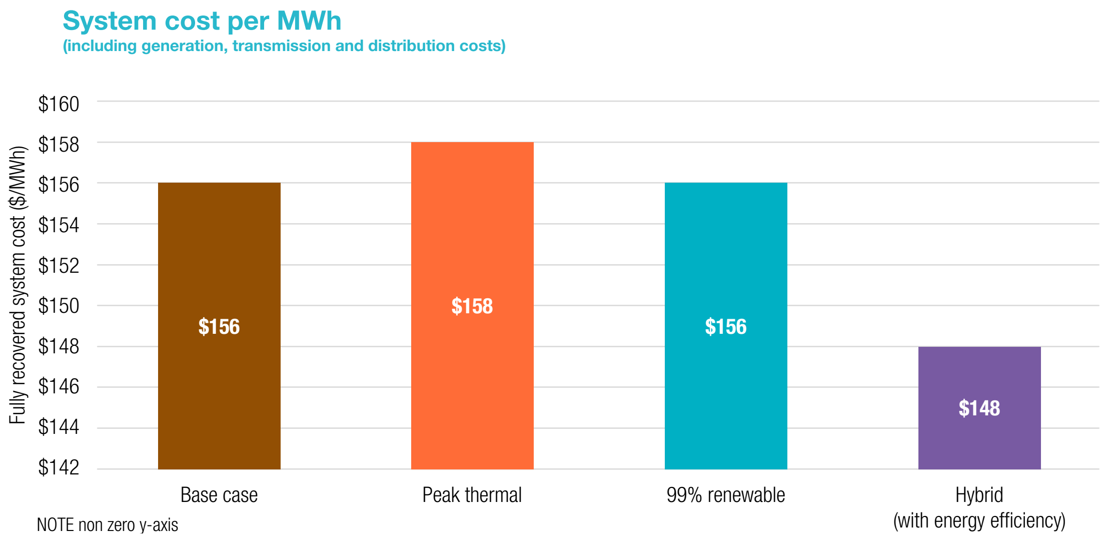


Figure 9: System cost per MWh

9 Discounted at 6% per annum.

3.3.3 Capital cost estimates

For both new renewable generation and energy efficiency investments, capital costs and related finance costs dominate estimates of cost.

Figure 10 below shows the estimated capital cost for each scenario. Detailed capital costs for energy efficiency measures are given in Section 4. The figure shows that as investment in renewable generation capacity declines across the three scenarios, so too does total capital cost.

Capital cost is particularly relevant when considering how to transition quickly, as solutions with higher capital costs may be riskier and more difficult to implement rapidly.

The hybrid scenario represents a low-emissions electricity scenario implemented at a capital cost that is approximately $2 billion less than the next best low-emissions scenario.

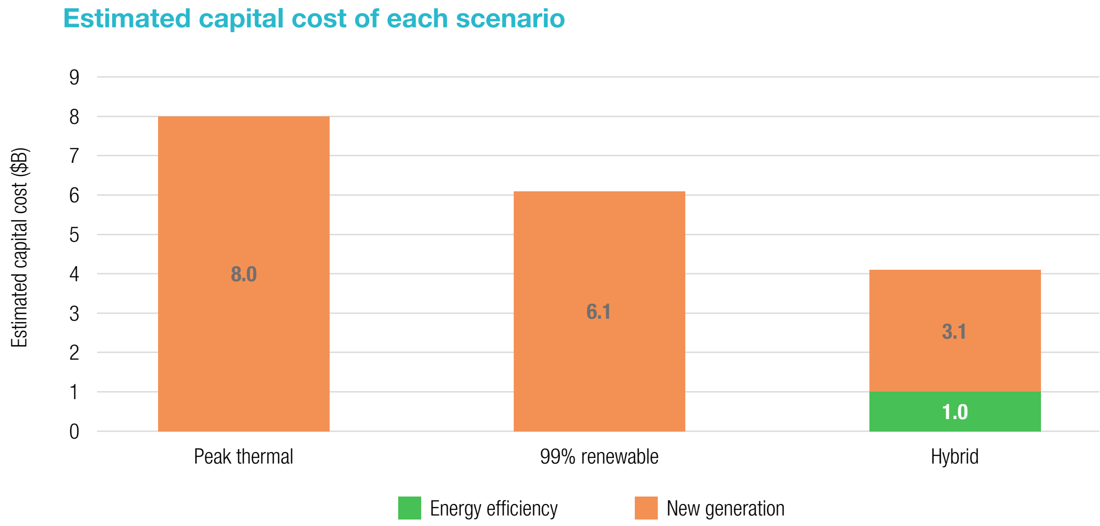


Figure 10: Estimated capital cost for each scenario

3.3.4 Electricity efficiency can lead to cheaper reductions in emissions

If the GHG estimates in Figure 8 are combined with the cost estimates in Figure 9, the GHG abatement cost can be estimated; that is, the effective cost of reducing emissions under the different scenarios, which is shown in Figure 11.

While the two generation only scenarios have GHG abatement costs that are higher than the current carbon price, the hybrid scenario results in emissions reductions and cost reduction, delivering a negative cost per tonne of emissions abatement.

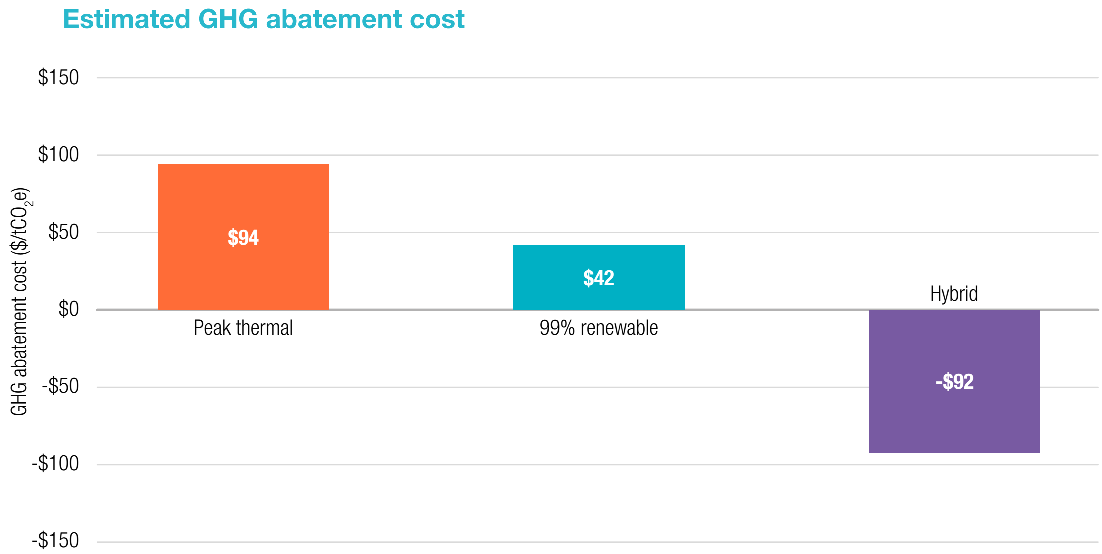


Figure 11: Estimated GHG abatement cost for each scenario relative to the base case

4 The case for intervention

Electrical energy efficiency opportunities identified offer the potential for a large reduction in emissions from thermal generation and a worthwhile contribution to achieving New Zealand's emission reduction targets.

If the current NZETS price does not fully capture the value of emissions reductions, then there is a market failure present when considering the uptake of efficient technologies.

Achieving an emissions reduction benefit requires acceleration of the rate of adoption.

> ***The largest and most attractive opportunities are from adoption by businesses, though there are also emissions reductions available from residential LED use and adoption of heat pumps for space heating.***

All of the opportunities identified are economically attractive for average and high utilisation applications because the energy cost savings over time justify the investment required to install the new technologies. Efficient technologies are being adopted but at a slower rate than would be expected based on financial economics alone. As an example, Figure 12 below shows an estimate of the uptake rate for efficient lighting under current policies out to 2030. While the share of LEDs is expected to grow quite rapidly, there is still around 35% of the lighting stock in 2030 made up of inefficient technologies.

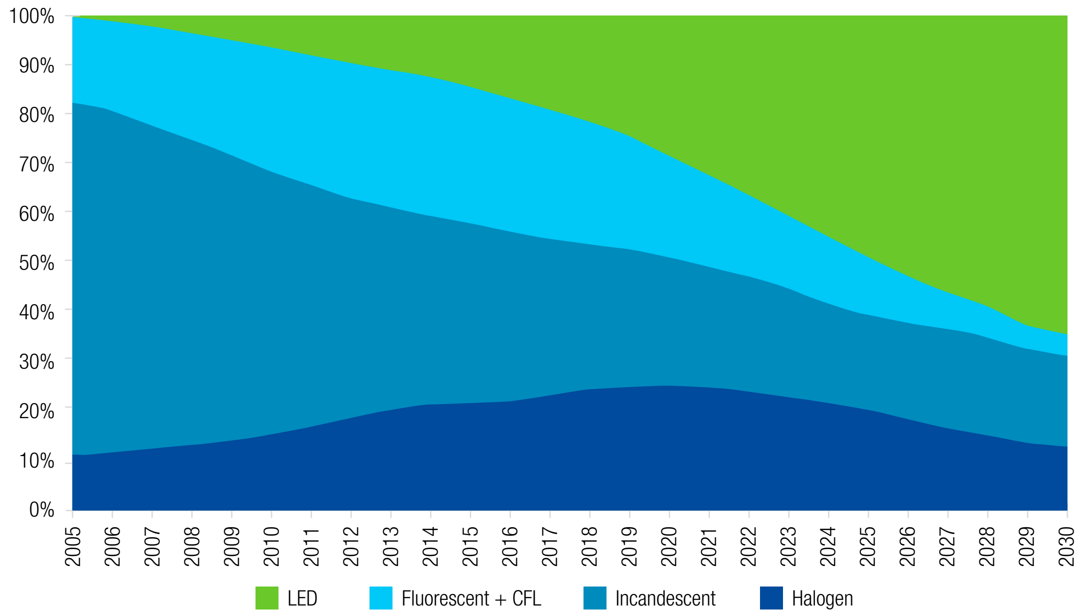


Figure 12: Forecast of BAU NZ residential lighting stock (Source: Beletich, 2019)

Businesses may fail to adopt a financially attractive electricity efficient technology for a range of reasons. In 2018, EECA commissioned research into the energy efficiency decision making of large firms[10]. That research, combined with understanding developed by EECA from other sources provides useful insight into why businesses may not implement energy efficiency opportunities.

Many businesses have plant managers, energy managers or other managers who have responsibility for implementing energy, environment or sustainability measures. It is uncommon for the managers responsible for energy efficiency to be senior managers so they may not be very influential within their organisations.

10 See EECA's report on this here https://www.eeca.govt.nz/news-and-events/news-and-views/pwc-report-finds-process-heat-energy-efficiency-gap/

Capital is usually constrained in businesses, and business leaders often focus on a small number of large opportunities that are very valuable. Small capital projects compete for capital and attention and are often required to have short payback periods, perhaps 12–18 months. Further, implementation of energy efficiency technologies may need to be managed around the need to keep production facilities operational.

Businesses may fail to adopt a financially attractive electricity efficient technology because they do not understand the benefits available or because those benefits, though worthwhile in a return on investment sense, are too small to be prioritised given other demands on management time.

The PwC research found the situation was sometimes different where larger private companies' decision-making was influenced by opportunities to get better environmental outcomes.

Taken as a whole, the findings indicate that greater encouragement of and focus on energy efficiency for economic or environmental reasons would contribute to accelerating uptake of energy efficiency technologies.

Other barriers to uptake include information and awareness, status quo bias and split incentives.

In aggregate, these barriers result in a slower transition to more energy efficient equipment than would be economically optimal.

Photo credit: Piero Lavo

It is beyond the scope of this paper to propose policy mechanisms to accelerate adoption, but interventions that have been used to encourage energy efficiency in other countries and in New Zealand include:

- Providing information about the technology and the value of the opportunity can overcome information barriers. Best practice guides, case studies and benchmarking are all examples of information provision.
- Regulation of energy using products, such as EECA's minimum energy performance standards, prevents the sale of inefficient technologies, resulting in a transition to more efficient technologies over time.
- Financial incentives, such as buy-back schemes, subsidies or low-cost loans can accelerate uptake of new technologies by overcoming capital priority constraints and encouraging replacement before the end of life of the existing technology.
- Emissions pricing is a useful tool to quantify the environmental externality and ensure it is included in decision-making.
- For rented commercial properties, such as office buildings, split incentives are common in that the landlord will bear the higher capital cost of a lighting upgrade, but the tenant will capture the ongoing energy savings. Regulation can be designed to address a landlord-tenant split incentive as evidenced by recent changes to residential rental regulations, such as the Residential Tenancies Act and Healthy Homes Guarantee Act.

5 Conclusion

The climate change challenge is recognised as a serious and increasing threat to the future of civilisation, and governments are developing responses. In New Zealand, the ICCC has been established and asked to develop recommendations to reduce emissions from thermal generation. Much of the dialogue in New Zealand focuses on how to ensure the emission reduction targets can be achieved by combining new technologies and policies, taking account of New Zealand's unique circumstances.

The large-scale opportunities to shift from internal combustion engines to electric vehicles and to replace coal and gas-fired process heat production with electric heat pumps are now well-recognised. Low-cost wind and solar electricity generation will provide the growth in electricity generation required.

EECA believes the opportunity to reduce thermal generation emissions by replacing the use of low efficiency electricity consuming equipment with high efficiency equipment deserves a higher priority in the electricity industry's planning. Sector planning and policy development should include energy efficiency alongside new renewable generation as part of an optimised system.

EECA's analysis demonstrates that energy efficiency initiatives using mature and proven technologies can make a large, near-term, low-cost and low-risk contribution to achieving reductions in carbon dioxide emissions from the energy industry. The opportunity is large enough to remove most of the emissions from thermal generation in New Zealand.

This paper is intended to stimulate and inform discussion about how electricity efficiency can be prioritised and accelerated as a means to achieving New Zealand's emission reduction goals.

6 Appendix 1: Table of electricity efficiency savings

Sector	End Use	Efficient technology	Capacity factor	Capex ($/kW input)	2016 Consumption (TJ) (EEUD)	Savings %	Uptake of efficient technology (TJ)	Capex ($M)	Cumulative capex ($M)	GWh saved	GWh saved cumulative	Levelised cost ($/MWh)
Commercial	Lighting	LED lights	50%	500	8,024	46%	4,256	135	135	1,035	1,035	13.4
Primary	Lighting	LED lights	50%	500	579	46%	307	10	145	75	1,110	13.4
Industrial	Lighting	LED lights	50%	500	1,178	46%	625	20	165	152	1,262	13.4
Commercial	Water heating	Heat pump	50%	3,750	3,256	70%	793	189	353	637	1,899	25.8
Primary	Water heating	Heat pump	50%	3,750	1,837	74%	472	112	466	379	2,278	25.8
Commercial	Space heating	Heat pump	50%	3,750	6,549	51%	1,324	315	780	920	3,197	29.8
Industrial	Space heating	Heat pump	50%	3,750	436	71%	125	30	810	87	3,284	29.8
Commercial	Motive power, stationary	Electric motor with VSD	50%	336	2,731	25%	2,048	44	854	190	3,474	31.3
Industrial	Motive power, stationary	Electric motor with VSD	50%	336	11,130	25%	8,347	178	1,031	773	4,246	31.3
Primary	Motive power, stationary	Electric motor with VSD	50%	336	801	24%	606	13	1,044	54	4,301	32.2
Residential	Lighting	LED lights	8%	500	5,679	47%	1,874	371	1,416	741	5,042	51.6
Residential	Space heating – peripheral	Heat pump	17%	1,718	1,383	59%	292	97	1,512	226	5,268	58.1
Residential	Clothes drying	Clothes dryer	4%	167	1,157	58%	489	65	1,577	186	5,454	62.3
Residential	Space heating	Heat pump	15%	1,718	5,075	37%	682	248	1,825	527	5,981	63.9
Residential	Water heating	Solar hot water cylinder (electric backup)	3%	3,167	12,165	70%	3,270	11,937	13,762	2,370	8,350	811.2

7 Appendix 2: Consumer benefits of efficient electrical technologies

Three cost-effective electricity efficient technologies are included in the hybrid scenario; LED lights, heat pumps for water and space heating, and more efficient electric motors. The main body of the paper discusses the benefits of these from a national, economic perspective.

This appendix provides examples of the consumer benefits arising from each of the technologies.

7.1 Lighting – LED lights

LED lights use an electronic circuit to produce the same amount of light as resistive filament lamps or fluorescent discharge tubes but use much less energy. The efficiency gain is because a much larger proportion of the electricity is turned into light rather than heat. The lamps cost more to purchase but they also last a lot longer, because running cooler means their operating conditions are less stringent.

Transitioning to LED lighting provides running cost benefits for both residential and commercial consumers. For example, a traditional 60W bulb can be replaced by a 12W LED bulb with the same lumen output. Although the average LED bulb costs much more than a traditional bulb, at an average of $5 per bulb, each 12W LED has an estimated running cost saving of $14.19 per year, providing a payback of the bulb cost in less than six months. That calculated saving is based on the bulb being used three hours a day at 27c per kWh[11]. Specific bulbs are used for more or less time, leading to different rates of savings and payback periods.

Larger commercial premises will also see improvements. For example, Ports of Auckland switched floodlights on 46 light towers from Halogen incandescent discharge (HID) to a new type of LED. The number of light fittings required to illuminate the site was reduced by 20%. The Port is estimated to save 66% on lighting costs, more than $270,000 annually, leading to payback within three years. In addition to cost saving, the LEDs are expected to provide up to 23 years of all-night lighting compared to three years for conventional lights, requiring less maintenance at height.[12]

7.2 Water and space heating – heat pumps

Heat pumps are energy efficient and cost-effective for many applications. Heat pumps can be used for water heating and space heating. Section 1.4.2 provides a brief explanation of how heat pumps work.

For consumers who currently use resistive electric water or space heating, there can be large benefits from converting to heat pumps. The shift to heat pumps can be readily observed in the residential market through the rise in installed heat pumps over the past 10–15 years.

Benefits can be substantial for commercial consumers, especially those who use large amounts of hot water or heat large areas.

11 From: https://www.energywise.govt.nz/tools/lighting/
12 https://www.eecabusiness.govt.nz/resources-and-tools/innovative-technology-demonstrations/ports-of-auckland/

Take, for example, a regional hospital that currently uses electrical resistive heating for producing hot water. The total water heating load for the site is 100 kW, with the system running at 60% of capacity over a year. The total electricity consumption of the hot water system is 525,000 kWh per year, with a cost of $105,000 per year (at $0.20/kWh).

Upgrading the hot water system to a heat pump with an average performance factor of 3.0 would require a capital investment of approximately $150,000, with an expected payback period of just over two years. Electricity required is expected to reduce to one-third of the existing consumption, or 175,000 kWh, resulting in operation costs reducing to $35,000. These reductions result in annual energy cost savings of $70,000, just under half of the capital cost required.

7.3 Motive power – electric motor with variable speed drive

Motors used across the commercial, industrial and primary sectors are big energy consumers. There are large gains to be realised through installing higher efficiency motors with variable speed drives (VSD). Advances in motor technology, largely driven by EU efficiency regulations, mean that newer motors use a lot less energy than their older equivalents.

A VSD increases the efficiency of a motor, by allowing it to operate at the ideal speed for the load required, usually without gearboxes or similar devices. That reduces wasted energy and increases process precision.

High efficiency electric motors with VSD are now readily available and can be swapped directly for older, less efficient equivalents.

There are many different industrial applications of electric motors with VSDs, with varying energy and cost savings for consumers.

For example, a medium-sized factory may have 20 electric motors driving various pieces of equipment. The total electric motor load might be 250 kW. With the system running at 40% of capacity over a year, the total electricity consumption is 876,000 kWh per year, at a cost of $122,000 per year (at an industrial electricity price of $0.14/kWh).

Upgrading the old motors to international standards for efficient electric motors compliant motors would increase efficiency by around 6% and installing VSDs in addition would reduce energy consumption during part-load conditions by 60%. The total capital cost for the upgrade is estimated at $84,000. It is expected that there would be a 25% reduction in electricity use, resulting in electricity consumption and running costs reducing to 650,000 kWh and $92,000 per year respectively. The annual energy cost savings of $30,000 result in a payback period for the project of approximately three years.

Additional benefits of higher efficiency motors include improved process precision, lower noise levels and extended equipment life.