Chapter 12:
Long-term scenarios to meet the 2050 target

Contents

Developing different scenarios allows us to see what the future of Aotearoa could look like. These scenarios are based on our modelling and analysis and help us determine the course of action we should embark on.

This chapter outlines four scenarios: Headwinds, Further Technology Change, Further Behaviour Change, and Tailwinds. These scenarios explore the uncertainty around how technologies and social factors could develop and present different ways of achieving our 2050 emissions reductions target.

12.1 Introduction

Under the Climate Change Response Act 2002 (CCRA), emissions budgets must be set with a view to meeting the 2050 targets. In simple terms, the emissions budgets are to act as stepping stones towards the 2050 targets.

To this end, we have developed long-term scenarios to explore and demonstrate how the 2050 target can be met. These scenarios build on our analysis of emissions reduction options *Part 2: Sectoral Challenges and Opportunities* and the path Aotearoa is on under current policies (*Chapter 11: Where are we currently heading?*), using our bottom-up model, ENZ. The analysis presented in this chapter supports our advice on how the emissions budgets and ultimately the 2050 target can be met.

This chapter covers:

- Key findings from the scenario analysis
- What our long-term scenarios are, and how we designed them
- Economy-wide emissions results – including breakdowns by gas and by sector, and post-2050 considerations
- Sector assumptions, results and insights – unpacking the detailed changes happening within each sector
- Cross-sector implications – considering the role of bioenergy, hydrogen and alternative carbon dioxide removals

12.2 Key findings from the scenario analysis

Overall, the four scenarios show a range of potential paths which are compatible with meeting the 2050 target. The following key findings can be drawn from our analysis:

12.2.1 Meeting the net zero long-lived gases target

- Aotearoa can achieve net zero emissions of long-lived gases by the 2040s with significantly lower levels of forest planting than previous studies have suggested.
- By fully deploying existing options to reduce gross long-lived gas emissions by 2050, Aotearoa could subsequently maintain net zero with relatively little additional effort. Aotearoa would also have options for delivering net negative emissions through additional afforestation, further reductions in long-lived gases or other forms of carbon dioxide removals.

12.2.2 Meeting the biogenic methane targets

- For biogenic methane, it is possible to meet the 2030 target and the less ambitious end of the 2050 target range through widespread adoption of low-emissions farm management practices and a combination of waste reduction and diversion from landfills. This is with less land use change to forestry than expected under current policies.
- Developing and widely adopting new technologies to reduce livestock methane emissions would enable Aotearoa to exceed the more ambitious end of the of the 2050 methane target range. Increasing landfill gas capture would also contribute.
- Without new technologies, meeting the more ambitious end of the target range would likely require significantly lower agricultural production from livestock and more land use change.

12.2.3 Transport

- Road transport can be almost completely decarbonised by 2050 by increasing walking, cycling and public transport use, reducing vehicle travel, and by switching to low-emissions vehicles. This would require a rapid increase in electric vehicle (EV) sales so that nearly all vehicles entering the country are electric by 2035.

12.2.4 Energy, industry and buildings

- Displacing fossil fuels with electricity is an essential part of the transition and will require a major expansion of the electricity system. Wind, geothermal and solar power can meet the expected growth in demand from electrifying transport and heat to 2050 while keeping electricity affordable. Despite this growth, the emissions from the generation of electricity can reduce considerably relative to today.
- Low and medium temperature heat in industry and buildings could be decarbonised by 2050 through a switch away from coal, diesel and gas to electricity and biomass. The scale of switching required would require a steady and sustained effort over the 2020s, 2030s, and 2040s.

12.2.5 Forests

- New native forests can be established on steeper, less productive land to provide a long-term carbon sink. With a sustained high rate of planting through to 2050, new native forests could provide a long-term carbon sink of more than 4 $MtCO_2$ per year, helping to offset residual emissions from hard-to-abate sources.
- Exotic production forestry continues to have a role to play in removing carbon dioxide, particularly until other more enduring sources of carbon removals, such as native forestry, can scale up. The deep reductions in gross emissions in our scenarios means the 2050 targets could be met with a significantly smaller area of new exotic forestry than expected occur under current policy settings. Our scenarios feature a total of 570,000–760,000 hectares of new exotic forests planted from 2021 to 2050.

12.2.6 General findings

- Inertia in the system, particularly due to stock turnover dynamics, limits the rate at which emissions can be reduced without escalating costs due to early scrappage of assets. For instance, because only a small fraction of the vehicle fleet turns over each year, even if all vehicles imported were electric immediately the reduction in emissions would take time to accrue.

- Energy efficiency and behaviour changes play an important role in many areas. These can help to cut emissions sooner and in hard-to-abate sectors. They can also contribute cost reductions and co-benefits.

12.3 Creating long-term scenarios

The Intergovernmental Panel on Climate Change (IPCC) defines a scenario as "*a plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g. rates of technological change, prices) and relationships*".[1]

We have developed four scenarios which are defined in terms of the nature and scale of assumed changes in technology and behaviours. These scenarios serve to explore the uncertainty around how technologies and social factors may develop. They help us to test and understand how this may affect the potential for individual mitigation options to reduce emissions and the set of choices and actions required to meet the 2050 target.

Many actions to reduce emissions are common to all scenarios, but differ in terms of the timing or level of uptake. Some actions – particularly emerging technologies – feature in only some scenarios.

The four scenarios are described in Table 12.1 and illustrated in Figure 12.1

Table 12.1 Scenario descriptions

Scenario	Description
Headwinds	In this scenario, there are higher barriers to uptake of both technology and behaviour changes across all sectors. It assumes conservative improvements in technology relative to the Current Policy Reference case. It assumes a modest change from existing behaviour trends among people and businesses.
Further Technology Change	In this scenario, technology changes help to deliver greater emissions reductions. Relative to the Headwinds scenario, technologies could be available sooner, perform better or have lower costs which help drive greater adoption.
Further Behaviour Change	In this scenario, there are fewer barriers to people and businesses changing behaviour and choosing low-emissions options. There are conservative improvements in technology as per the Headwinds scenario, but barriers to adopting existing technologies are lower.
Tailwinds	Our most optimistic scenario, which combines the further technology and further behaviour change assumptions.

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[1] (IPCC, 2018)

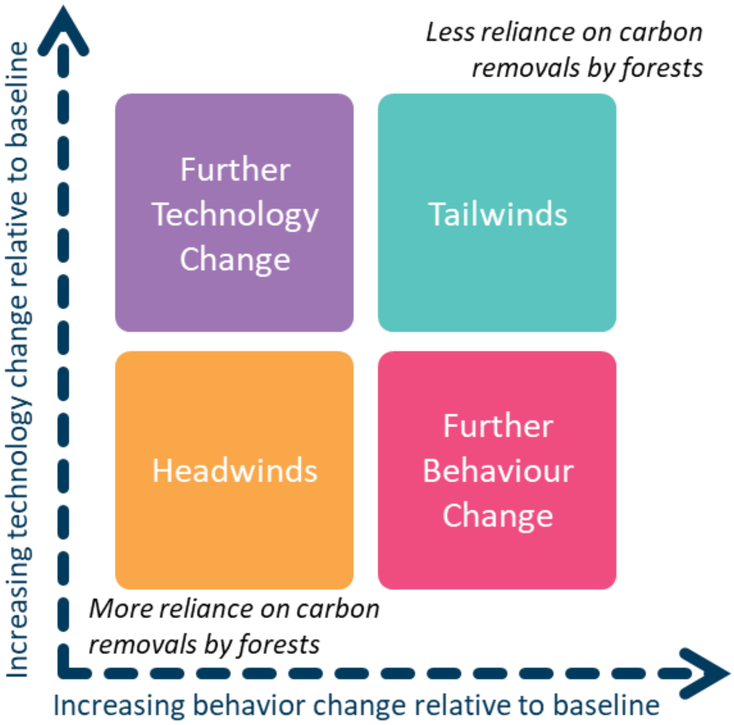

Figure 12.1: Scenario structure

12.3.1 How our scenarios differ from the Current Policy Reference case

As outlined in *Chapter 11: Where are we currently heading?*, current government policies and settings do not put Aotearoa on track to meet the targets in the CCRA. Our Current Policy Reference case indicates that emissions of long-lived greenhouse gases would not reach net zero by 2050 and biogenic methane emissions would only be reduced by around 7% by 2030 and 11% by 2050 compared to 2017 levels.

Our scenarios have been developed to test how the targets in the CCRA could be met. Thus, they are a step change from the world represented by the Current Policy Reference case and represent a fundamentally different future.

12.3.2 Scenario design principles

The scenarios have been developed to examine different ways in which the 2050 targets and the 2030 biogenic methane target can be met. In doing so, we have taken into account the requirements and considerations of the CCRA. We have applied the principles laid out in the Commission's advice *Ināia Tonu Nei* (see *Chapter 5: Recommended emissions budgets*).

Of importance is the long-term perspective to ensure that our path to meeting the 2050 targets does not impose unfair burdens on current and future generations. A path relying excessively on carbon dioxide removals from forestry while delaying the actual decarbonisation of our energy system and economy would fail to ensure this.

Some paths to 2050 could achieve net zero emissions of long-lived greenhouse gases in a way which can be sustained indefinitely with minimal further effort required after 2050. We call this ‘locking in net zero’. Choosing such a path would require two key transformations:

- decarbonising the sources of long-lived gas emissions as far as possible
- building a sustained carbon sink large enough to offset residual emissions without ongoing land use conversion

The scenarios have been developed to reflect these objectives through a focus on reducing gross emissions and establishing new permanent native forests.

12.3.3 How we use modelling and assumptions to build our scenarios

Within the ENZ model, many emissions reduction actions are imposed by assumption (Figure 12.2). We have arrived at assumptions for effectiveness and adoption in each scenario based on an assessment of available evidence, engagement with experts and stakeholders and consultation feedback. These assumptions take into account likely costs and benefits of the actions and judgements about realistically achievable rates of change. These assumptions are set out in the assumptions database published on the Commission’s website.

ENZ simulates changes in some sectors by reference to the abatement cost for particular actions, where actions are taken if their abatement cost is less than a specified emissions value which is imposed on the model. The emissions values, in dollars per tonne of emissions, are incorporated into decision making alongside the other cost factors, such as fuel and capital costs.

The main areas where the emissions values influence decisions in the model are electricity generation, fuel switching in industrial process heat and space and water heating, and the choice of vehicle technology (internal combustion engine (ICE) or electric) for vehicles entering the fleet.

For agriculture, forestry and waste, explicit emissions values are not used in ENZ. In the scenario design, the level of exotic afforestation is selected to ensure there is sufficient removal of carbon dioxide so that the net zero component of the 2050 targets is met.

The emissions values used in the scenarios have been set at a level to achieve deep decarbonisation of the areas it applies to – particularly process heat – by 2050. The path of emissions values is shown in Figure 12.3. We constructed this by:

1. Identifying the value needed in 2050 (around $250)
2. Discounting this back using a 3% discount rate to a value in 2030 (~$140)
3. Drawing a straight line to this from estimated New Zealand Emissions Trading Scheme (NZ ETS) prices in 2020 ($30).

This is similar to the approach the UK Government uses to set ‘carbon values’ for policy appraisal.

The emissions values used in the scenarios should not be directly interpreted as emissions prices which would be observed in the NZ ETS. The actions selected under the scenarios could be encouraged through a mix of pricing and other policies, which could mean that the market price in the NZ ETS would not necessarily equal the emissions values needed to meet the 2050 targets.

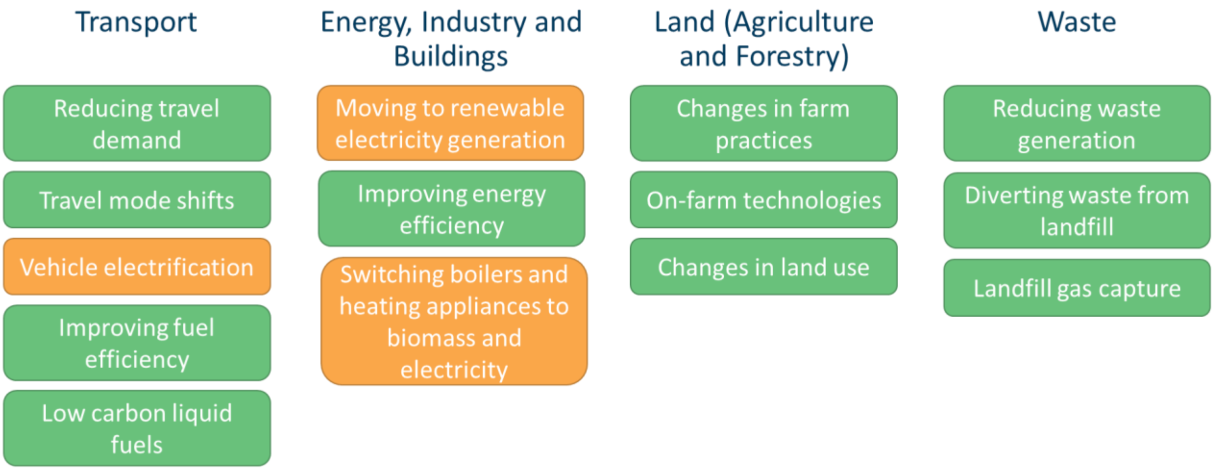

Figure 12.2: Key emissions reduction options represented in the ENZ model. For the options in orange boxes, the model simulates their uptake in each year based on costs, available resources, and other factors. For the options in green boxes, we specify their uptake

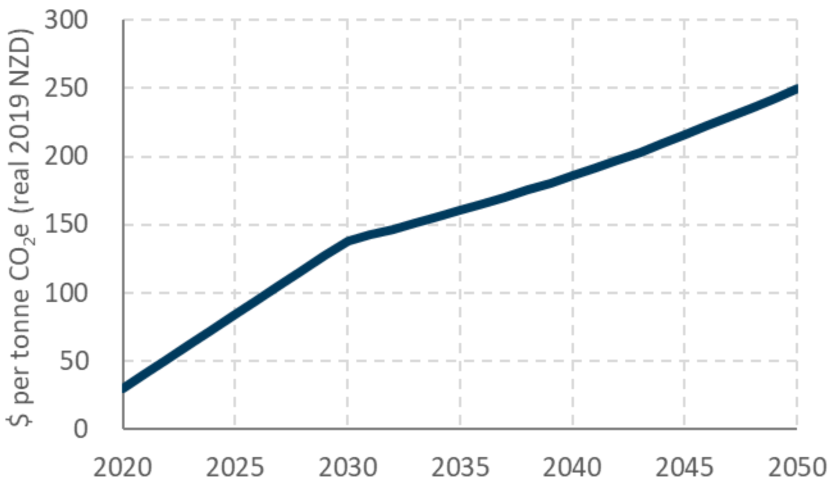

Figure 12.3: Emissions values for the energy and transport sectors applied in the scenarios.

Source: Commission analysis

12.4 Economy-wide emissions results

12.4.1 Long-lived gases

Figure 12.4 shows the trajectories of net long-lived gas emissions in the four scenarios and the Current Policy Reference case. The year that net zero is first reached ranges from 2040 in Tailwinds to 2048 in Headwinds.

The trajectories show relatively little difference until the late 2020s but diverge significantly thereafter. This in part reflects time lags between when some actions are taken (for example, scaling up EV sales) and the resulting emissions reductions. The results also illustrate that the behaviour changes have a more significant impact early on, while the assumed technology changes would make a greater impact in the long run.

Gross emissions of long-lived greenhouse gases in 2050 range from 12.0 $MtCO_2e$ in the Tailwinds scenario to 20.3 $MtCO_2e$ in Headwinds, compared with 48.6 $MtCO_2e$ in 2019 (Figure 12.5). The Further Technology Change and Tailwinds scenarios reach net zero emissions earlier and with less reliance on carbon removals.

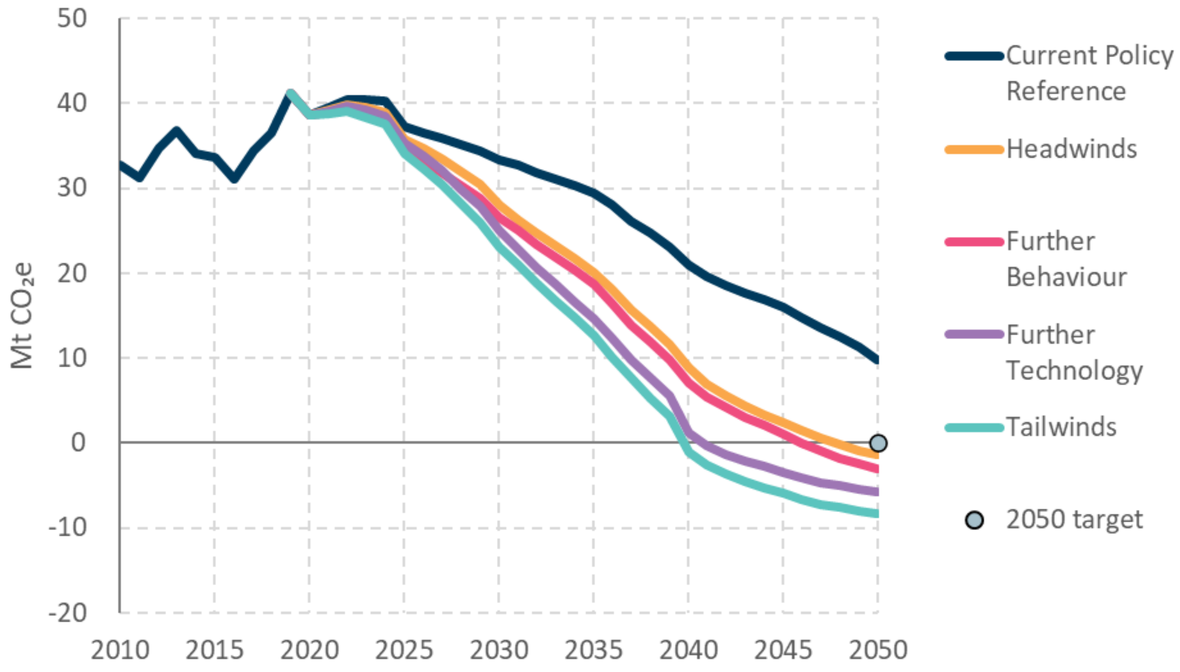

Figure 12.4: Net long-lived greenhouse gas emissions from 2010-2050

Source: Commission analysis

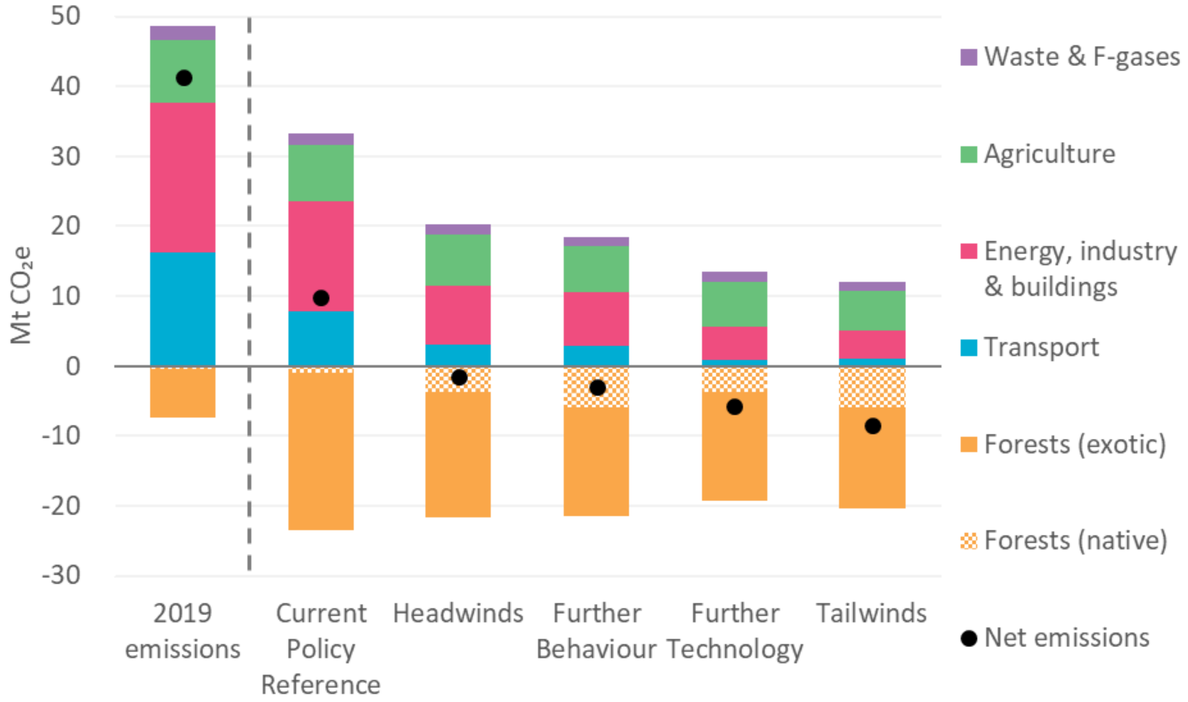

Figure 12.5: Long-lived greenhouse gas emissions by sector in 2050 compared with 2019. Note long-lived greenhouse gases from agriculture are nitrous oxide and carbon dioxide.

Source: Commission analysis

12.4.2 Biogenic methane

The scenarios all meet the 2030 and 2050 targets for biogenic methane but display a wide range in their emissions paths (Figure 12.6). This mainly reflects the different assumptions around the availability, effectiveness and uptake of technologies to reduce enteric methane emissions from ruminant livestock.

The Headwinds scenario indicates that it is possible to meet the less ambitious end of the 2050 target range with very limited contribution from such technologies and with less land-use change to exotic forestry than in the Current Policy Reference case. The Further Behaviour Change scenario achieves a 31% reduction from 2017 levels, shows the significant additional emissions reductions possible through the combination of improved farm practices, a greater shift from livestock agriculture to horticulture, and greater diversion of organic waste from landfills.

The Further Technology Change and Tailwinds scenarios indicate that it could be possible to meet or overachieve the more ambitious end of the 2050 target range, should the optimistic assumptions on methane-reducing technologies eventuate.

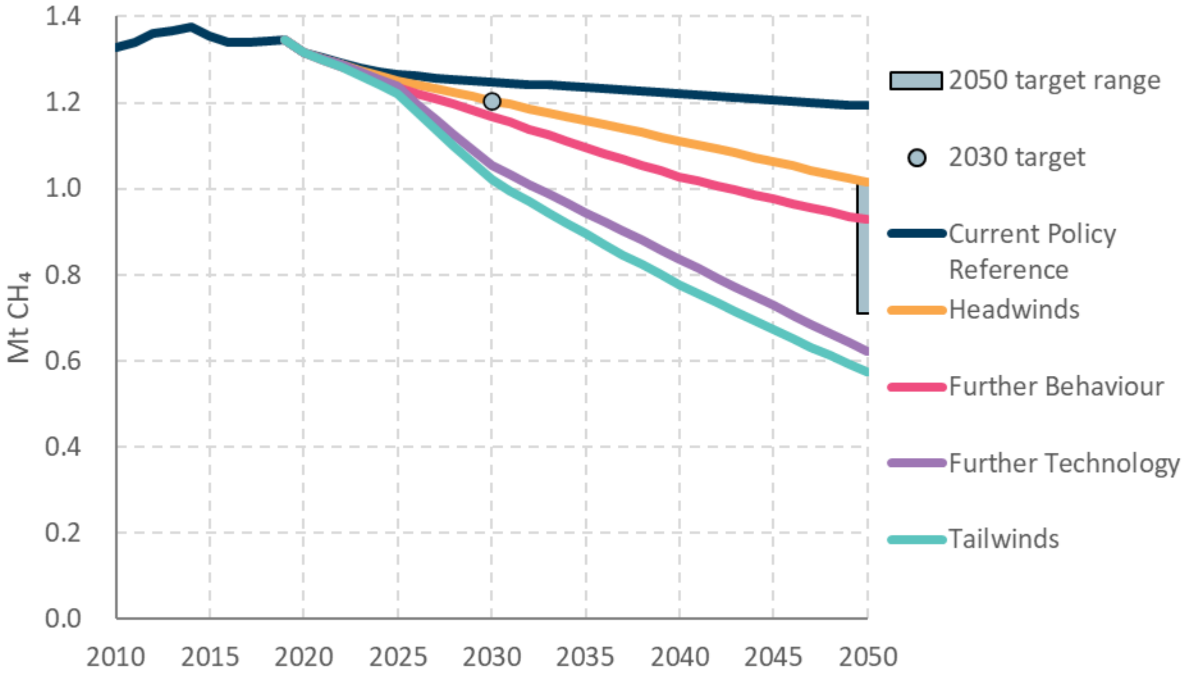

Figure 12.6: Biogenic methane emissions from 2010-2050

Source: Commission analysis

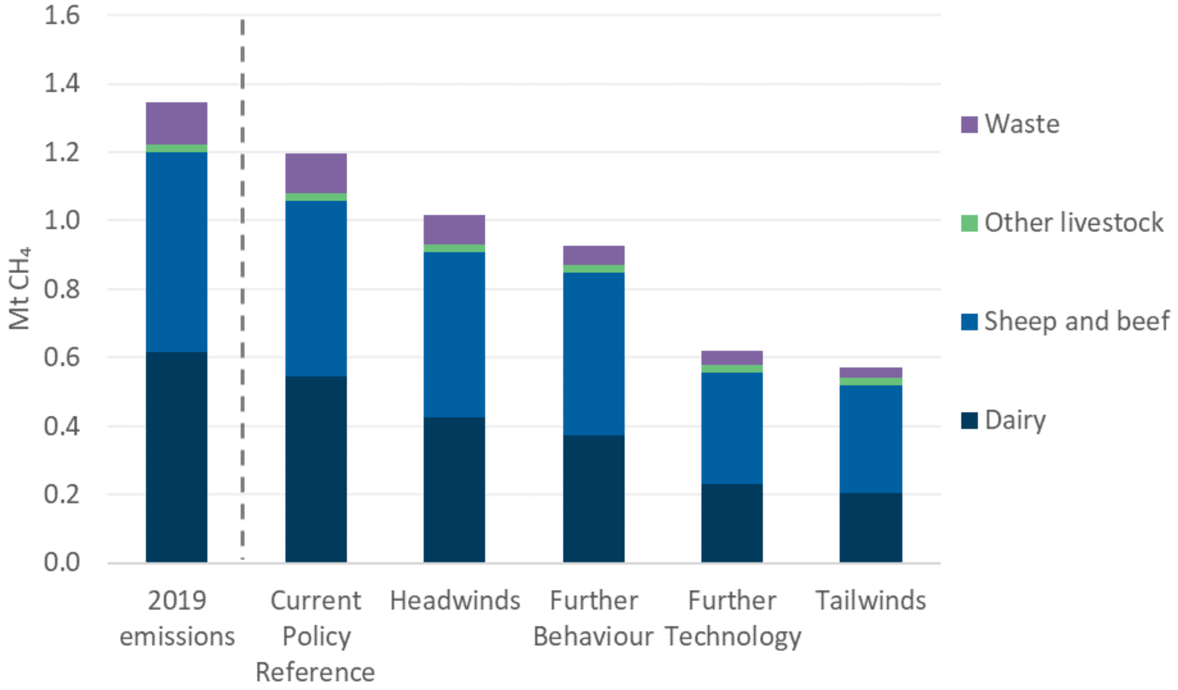

Figure 12.7: Biogenic methane emissions by sector in 2050 compared with 2018

Source: Commission analysis

Table 12.2: Summary emissions results for the scenarios

		Headwinds	Further Behaviour	Further Technology	Tailwinds
Long-lived gases					
Year net zero first reached		2048	2047	2041	2040
Emissions in 2050 (MtCO$_2$e)	CO$_2$ (gross)	11.8	10.9	6.1	5.4
	CO$_2$ (net)	-9.9	-10.6	-13.1	-14.9
	N$_2$O	6.8	6.2	5.8	5.3
	F-gases	1.2	1.0	1.2	1.0
	CH$_4$ (non-biogenic)	0.5	0.4	0.4	0.3
	Total (gross)	20.3	18.4	13.5	12.0
	Total (net)	-1.4	-3.0	-5.8	-8.4
Change in emissions, 2019 to 2030 (%)	CO$_2$ (gross)	-20%	-23%	-30%	-32%
	CO$_2$ (net)	-39%	-43%	-49%	-54%
	N$_2$O	-9%	-11%	-11%	-14%
	F-gases	-20%	-33%	-20%	-33%
	CH$_4$ (non-biogenic)	-23%	-26%	-27%	-29%
	Total (gross)	-18%	-22%	-26%	-29%
	Total (net)	-32%	-36%	-39%	-44%
Change in emissions, 2019 to 2050 (%)	CO$_2$ (gross)	-68%	-71%	-84%	-86%
	CO$_2$ (net)	-133%	-135%	-144%	-150%
	N$_2$O	-19%	-26%	-31%	-37%
	F-gases	-36%	-47%	-36%	-47%
	CH$_4$ (non-biogenic)	-50%	-58%	-61%	-67%
	Total (gross)	-58%	-62%	-72%	-75%
	Total (net)	-103%	-107%	-114%	-120%
Per capita emissions in 2050 (tCO$_2$e per person)	CO$_2$ (gross)	1.9	1.7	1.0	0.9
	Total (gross)	3.3	3.0	2.2	1.9
	Total (net)	-0.2	-0.5	-0.9	-1.3
Cumulative emissions, 2021-2050 (MtCO$_2$e)	CO$_2$ (gross)	740	711	598	580
	Total (gross)	1026	978	868	833
	Total (net)	558	516	435	377
Biogenic methane					
Emissions in 2050 (MtCH$_4$)		1.02	0.93	0.62	0.57
Change in emissions, 2017 to 2030 (%)		-10%	-13%	-21%	-24%
Change in emissions, 2017 to 2050		-24%	-31%	-54%	-57%
Per capita emissions in 2050 (tCH$_4$ per person)		0.16	0.15	0.10	0.09

Source: Commission analysis

12.4.3 Emissions reductions by sector

Figure 12.8 shows changes in emissions across sectors from 2019 to 2050 in the Headwinds and Tailwinds scenarios, alongside the Current Policy Reference case. A broad summary of the major drivers of change in each sector follows.

Figure 12.8: Change in emissions from 2019-2050 by sector for the Headwinds and Tailwinds scenarios. The top chart shows the percentage change and the bottom shows the absolute change.

Source: Commission analysis

Transport

Emissions reductions are slow to begin, especially in the Headwinds scenario, but gather pace as EV sales reach critical mass and then steadily take over the fleet. Reduced travel demand and shifting passenger and freight transport to lower-emissions modes help to deliver and sustain earlier emissions cuts.

Road transport, as well as rail and domestic shipping, are almost fully decarbonised by 2050 in the Tailwinds scenario. In Headwinds, slower uptake of EVs is countered to an extent by improvements in fuel efficiency of ICE vehicles, including through higher uptake of conventional hybrids.

Domestic aviation emissions fall slightly in the Headwinds scenario through improved efficiency, while in the Tailwinds scenario these are heavily reduced by 2050 through electrification of shorter trips and use of low-carbon liquid fuels.

Energy, Industry and Buildings

The Current Policy Reference case already sees reductions over time in energy and industry emissions due to new renewable generation displacing fossil fuel generation and the assumed closure of aluminium and methanol plants (*Chapter 11: Where are we currently headed?*). Further emissions reductions in our scenarios come from:

- Fuel switching and further efficiency improvements in food processing and other medium temperature process heat uses.
- Electrification of off-road vehicles and machinery, which is assumed to occur at a similar pace to electrification of heavy trucks.
- Upstream and distribution emissions reductions in fossil fuel production due to reduced consumption.

Tailwinds also sees the steel plant converting to emissions-free production using green hydrogen around 2040, the use of low-carbon liquid fuels and carbon capture and storage for geothermal electricity generation.

Tailwinds sees building heat almost fully decarbonised by 2050 through switching away from fossil gas. In Headwinds a slower transition sees nearly half of current fossil gas use remaining.

Agriculture

Changes in emissions follow a broadly similar pattern across the Headwinds and Tailwinds scenarios but with much deeper reductions in Tailwinds through its combination of widespread adoption of new technologies, inhibitors, improved farm management and some land-use change from dairy into horticulture or other low-emissions uses. The widespread adoption of methane inhibitors and vaccines in the Tailwinds scenario has a particularly large impact. Land-use change to exotic forestry – while significantly reduced compared with the Current Policy Reference case – still plays a significant role, especially in Headwinds.

Waste

Methane emissions from waste are reduced across all scenarios with the Current Policy Reference seeing the smallest reductions due to no changes from the status quo on organic waste generation, waste recovery and landfill gas capture. The Headwinds scenario makes conservative assumptions around waste reduction and recovery and landfill gas capture. The Tailwinds scenario assumes sharp increases in organic waste recovery and landfill gas capture. Nitrous oxide emissions increase across all scenarios, but have larger rates of increases in the Headwinds and Tailwinds scenario due to more waste going to composting and anaerobic digestion.

F-gases

Emissions reductions beyond the Current Policy Reference case come from increased recovery and destruction of hydrofluorocarbons (HFCs) in end-of-life equipment.

12.4.4 Looking beyond 2050

The scenarios indicate that it is possible to reach a point where net zero could be sustained with little additional effort beyond 2050.

Figure 12.9 demonstrates this with the Tailwinds scenario, which would come closest to achieving this goal. By 2050, the transport, energy and industry sectors would be largely decarbonised, with carbon dioxide emissions reduced almost 90% from 2019. Meanwhile, 0.7 million hectares of new native forest would lead to a long-term carbon sink of over 5 $MtCO_2$ per year, similar in size to the residual nitrous oxide emissions.

After 2050, emissions would still bounce back above net zero to around 4 $MtCO_2e$ in 2075 without new mitigation actions or further afforestation (solid black line).[2] Further options exist to reduce the residual emissions after 2050 (such as hydrogen for high-temperature heat) and to pursue other sources of carbon dioxide removals, but these have not been modelled here. Alternatively, continued planting of 5,000 hectares per year of exotic forest would be sufficient on its own to sustain net zero emissions (dotted black line).

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[2] Carbon dioxide emissions shrink slightly further after 2050 in the model, mainly from continued electrification of off-road vehicles with stock turnover.

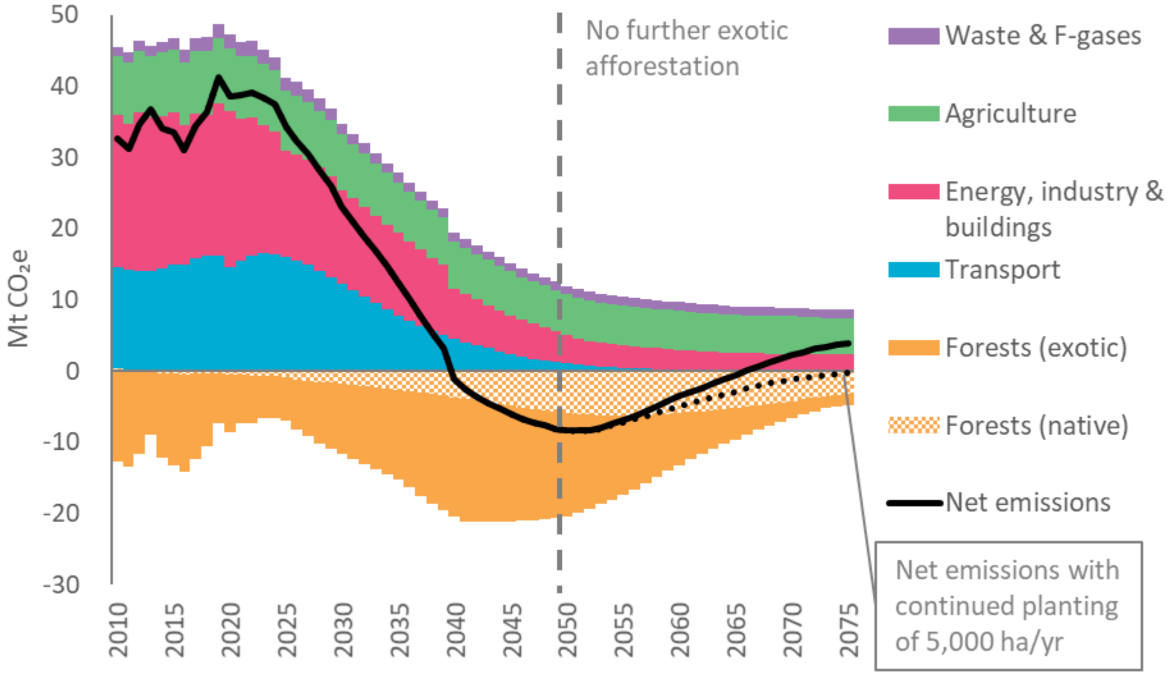

Figure 12.9: Long-lived greenhouse gas emissions to 2075 in the Tailwinds scenario, with and without further afforestation after 2050

Source: Commission analysis

The Headwinds scenario would leave more work to be done after 2050, due to its slower reduction in gross emissions and slower rate of native afforestation. By implementing additional mitigations which occur in Tailwinds (such as biofuels and zero-emissions steel production), Headwinds could arrive at a similar point sometime after 2050. Alternatively, net zero could be sustained in this scenario without additional mitigation actions, but with higher continued afforestation of around 15,000 hectares of exotic forest per year.

12.5 Sector assumptions, results and insights

12.5.1 Total primary energy use

The scenarios show that for Aotearoa to achieve a low-emissions future a transition is required in primary energy supply away from fossil fuels and towards renewable sources. Electricity generated from wind, solar and geothermal, along with increasing use of biomass as a combustible fuel displace much of the current energy supply from oil, gas and coal in all four scenarios.

This transition, shown in Figure 12.10 for the Tailwinds scenario, takes Aotearoa to a position where total primary energy source is between 80-90% from renewable sources by 2050.

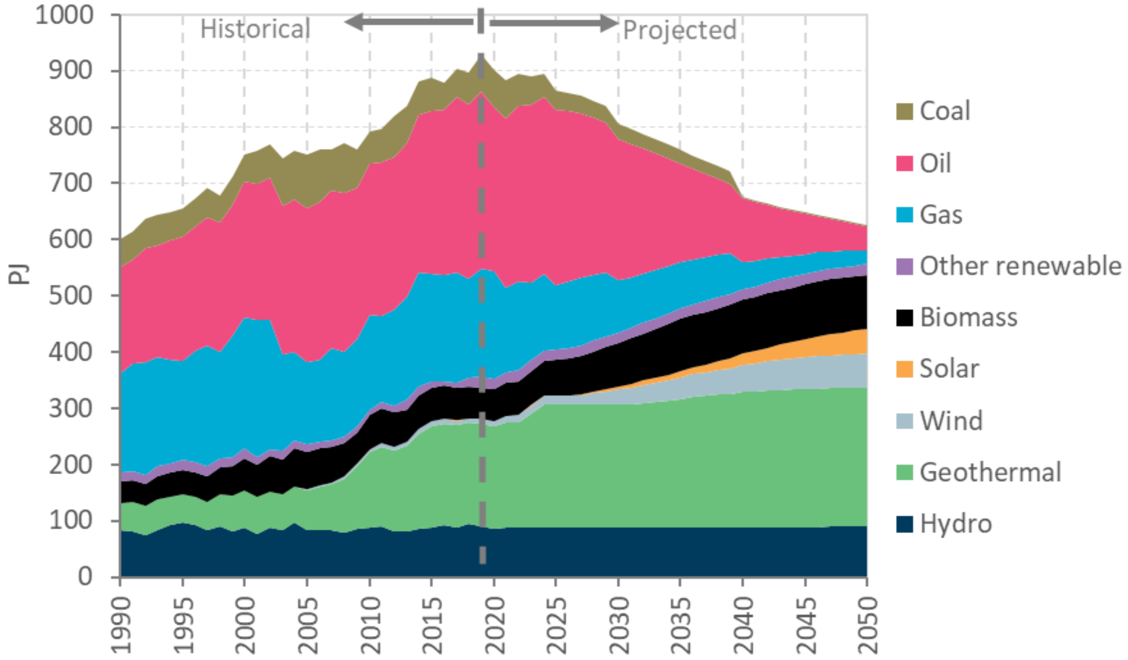

Figure 12.10: Total primary energy for the Tailwinds scenario

Source: Commission analysis

Improvements in energy efficiency mean that the total energy required in 2050 is around 30% less than 2019. This reduction is largely due to the replacement of ICEs with electric motors.

Table 12.3: Renewable percentage of total primary energy supply

	2019	2035	2050
Current Policy Reference	38%	46%	58%
Headwinds	38%	53%	78%
Further Behaviour	38%	54%	79%
Further Technology	38%	62%	88%
Tailwinds	38%	63%	89%

The percentage of renewable energy can be calculated either on the supply side, as a share of total primary supply, or on the consumption side as a share of total energy consumed. This can make a substantial difference to the figure in a given year. It is therefore an important metric to consider, for example, in setting targets. Renewable energy as a share of total primary energy supply is the measure in the *Energy in New Zealand* publication and currently around 40% as shown in the table above. One disadvantage of this measure is that geothermal energy used for electricity generation distorts the renewable totals as it has a very low conversion efficiency to electricity. This means the measure is particularly sensitive to the timing of future geothermal builds. It also includes non-energy usage of fossil fuels – such as the fossil gas which becomes embedded in methanol.

The renewable energy share in total final consumption is the percentage of final consumption of energy that is derived from renewable resources. Some international targets on renewables, such as those in the EU Directive and the UN Sustainable Development Goals, have been set by looking at final consumption shares. Table 12.4 below frames the scenario energy transition in terms of renewable energy as a share of total final consumption.

Table 12.4 Renewable energy as a share of total final consumption

	2019	2035	2050
Current Policy Reference	29%	33%	46%
Headwinds	29%	41%	74%
Further Behaviour	29%	43%	76%
Further Technology	29%	53%	87%
Tailwinds	29%	54%	89%

12.5.2 Transport

Transport emissions have been a major source of the growth in emissions since 1990 in Aotearoa and have continued to grow rapidly in recent years. Our scenarios see a dramatic reversal of this as shown in Figure 12.11. The Tailwinds scenarios sees steep emissions reductions beginning almost immediately, with emissions falling to around 1 $MtCO_2e$ by 2050. In Headwinds, the transition is slower to get underway, with emissions reductions lagging Tailwinds by around five years and around 3 $MtCO_2e$ remaining in 2050. The other two scenarios illustrate the impact from further technology and behaviour changes over time.[3]

Overall, the reduction in transport emissions primarily comes from the electrification of road transport – both light and heavy vehicles – which currently makes up the largest share of transport emissions. Reduced travel demand and reducing the use of light vehicles by shifting more travel to active and public modes also reduces emissions, with the most impact early on. The Further Technology and Tailwinds scenarios feature some electrification of air travel as well as the use of low-carbon fuels to target transport types which are difficult to electrify.

Figure 12.12 shows the total domestic transport emissions in 2050 under four scenarios compared to 2019.

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[3] Emissions in the Further Technology Change scenario are seen to be lower than the Tailwinds scenario in the later years, despite higher levels of vehicle travel. This happens because of the way vehicle fleet dynamics are modelled in ENZ: less light vehicle travel leads to a reduction in the size of the light vehicle fleet, which then leads to a reduction in the number of vehicles exiting and entering the fleet, therefore a slower turnover. This may be unrealistic. However, a shrinking difference in the emissions impact of transport behaviour change as the vehicle fleet is progressively electrified is to be expected.

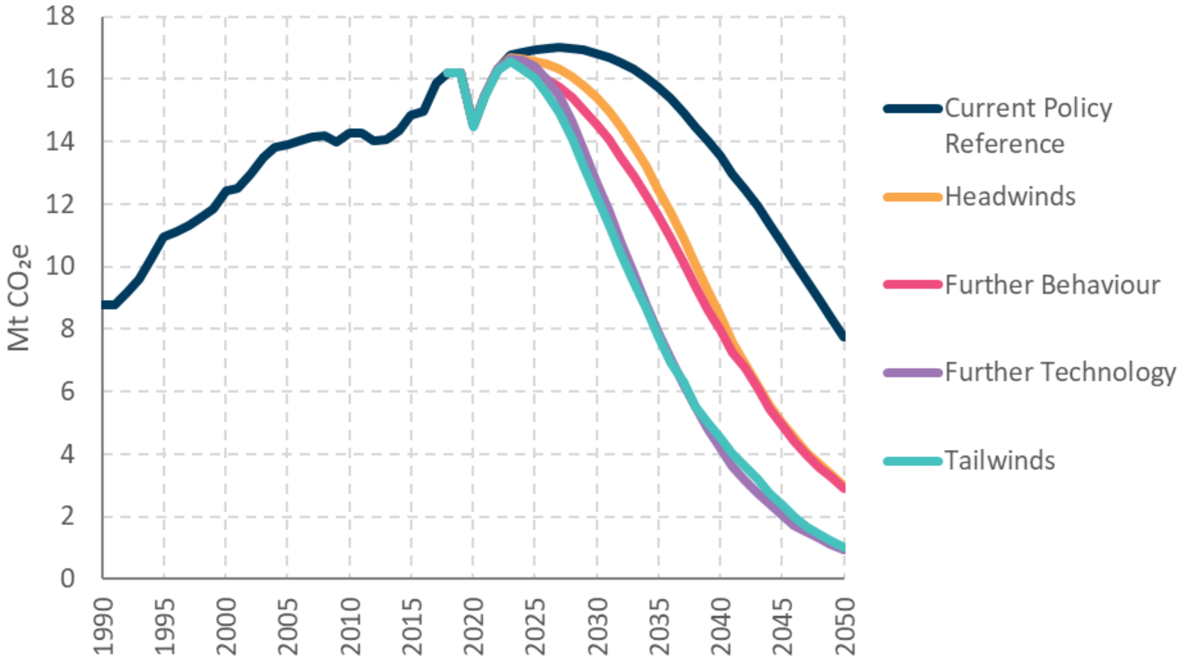

Figure 12.11: Total transport emissions by scenario

Source: Commission analysis

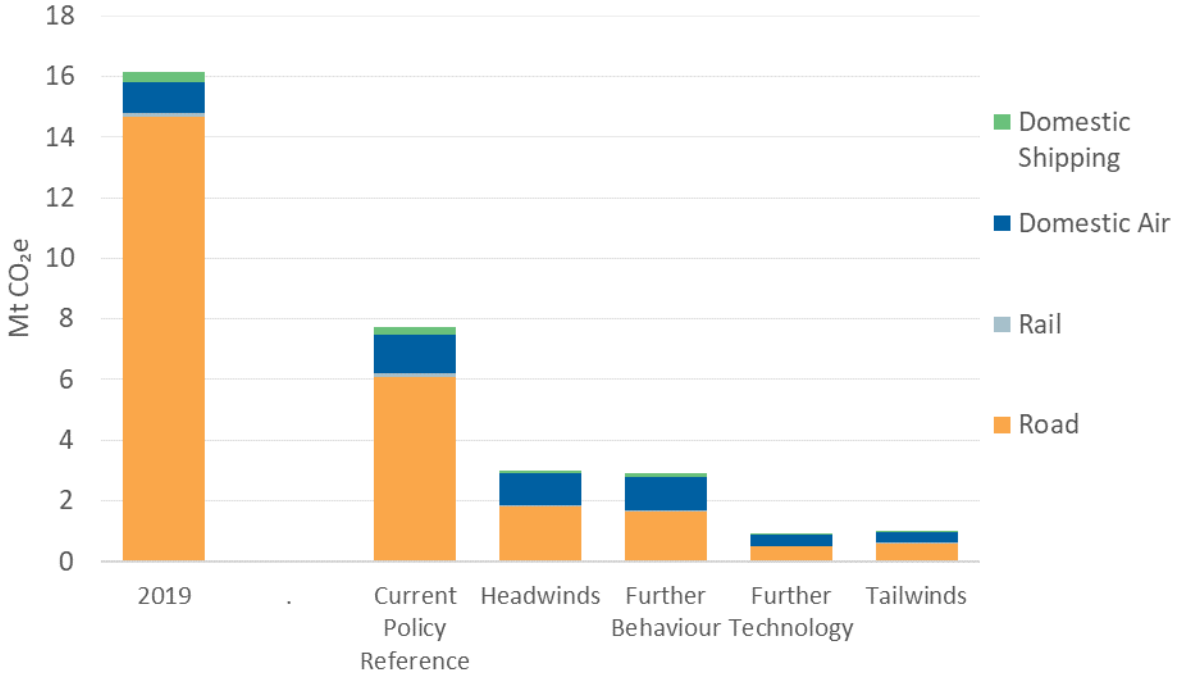

Figure 12.12: Transport emissions in 2050 compared to 2019

Source: Commission analysis

Light vehicles (cars, SUVs, vans and utes)

Reducing the vehicle kilometres travelled by light vehicles

Figure 12.13 shows the total vehicle-kilometres travelled by light vehicles in the scenarios compared with the Current Policy Reference case. This includes commercial as well as household travel. The figure shows the impact that behavioural changes, including reduced need for travel and change in transport mode, can have on projected vehicle-kilometres.

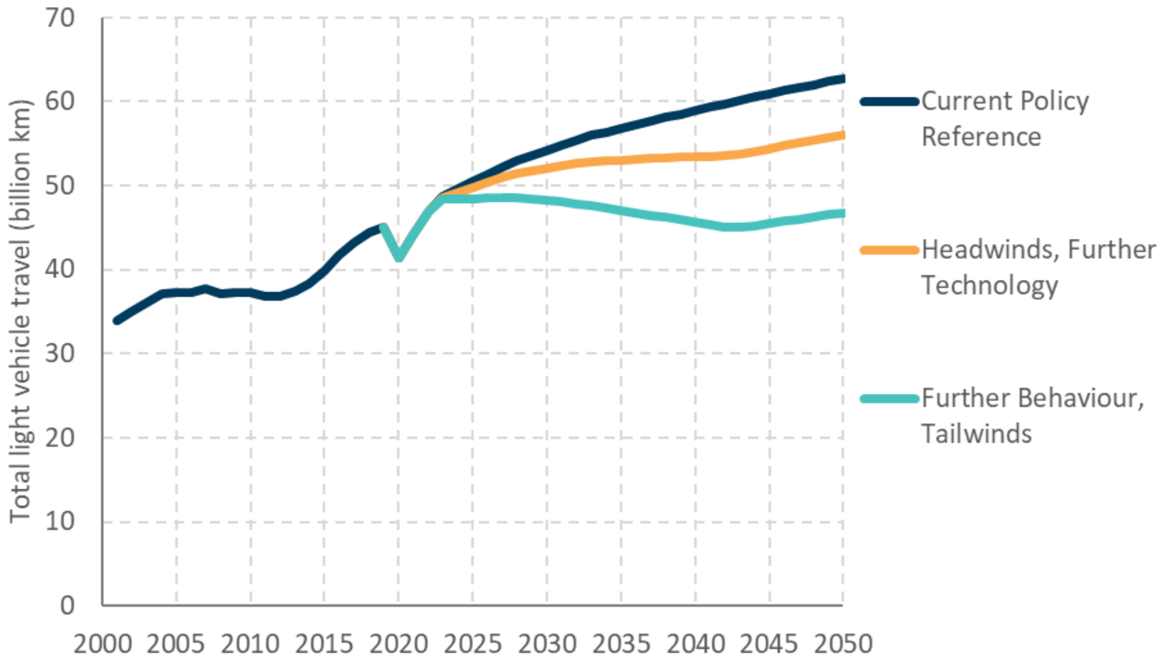

Figure 12.13: Vehicle-kilometres travelled by light vehicles

Source: Commission analysis

In our Tailwinds scenario we estimate that 30% of labour force can work from home and that by 2030, this 30% works from home an average of one day a week more than currently. This reduces travel to work by 6% compared to the Current Policy Reference case; by 2040, this becomes 12%. We also assume that the average trip is shortened due to compact urban design.

Further reductions in light vehicle kilometres travelled come from increased walking, cycling and public transport use, with proportionate reductions in vehicle driver and vehicle passenger travel. For example, in the Tailwinds and Further Behaviour scenario, after accounting for reduced total travel demand:

- By 2030, cycling is up 250% nationally compared to 2019. By 2040 cycling has increased ten-fold
- By 2030, public transport use is up 180% nationally compared to 2019. By 2040 public transport use is up more than 300%

Despite these large shifts, light vehicles continue to dominate total passenger kilometres travelled in all scenarios, as shown in Figure 12.14 below. Total passenger kilometres for light vehicles includes private car use as both drivers and passengers, motorcycles, and taxis and shared vehicle options such as car-share. Walking and cycling could also incorporate new micro-mobility options such as e-scooters.

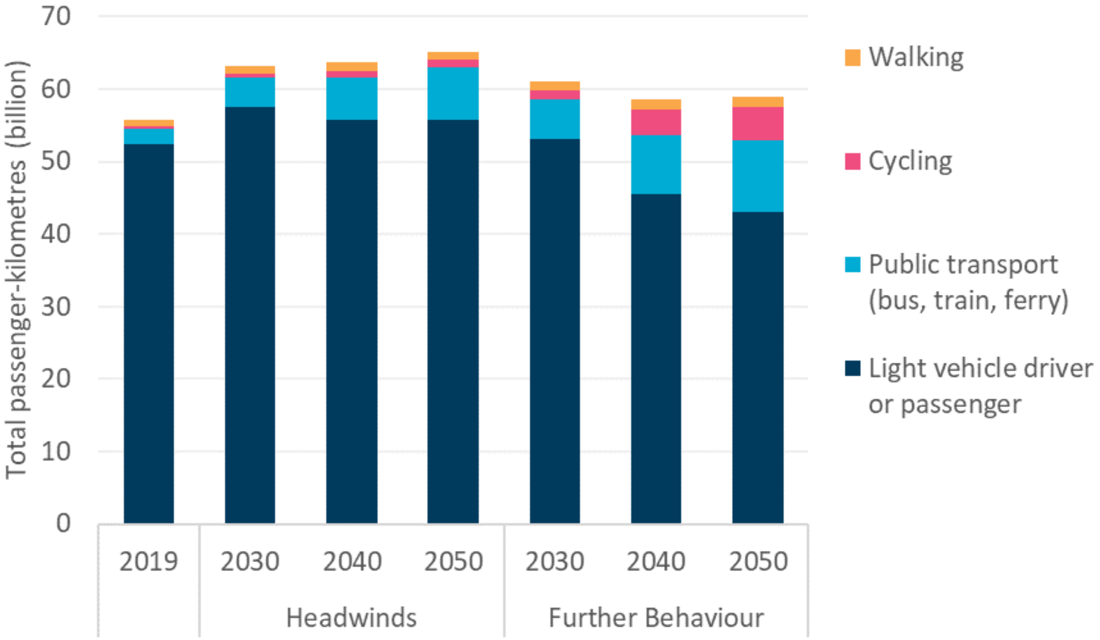

Figure 12.14: Total national passenger kilometres travelled by different modes in the Headwinds and Further Behaviour Change scenarios compared to 2019. Light vehicle driver and passenger includes taxis and shared vehicles and motorbikes.

Source: Commission analysis

Uptake of electric vehicles

In the modelled scenarios, newly registered light vehicles move to 100% electric well before 2050. The Tailwinds and Further Technology scenarios reach this point by around 2030, whereas in the Headwinds and Further Behaviour it does not occur until around 2040. Here the term 'newly registered' includes both vehicles imported new and vehicles imported used.

The top chart in Figure 12.15 shows the percentage of newly registered light vehicles that are electric for the scenarios and the Current Policy Reference case. The share of EVs in the total vehicle fleet lags behind these uptakes due to the slow turnover of the fleet in Aotearoa. The bottom chart in Figure 12.15 shows the total percentage of light vehicles in the fleet that are electric by scenario. In none of the scenarios is a 100% electric fleet achieved by 2050, though the Tailwinds and Further Technology scenarios get very close.[4] However, because newer vehicles are driven more than older vehicles, the share of vehicle-kilometres travelled is very close to 100%.

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[4] The modelled share of EVs in the fleet is higher in the scenarios with less behaviour change for the same reason as described in footnote 3 above. Essentially, the ENZ model assumes that fewer vehicles are newly registered and the turnover of the fleet slows slightly.

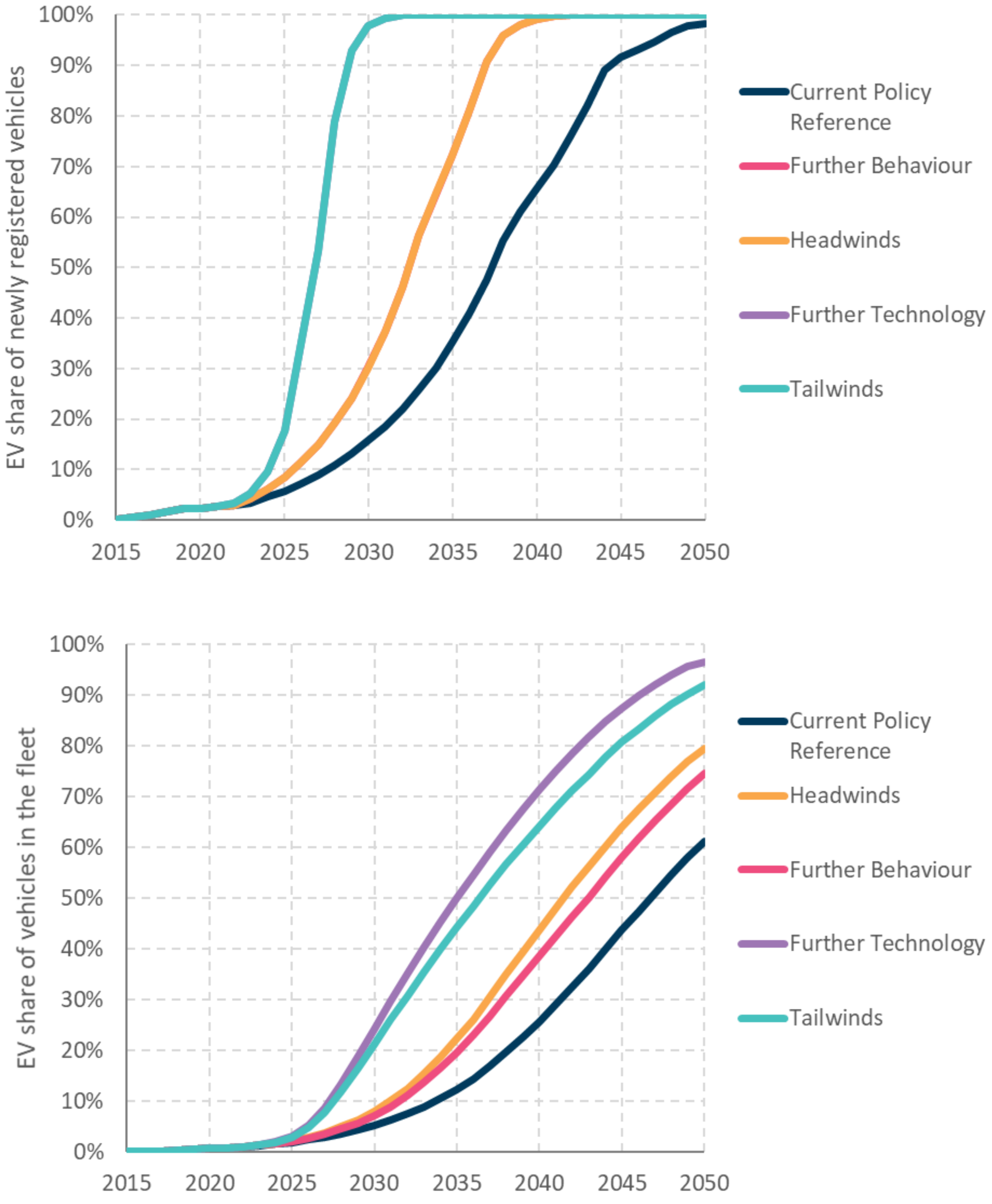

Figure 12.15: Percentage of newly registered light passenger vehicles that are electric by scenario (top) and percentage of total light passenger vehicle fleet that are electric (bottom). In the top chart, Further Behaviour and Further Technology are almost identical to Headwinds and Tailwinds, respectively.

Source: Commission analysis

Box 12.1: Modelling electric vehicle uptake

EVs are currently more expensive than ICE vehicles, but their costs are projected to reduce through a combination of falling battery costs and other manufacturing cost reductions as automakers retool their production lines and scale up EV production. The cost of lithium ion batteries has already fallen 88% from 2010 to 2020 and is projected to more than halve again by 2030.[5]

ENZ models the uptake of EVs over time by assuming that vehicle buyers choose between conventional vehicles and EVs based on the total cost of ownership. For all scenarios and all vehicle types, we have used an assumed five-year ownership period. Our modelling assumes an initial purchaser bias against EVs. It also applies different uptake constraints for each scenario to proxy various barriers that could impede the cost-effective uptake of EVs. More information is provided in Appendix 1 of *Chapter 11: Where are we currently heading?,* and detailed assumptions are provided in the assumptions database published on the Commission's website.

Figure 12.16 shows the different components of the total cost of ownership for a new car purchase in 2021, 2025 and 2030. In addition to the falling capital costs, the operating cost for the battery electric car also falls. This is because we assume a shift to cost-reflective electricity pricing, with vehicles primarily charged overnight at a low rate.

Figure 12.17 shows the same information for a medium truck (which we define as less than 30 tonnes gross vehicle mass).

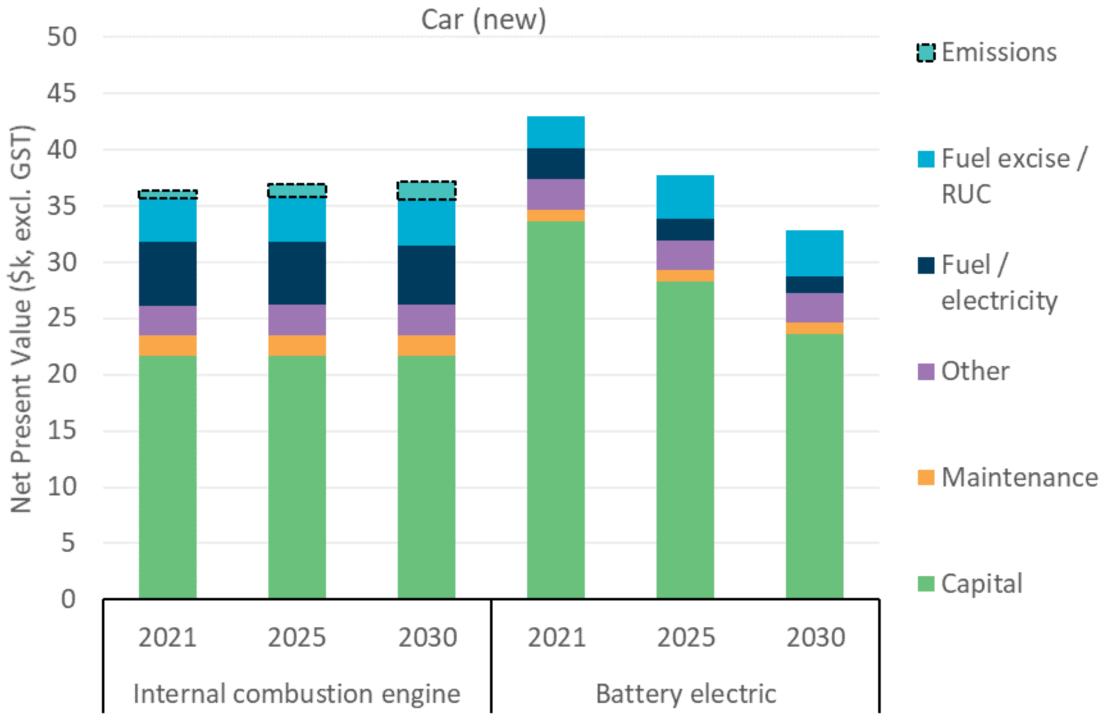

Figure 12.16: Projected five-year total cost of ownership for a new battery electric car compared with a new petrol car in the Headwinds scenarios (private perspective)

Source: Commission analysis

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[5] (BNEF, 2020)

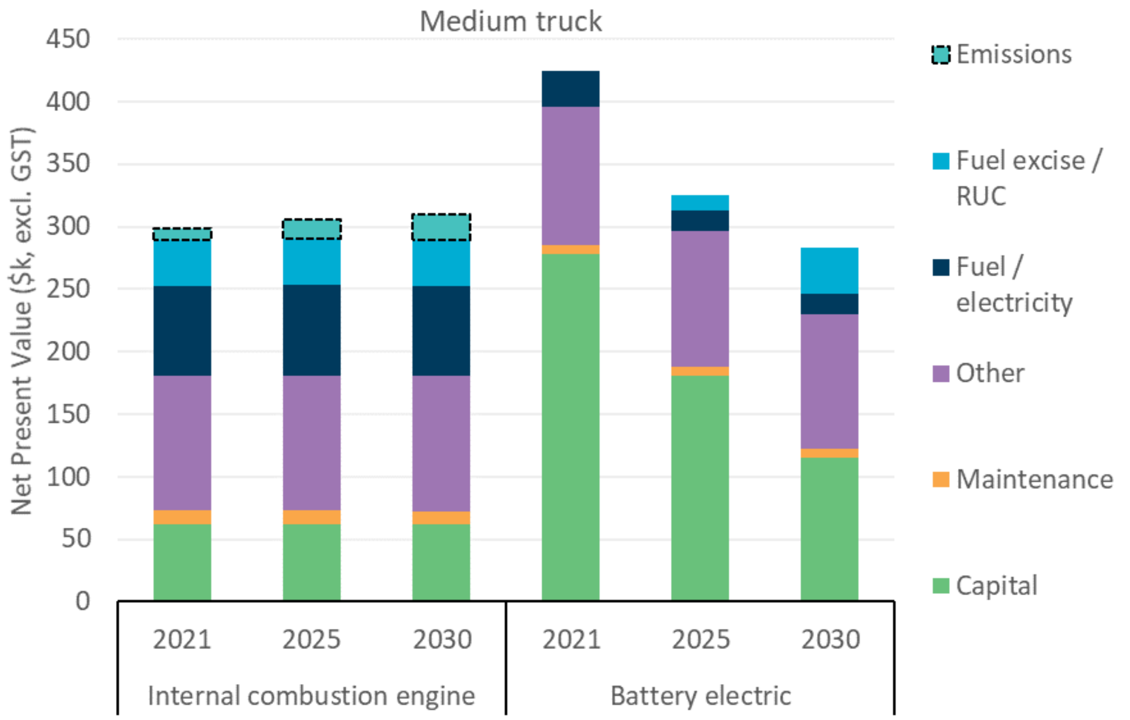

Figure 12.17: Projected five-year total cost of ownership for a new battery electric medium truck compared with a new diesel truck in the Headwinds scenarios (private perspective)

Source: Commission analysis

Notes:

1. Capital costs are calculated as purchase cost minus resale value after five years, assuming depreciation rates of 14% for ICE vehicles and 16% for battery EVs, and an 8% interest rate.
2. Average battery range is assumed to increase from 330 km in 2020 to 375 km in 2030 for cars, and from 440 km to 500 km for medium trucks.
3. ‘Other’ costs include vehicle registration, insurance, and tyres. For trucks and other commercial vehicles, this also includes the cost of the driver.
4. Electricity costs include estimated charger and network costs and assume a move to cost-reflective pricing by 2030 with most charging occurring overnight.
5. Fuel costs include commodity and distribution costs, with the fuel excise tax component of the petrol price shown separately.
6. Electric light vehicles are assumed to pay road user charges in full from 2022 onwards, and heavy vehicles from 2028.
7. Emissions costs are calculated using assumed emissions values shown in Figure 12.3,

Table 12.5: Year that a new battery EV becomes cheaper than a new ICE vehicle on five-year total cost of ownership under our scenario assumptions (including emissions values)

	Headwinds and Further Behaviour scenarios	**Further Technology and Tailwinds scenarios**
Cars and SUVs	2026	2025
Vans and utes	2026	2025
Buses	2020	2020
Medium trucks	2028	2026
Heavy trucks	2030	2029

Source: Commission analysis

Vehicle efficiency

Figure 12.18 shows the assumed changes in emissions per kilometre for new internal combustion vehicles entering the fleet, for the two classes of light vehicles: light passenger vehicles (cars/SUVs) and light commercial vehicles (vans/utes).

The Further Technology and Tailwinds scenarios assume no improvement from the Current Policy Reference case, as these scenarios represent a future where Aotearoa and the world move decisively and rapidly towards EVs.

In the Headwinds and Further Behaviour scenarios, we assume that the slower adoption of EVs is accompanied by greater focus on reducing the emissions intensity of ICE vehicles, particularly through the increased uptake of conventional hybrid vehicles.[6] The improvements in this scenario are consistent with hybrids making up approximately 60% of all light ICE vehicle registrations (including used imports) by 2030, and close to 100% by 2040. This compares with around 30% of light passenger vehicles in 2030 in the Current Policy Reference, based on Ministry of Transport's 'base case' projections.

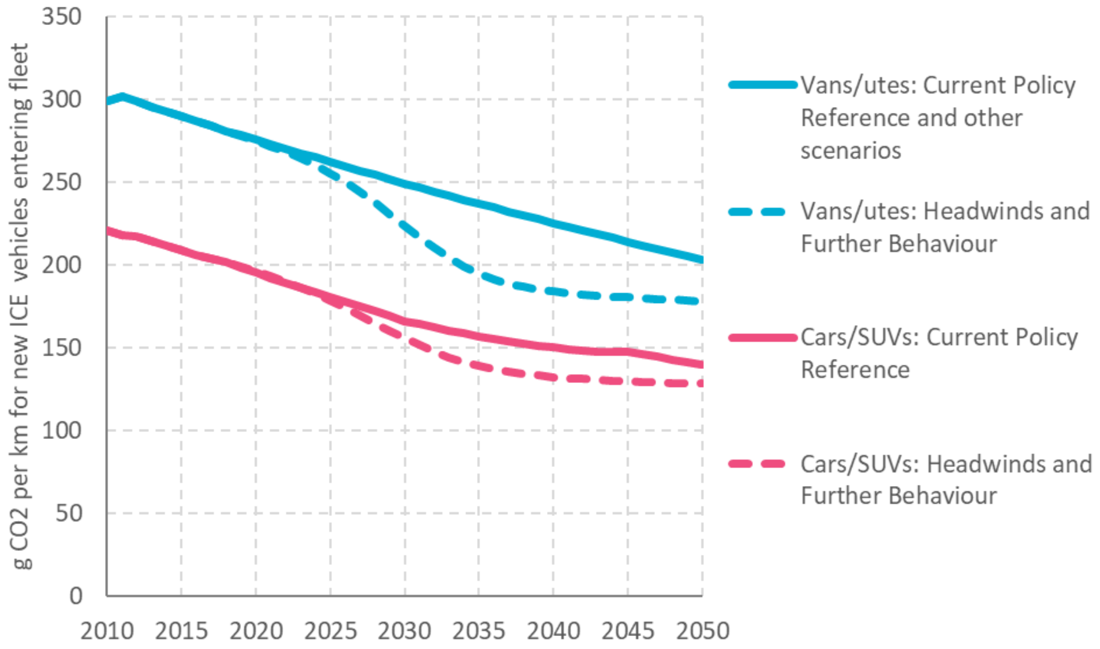

Figure 12.18: Assumed CO_2 emissions per kilometre travelled for new internal combustion vehicles entering the fleet in our scenarios

Source: Commission analysis

Heavy road vehicles (trucks and buses)

Trucks and buses are also increasingly electrified in these scenarios. However, because of weight, usage and costs, the uptake is different for these vehicle types. This variation is shown in comparison to light passenger vehicles in Figure 12.19 for the Tailwinds and Further Technology scenarios.

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[6] Although conventional hybrid vehicles are at least partly powered by electric motors, they are still considered ICE vehicles as their batteries cannot be charged from the grid.

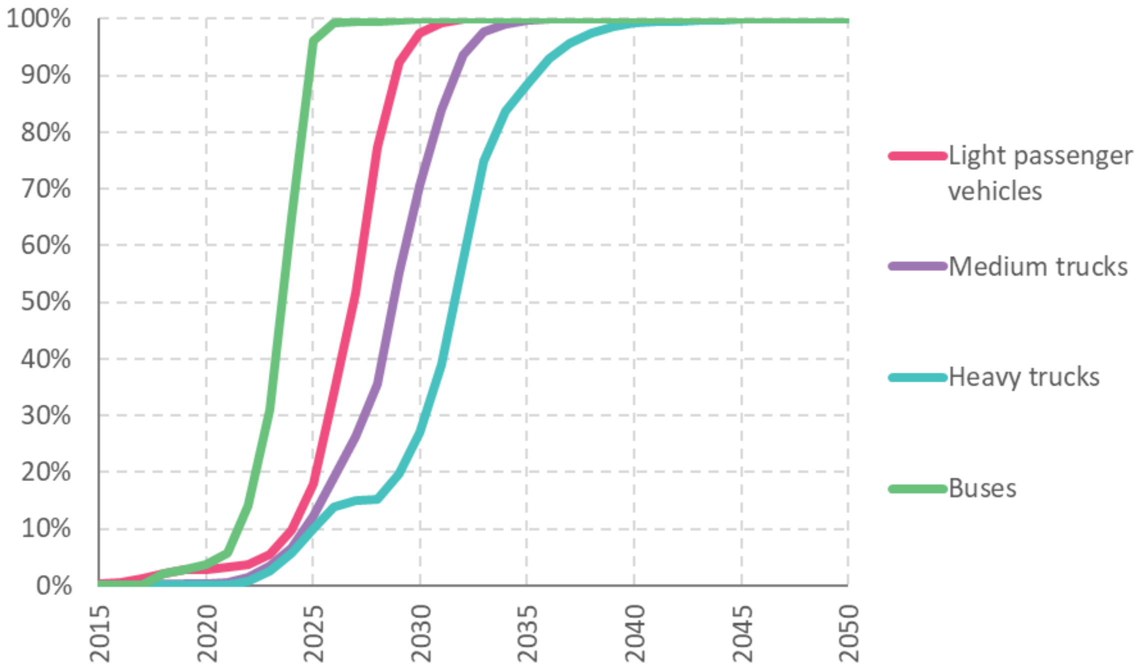

Figure 12.19: Percentage of newly registered trucks and buses that are electric for the Tailwinds and Further Technology scenarios

Source: Commission analysis

Heavy trucks[7] are the most challenging vehicles to electrify as they may be approaching legal size and weight limits for trucks, so batteries could reduce the payload the truck can carry. However, innovations that are reducing the size and recharge time of the batteries are developing quickly. While we have modelled battery EVs as the electrification route, this could also represent the adoption of hydrogen fuel cell vehicles (see Box 12.2: Hydrogen for transport).

Medium trucks[8] are less challenging to electrify and the economics of electrifying medium trucks is improved from higher utilisation that results in lower operating costs.

Table 12.6: Year by which 100% of newly registered vehicles are electric for all road vehicle classes

	Headwinds & Further Behaviour	Tailwinds & Further Technology
Light passenger vehicles	2042	2032
Medium trucks	2046	2037
Heavy trucks	after 2050	2046
Buses	2040	2030

Buses present an attractive electrification opportunity. This is especially true of public transport buses because they generally do not travel far in a day and because electric buses can be highly efficient in stop-and-go traffic. The reason is that they can use otherwise wasted energy from

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[7] Heavy trucks are defined here to have a fully loaded weight greater than 30 tonnes.
[8] Medium trucks are defined here to have a fully loaded weight less than 30 tonnes.

braking to recharge their batteries. Electric buses also have the valuable urban co-benefits of being quiet and free of exhaust fumes.

Emissions from trucking may also be reduced by diverting freight to rail and coastal shipping, which have lower emissions per tonne-kilometre. Our Headwinds and Further Technology scenarios assume a 19% increase in rail and coastal shipping freight tonne-kilometres by 2040 compared to the Current Policy Reference case due to diversion of freight from trucks. This equates to around 5% of total freight tonne-kilometres switched. Our Tailwinds and Further Behaviour Change scenarios assume a 61% increase in rail and coastal shipping tonne-kilometres by 2040 compared to the Current Policy Reference case due to diversion of freight from trucks. This equates to almost 15% of total freight tonne-kilometres switched.

Aviation

Options to limit emissions from domestic aviation beyond what is assumed in the Current Policy Reference case are currently limited. Historically, efficiency improvements have occurred at an impressive rate that has seen domestic aviation emissions held fairly constant since 1990 despite large growth in passenger-kilometres. Our scenarios assume that additional efficiency improvements beyond the 1.25% per year assumed in the Current Policy Reference case are possible. We assume annual improvements in 1.75% in the Further Behaviour and Further Technology scenarios, and 2.25% in the Tailwinds scenario. This reflects that both behaviour changes (such as avoiding short haul plane trips, which are less efficient) and technology changes can contribute to increased efficiency.

Electrification of aircraft is challenging due to the weight of the batteries. However, there is growing interest in battery electric and hydrogen planes around the world and from Aotearoa airlines. Electric aviation is assumed to become viable only in the Tailwinds and Further Technology scenarios. In these scenarios, the percentage of domestic air passenger-kilometres in electric aircraft rises from zero in 2030 to 20% by 2040 and 50% by 2050.

There is also an assumed uptake of low-carbon liquid fuels in the Tailwinds and Further Technology scenarios for all types of transport, as well as for off-road vehicles and equipment. Our modelling assumes these low-carbon liquid fuels to be biofuels, however, they could also be synthetic e-fuels made from green hydrogen. Low-carbon liquid fuel production starts at a small amount in 2025 and grows steadily to 9.5 PJs, or about 270 million litres, by 2035. These low-carbon liquid fuels could be blended into all liquid fuels. In 2035, this would be a relatively small share of liquid fuels, about 6%. However, after 2035, increasing electrification causes liquid fuel demand to drop off rapidly.

Competitive ground transport alternatives are limited for most domestic air travel and likely to remain so for the foreseeable future. There is a potential role for communications technology to substitute for some business travel. We have not, however, assumed any demand shifts in our domestic aviation scenarios.

The impacts of demand shifts on international aviation could be more significant given the cost and environmental impacts of long-distance air travel to and from Aotearoa. Also, improving communications technology, as demonstrated in the COVID-19 experience, may permanently reduce the demand for international business travel.

International aviation emissions are not included in the Commission’s initial emission budgets, but are considered in the ENZ model, and linked to demand for tourist bus services. In the Headwinds and Further Technology Change scenarios, we assume people become more conscious of the environmental impacts of international aviation and choose to limit their trips. By 2030, we assume that international aviation is down 10% compared to the Current Policy Reference case and grows at half the Current Policy Reference case rate thereafter. These impacts are even stronger in the Tailwinds and Further Behaviour Change Scenarios, which assume that by 2030, international aviation is down 25% compared to the Current Policy Reference case and ceases to grow thereafter.

Domestic Coastal Shipping and Cook Strait Ferries

In all our scenarios, we have used the simple assumption that domestic shipping will convert to electricity at the same rate as heavy road freight. Within the model, this means that the share of freight tonne-kilometres running on electricity is equal to the share of electrified heavy truck vehicle-kilometres.

As previously discussed for heavy trucks, while we have modelled this as direct electrification, this could represent an uncertain mix of battery, hydrogen, or ammonia-powered shipping (see Box 12.2: Hydrogen for transport). One potentially attractive route is for plug-in hybrid ships which could be upgraded in future years as battery technology continues to improve and reduce in cost. The upgraded batteries would allow the ships to reduce the fraction of their travel that is fossil fuel powered.

On the demand side, coastal shipping benefits from a diversion of freight from trucks, discussed above.

Rail

Emissions from rail freight could be reduced through electrifying additional lines, although this would be economic only on heavily used lines. The North Island Main Trunk between Auckland and Wellington is already mostly electrified, with two remaining short gaps between the end of the Auckland commuter zone and Hamilton and the end of the Wellington commuter zone and Palmerston North. The Current Policy Reference case assumes electric operations are retained between Hamilton and Palmerston North, as this is an existing policy. Rail passenger operations, which serve mainly the Auckland and Wellington metro areas, are also already mostly electrified.

The Tailwinds and Further Technology Change scenarios assume the gaps in the Auckland to Wellington electrification are filled, as well as electrification of the short and heavily used connecting line from Hamilton to Tauranga, by 2026. Complete electric operations would then be possible between five major cities on the North Island.

Beyond this, rail is treated similarly to coastal shipping in our scenario modelling. We assume that once the share of electrified heavy truck kilometres catches up with the share of rail freight carried on electric lines, further electrification of rail will proceed in step with heavy trucks. This could include the use of battery-powered, hydrogen or hybrid locomotives on non-electrified rail lines.

On the demand side, rail freight benefits from a diversion of freight from trucks, discussed above.

Box 12.2: Hydrogen for transport

Hydrogen has not been modelled as an emissions reduction option in the scenarios presented here. In our consultation, we heard from councils and industry that there are multiple green hydrogen heavy transport projects underway. While we have modelled battery electric trucks as the electrification route, the resulting uptake could also represent fuel cell trucks powered with green hydrogen. While the emissions outcomes would be similar, this would have different implications for the energy system, as a fuel cell vehicle running on green hydrogen requires roughly three times as much input electricity as a battery EV.

There are, however, segments of the transport sector which are difficult to power with battery EVs. Aircraft are the most obvious example, as today's batteries are too heavy to power long-distance aircraft. Battery electric heavy trucks are another, as they may have to travel long distances pulling heavy loads without stopping to recharge. The size and weight of the batteries could also reduce the carrying capacity of the truck. Off-road vehicles and equipment may also be challenging to electrify, especially the types used to work long hours in remote locations. In these three segments, as well as for long-distance ships and railway locomotives, hydrogen may have a role to play.

There are at least three potential future low-carbon options for these hard-to-electrify segments of the transport sector. One is low-carbon liquid fuels, either biofuels or liquid electrofuels (e-fuels), which could be used in conventional ICE vehicles. E-fuels are liquid fuels that could be made from green hydrogen and captured carbon dioxide. Another option is improved battery technology, which might offer significantly more energy storage per unit of weight. The third is direct use of hydrogen. Since each of these low-carbon technologies are evolving rapidly, it is too early to say which could emerge as the winner.

12.5.3 Energy, industry and buildings

Electricity demand, generation and emissions

The scenarios show increasing electricity demand due to the electrification of transport, off-road vehicles, industrial and building heating. These electrification measures are all necessary to meet the 2050 emission targets. This demand growth is shown below for the Tailwinds scenario with annual demand for electricity increasing from around 40 TWh in 2019, to around 60 TWh by 2050. As is the case in the Current Policy Reference, it is assumed that the Tiwai Point aluminium smelter closes at the end of 2025 and this frees up some generation capacity for other uses. The total growth in demand from electrification of the economy is around 25 TWh.

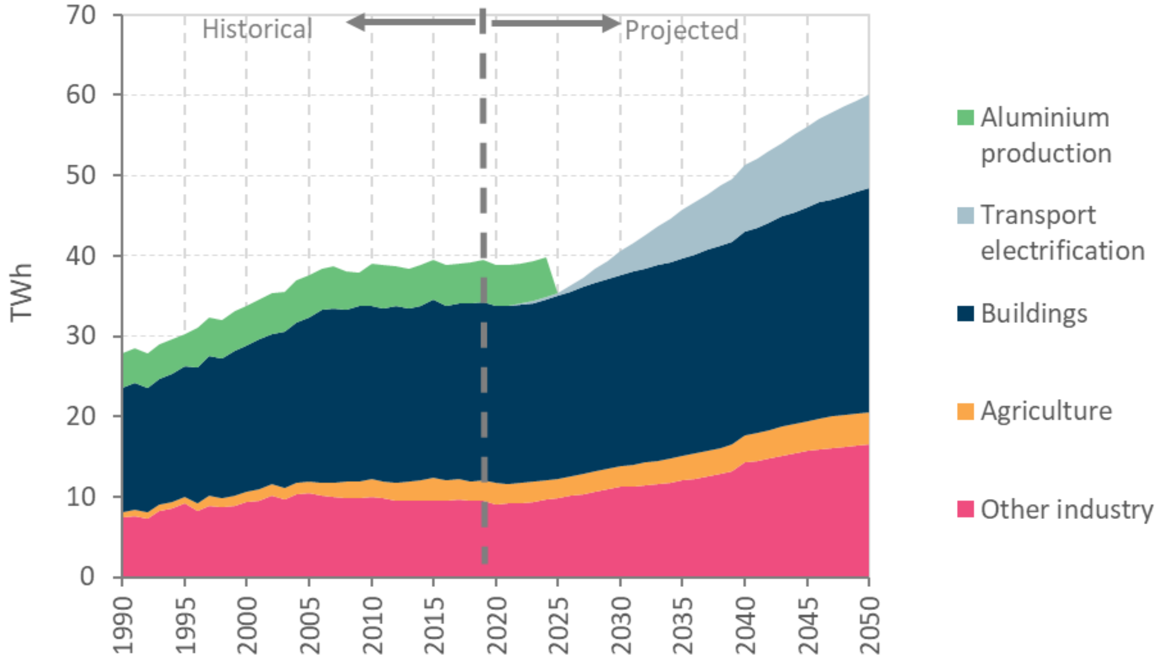

Figure 12.20: Electricity demand growth in the Tailwinds scenario

Source: Commission analysis

Most of the electricity demand growth in the scenarios is met by new wind generation; the installed base increases by an order of magnitude and generates up to 20 TWh per annum. In addition to this, by 2050 new geothermal generation contributes around 3 TWh per annum of generation, and utility solar, mostly built beyond 2030, contributes between 8 and 12 TWh per annum. The change in the electricity generation by generation type for the Tailwinds scenario is shown in Figure 12.21 below.

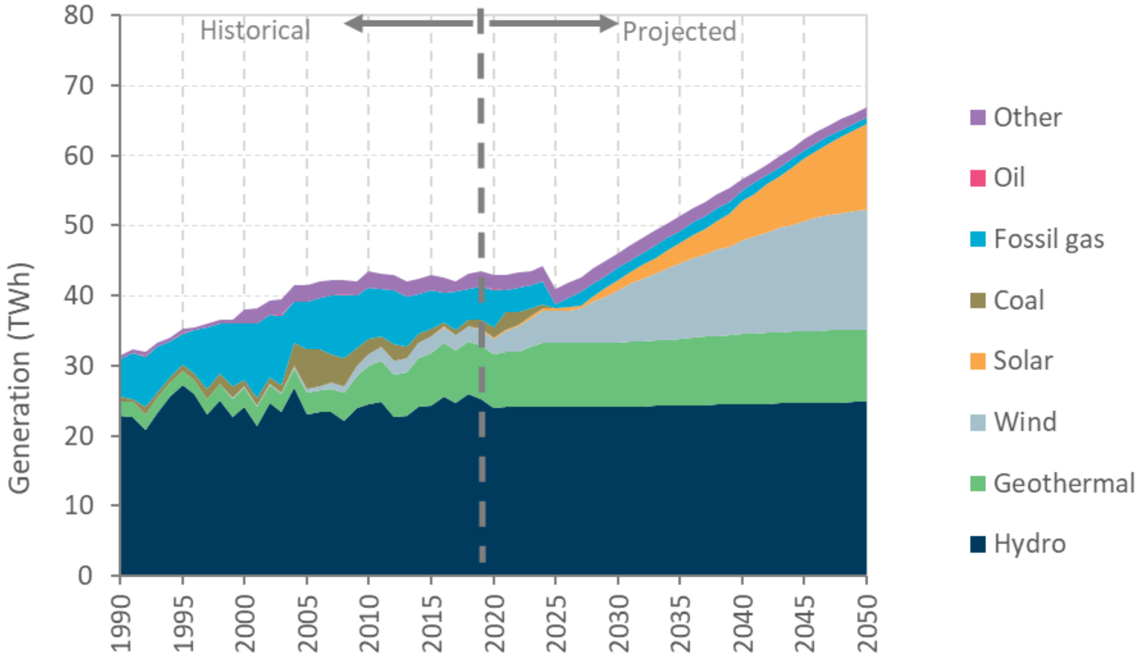

Figure 12.21: Electricity generation growth in the Tailwinds scenario

Source: Commission analysis

In these scenarios, the maximum rate at which electricity system expands is 1.6 TWh per year. The generation capacity required to supply this increment is equivalent to an additional three wind farms of the scale of the West Wind project on Wellington’s West Coast.

Electrification also requires considerable expansion and increases in capacity of electricity transmission and distribution infrastructure, and connections to new generation sites and remote areas.

As was the case in the Current Policy Reference projections, coal and gas play a reducing share as fuels for electricity generation. However, in these scenarios thermal generation plays an even smaller role and contributes fewer emissions due to the higher emission price assumed to be faced by electricity generators.

Our scenarios suggest that fossil fuels could stop being used as a fuel for baseload electricity generation and instead be used exclusively for flexible generation. Flexible generation includes providing peaking capacity during cool winter nights and during dry year periods when the hydro lakes are low.

Electricity generation is currently the second largest consumer of gas in Aotearoa. Although the share of gas generation decreases in all four modelled scenarios, gas generation remains a critical part of the electricity system for meeting peak requirements and dry year needs. Most importantly, in these scenarios, gas provides cover for dry year conditions which reduce the energy resource for hydro generation.

Despite increasing demand for electricity across all scenarios, emissions from the generation of electricity are projected to decrease from around 5 $MtCO_2e$ in 2019 to below 2 $MtCO_2e$ by 2035 as is shown for the Tailwind scenario in Figure 12.22. Much of the reduction from current levels occurs before 2025 and is due to the displacement of baseload fossil generation (gas and coal) with lower-cost renewables.

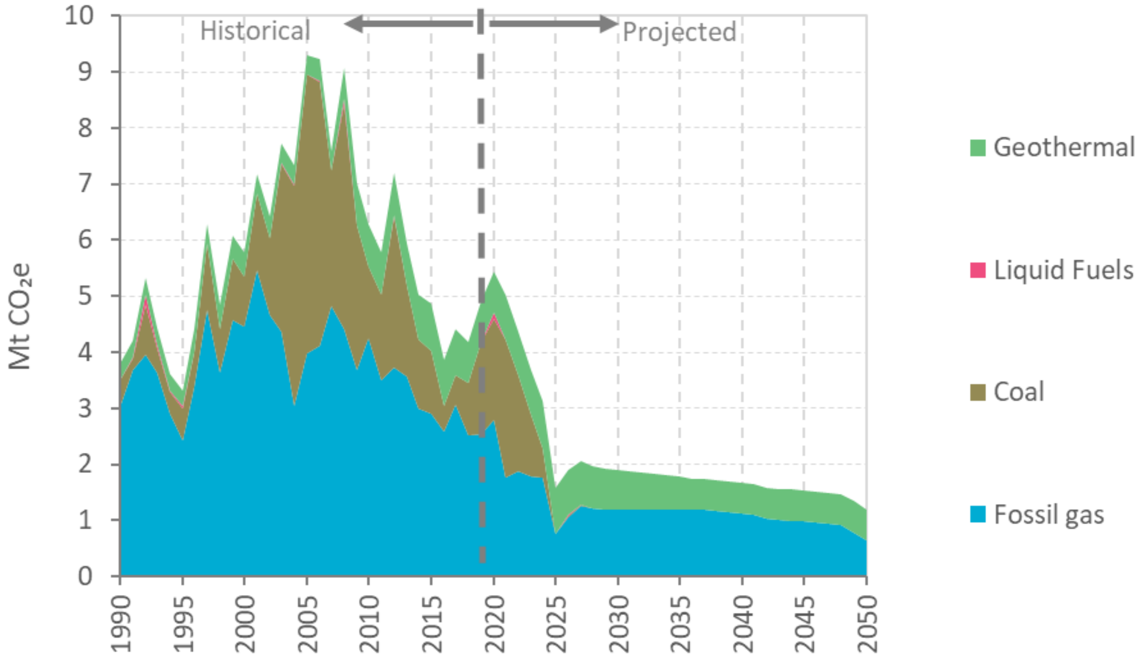

Figure 12.22: Electricity generation emissions in the Tailwinds scenario

Source: Commission analysis

Figure 12.23 below shows residual electricity generation emissions in 2050 across all scenarios. In the Further Technology scenario and the Tailwinds scenario, carbon capture and storage are applied to geothermal fields. This achieves a 35% reduction in the generation emissions and is the main reason for the variation in emissions shown between the scenarios.

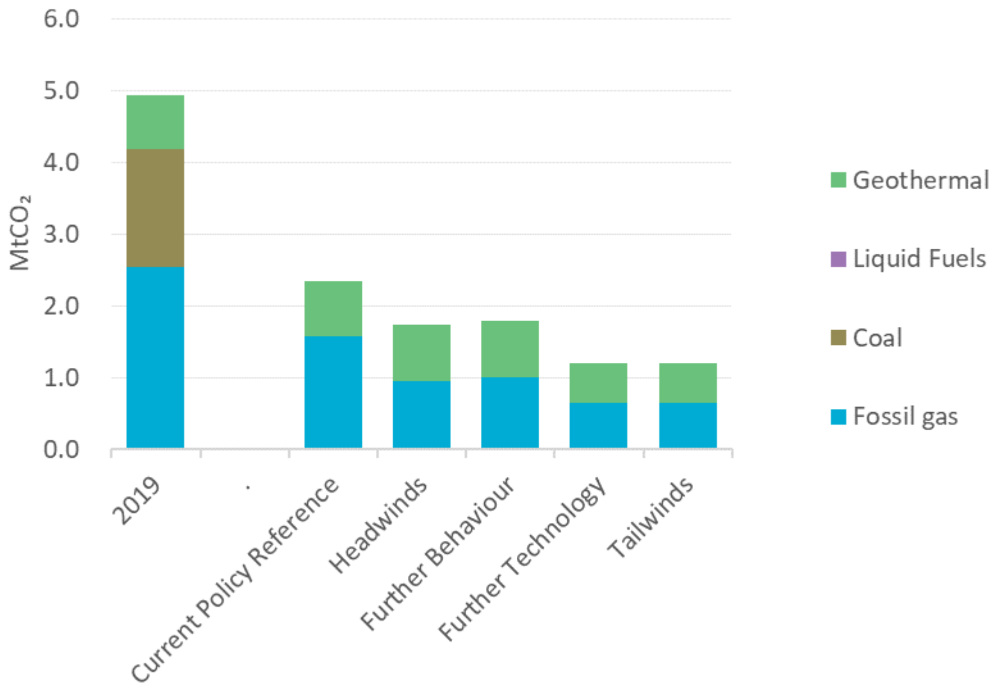

Figure 12.23: Electricity generation emissions in 2050 compared with 2019

Source: Commission analysis

Emissions from geothermal generation vary widely from field to field, with the worst emitting fields being comparable to gas generation. However, these high emitting fields have naturally degassed in recent years and we assume a continuation of their historic rate of reduction in emission intensity.

Box 12.3: What would a pumped storage system mean for the electricity sector?

The Commission considered the emissions reduction potential of a large pumped storage scheme, such as that under investigation as part of the NZ Battery project, led by the Ministry of Business, Innovation and Employment (MBIE). The Interim Climate Change Committee investigated a 100% renewables target in 2019 and recommended that decarbonising process heat and transport offered greater potential.

The ‘dry year problem’ happens when hydro-power catchments do not receive enough rain or snowmelt and the level of the storage lakes gets low. When this occurs some form of back-up is needed; this is currently provided by fossil fuel generation. As set out by MBIE, the purpose of the NZ Battery project is to evaluate the viability of pumped hydro. The project will consider this solution against alternative methods to resolve the storage problem in Aotearoa in order to achieve 100% renewable electricity and help to decarbonise the wider energy system.

Although all of our ENZ scenarios achieve significant reductions in emissions from electricity generation, none of them achieve a 100% renewable, or emission-free electricity sector. The scenarios show that it is possible to meet the 2050 emissions target without achieving 100% renewable electricity.

We undertook further modelling runs to examine the emissions savings a pumped hydro scheme operating at Lake Onslow could provide. This modelling is based on the demand profiles from the ENZ scenarios and performed using Energy Link’s E-market and I-gen models. In this standalone modelling piece, a pumped storage scheme with 5 TWh of storage is deployed in the model in 2032 and is filled and fully operational by 2035. The scheme is assumed to operate in the market in a similar way to existing hydrogeneration. Once operational the storage scheme dramatically reduces the impact of varying hydro flows on the electricity sector and this reduces the dependence on gas.

Figure 12.24 shows the difference in thermal generation required in a system with and without this pumped storage scheme. The base year chosen is the “average” hydro over the last 87 years on record.

The result shows that once operational the scheme removes around 0.6 TWh of thermal generation per year. This is equivalent to 0.3 $MtCO_2$ of emissions per year.

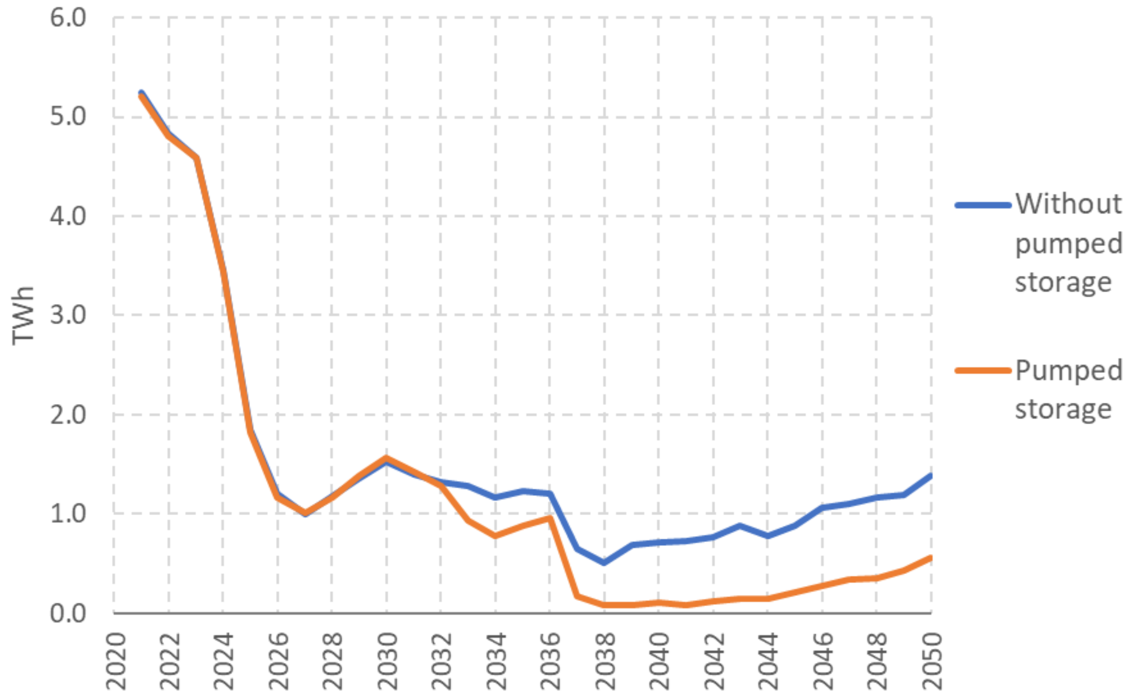

Figure 12.24: Total annual thermal generation in electricity system with and without a pumped storage scheme. This is for a demand profile representative of the Headwinds scenario; the totals are averages across a full record of hydrological years and do not include cogeneration. The Step reduction in generation from 2036-2037 is caused by the forced closure of the e3p gas generation plant.

Source: Commission analysis

Gas could remain a component of the electricity system in Aotearoa. Electricity supply security challenges may occur if the size of the gas market was to contract as is shown in these scenarios. The occasional use of gas for electricity generation may not be supported in the same manner as it is currently which could lead to electricity price increases and supply interruptions which could hinder decarbonisation efforts.

This result is not an endorsement of such a scheme as there remains considerable uncertainty around the cost and practicality. The NZ Battery project which is currently being undertaken by MBIE will make recommendations as to whether this is a solution that Aotearoa should pursue.

Buildings

Emissions from the combustion of fossil fuels for heating and cooking in buildings decrease significantly in all scenarios relative to 2019 and to the Current Policy Reference case. This is partly a result of improvements in energy efficiency due to thermal performance improvements and operational changes. In addition to this, these scenarios explore fuel switching away from the use of fossil fuels for heating systems.

Efficiency improvements in existing and new buildings are varied across the scenarios. The Further Technology and Tailwinds scenario achieve the greatest reduction in the operational energy intensity of buildings by improved new build standards and from retrofitting existing buildings.

Figure 12.25 shows the historical share of building energy supply and a future transition from fossil gas to electricity for the Tailwinds scenario. The plot also shows that total energy demand can remain constant, or even reduce, despite an increasing population due to improvements in energy efficiency.

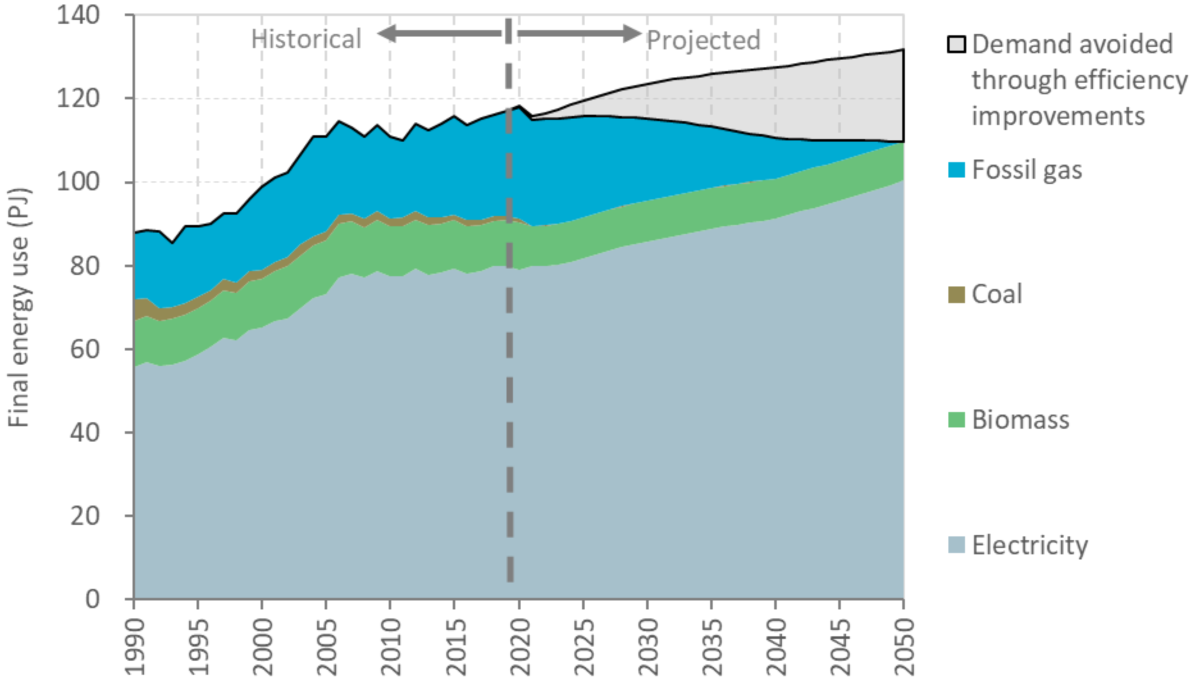

Figure 12.25: Historical and projected supply of energy in buildings for the Tailwinds scenario. The demand avoided wedge shows the energy avoided through improvements in efficiency relative to the Current Reference Policy case efficiency improvements.

Source: Commission analysis

In all scenarios the adoption of fossil gas and bottled LPG in new builds stops before 2040 and the Further Behaviour and Tailwinds scenarios achieve the largest emissions reduction by transitioning the use of fossil gas in all buildings to electricity or biomass by 2050. The use of coal for heating is largely eliminated in all scenarios by 2030. The reduction in emissions for the Tailwinds scenario is shown in Figure 12.26 below.

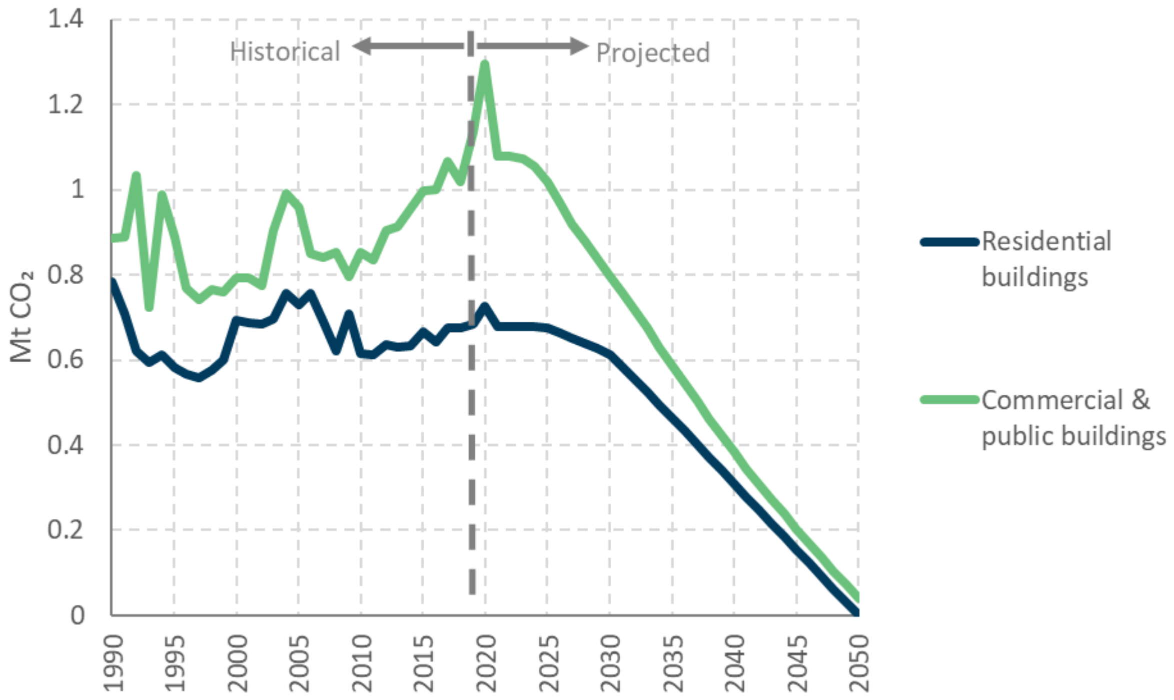

Figure 12.26: Historical and projected emissions from fossil fuel combustion in buildings in the Tailwinds scenario

Source: Commission analysis

Heating systems in buildings can have a long operational life and the phased reduction of gas and LPG systems are assumed to be compatible with normal capital replacement cycles. These scenarios require the replacement of end-of-life gas heating systems with electric heat pumps and hot water cylinders.

Figure 12.27 shows the residual emissions from fossil fuel combustion in buildings at 2050. In the Further Behaviour and Tailwinds scenarios which have eliminated gas from heating in buildings, residual emissions in 2050 are primarily from the combustion of biomass in home fireplace[9] and liquid fuel use for commerical motors.

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[9] Although it is generally assumed that combustion of biomass has zero net emissions, there are methane emissions associated with the incomplete combustion of biomass in home fireplaces.

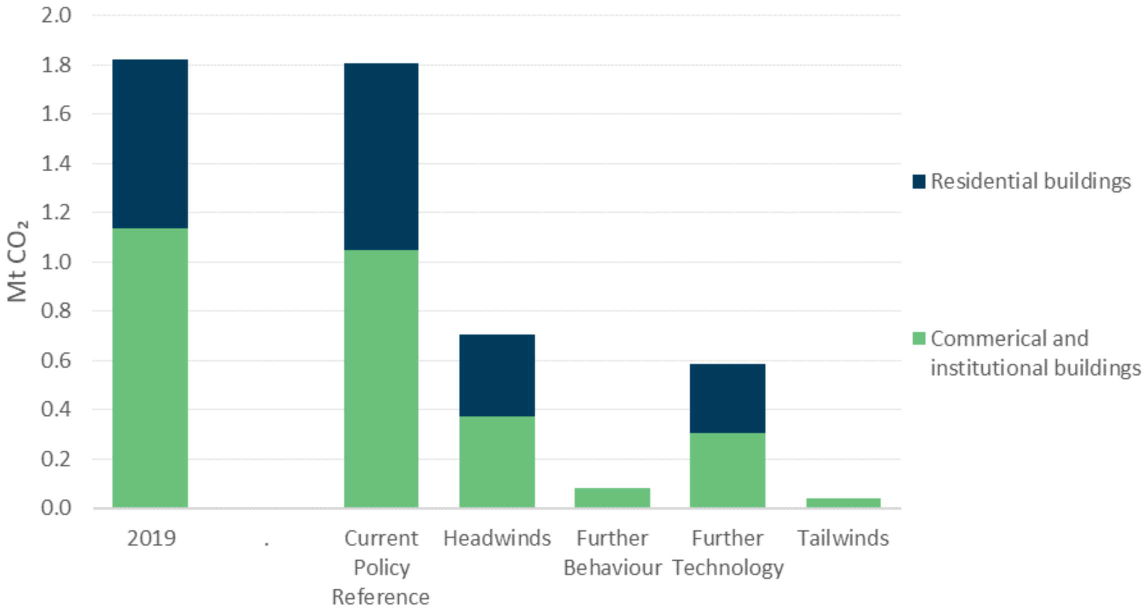

Figure 12.27: Fossil fuel combustion emissions in buildings in 2050 across the modelled scenarios

Source: Commission analysis

Low and medium temperature process heat

In all scenarios the food processing sector is almost completely decarbonised by achieving widespread energy efficiency improvements and switching heating from coal, fossil gas and diesel to biomass and electricity. This is achieved without significant changes to the total amount of food produced relative to today.

The wood, pulp and paper processing sectors also achieve significant reductions in emissions across all scenarios. In these processing applications, the use of fossil gas and coal for low and medium temperature applications is displaced with woody biomass.

In all scenarios, total food processing energy use peaks immediately and the overall energy intensity begins to reduce. The rate of improvement in energy efficiency is varied across the scenarios and by 2050 the sector achieves a reduction of 20-40% in energy intensity relative to the starting year.

Simultaneous to these efficiency improvements, boiler heating begins to switch away from coal. In regions where readily available, woody biomass is used by blending with coal in existing boilers and then being used in replacement boilers which are optimised for biomass combustion. The modelled biomass resource is forestry residue and what are currently exported pulp logs.[10] No domestic uses of timber are diverted for this energy resource.

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[10] Pulp logs are low quality logs used for making paper and other pulp products.

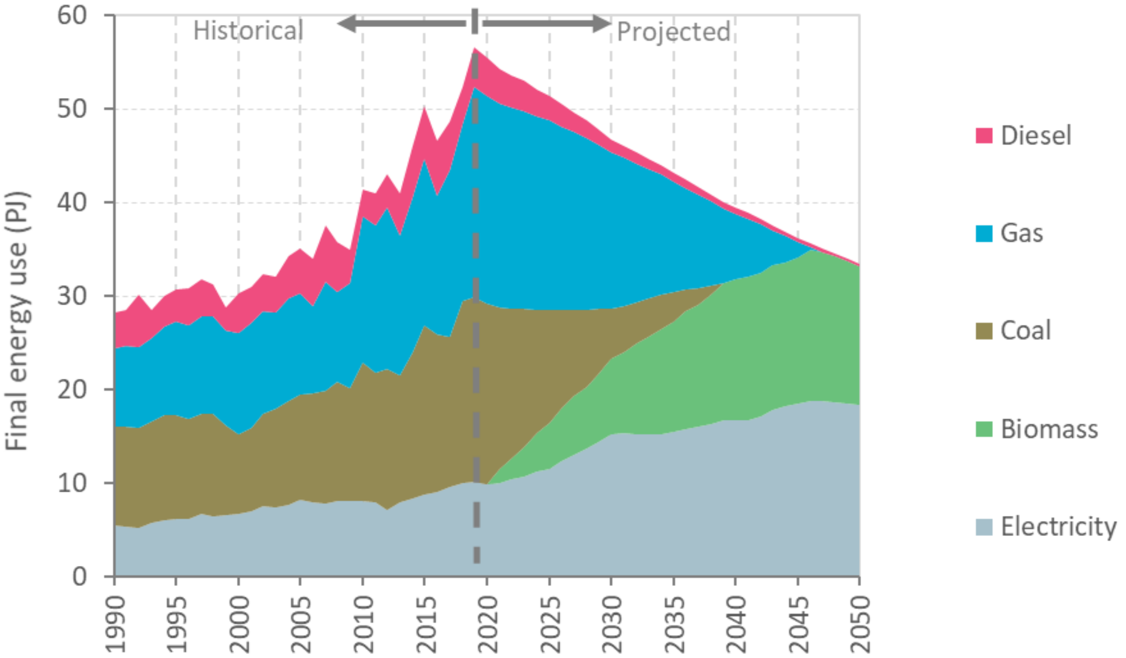

Figure 12.28: Food processing fuel use in the Tailwinds scenario

Source: Commission analysis

Electrification of process heat also occurs in these scenarios, but more gradually than switching to biomass. It is assumed that heat pumps, which offer highly efficient heating, are used for low temperature heating applications in food processing but that their uptake is gradual as they are difficult to integrate in existing factories. Electrode boilers also play a considerable role but mostly in regions where the supply of biomass is limited.

The scenarios demonstrate a balance between the use of bioenergy and electricity for process heat in these projected futures. There is uncertainty around both the availability of biomass resource and the extent to which biomass can be practically and economically used. The scenarios explore this uncertainty by varying the regional availability of the biomass resource. The Headwinds and Further Behaviour scenarios have 50% of the biomass resource that is available in the Tailwinds and Further Technology scenarios. Because biomass is generally a lower cost option than electrification, decarbonisation of the sector is slower in the scenarios where the biomass supply is restricted. This is shown in Figure 12.29.

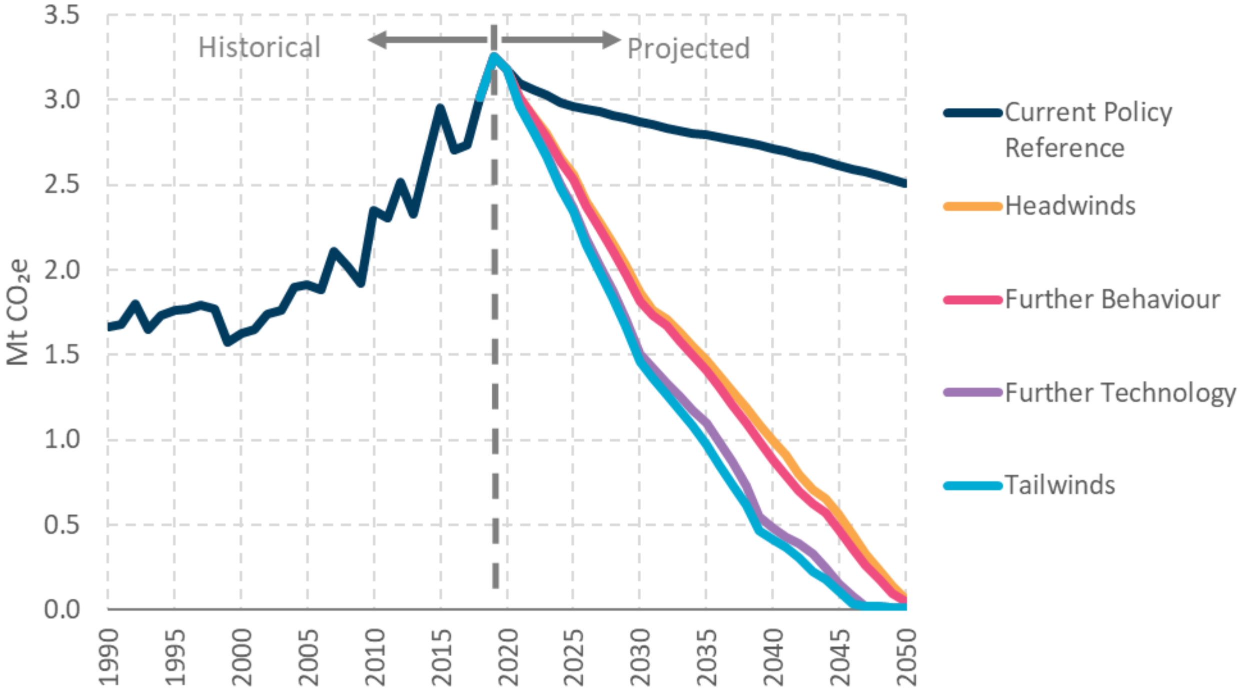

Figure 12.29: Food processing emissions across the modelled scenarios

Source: Commission analysis

In our scenarios, improvements in energy efficiency and fuel switching to biomass or electricity combine to achieve a reduction in the use of coal averaging between 0.8 and 1.0 PJ per year across the food processing sector. This is a rapid energy transition and is equivalent to the conversion of one of the largest dairy processing plants or a number of smaller sites per year.[11] At this rate, coal is eliminated from food processing by 2040 in the Tailwinds and Further Technology scenarios and by 2043 in the Headwinds and Further Behaviour. In total the use of 20 PJ per year of coal is displaced – this is a vast amount of energy and this future would require significant electricity infrastructure upgrades, the construction of new electricity generation, factory conversions and the establishment of a significant biomass supply chain.

The food processing sector does not begin fuel switching away from fossil gas until after 2030 in these scenarios, although the use of gas has been reduced prior to this from efficiency improvements. Starting in the 2030s, the sector begins to replace the use of gas with biomass and electricity and has completely converted by 2050.

There are technologies which are not reflected in our modelled scenarios which could significantly alter the ease and cost at which this sector can decarbonise. High temperature heat pumps are an emerging technology which could potentially produce much of the steam required for food processing factories. The high coefficient of performance of these heat pumps would reduce the effective electricity cost per amount of heat which would significantly reduce the cost of electrification as a low-emission heating option.

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[11] Fonterra converted the 40 MW boiler at their Te Awamutu plant in 2020 to run off wood pellets. The coal that this displaced is equivalent to around 1 PJ.

Fossil fuel production

The scenarios show emissions from the production of fossil fuels are projected to decrease from around 2 $MtCO_2$ today to less than 1 $MtCO_2$ by mid-century. We have assumed a reduction in the emissions from fossil fuel production (vented and flared carbon dioxide and fugitive methane emissions) as overall demand for fossil gas reduces. The reduction in fossil fuel produciton emissions for the Tailwinds scenario is shown in the figure below.

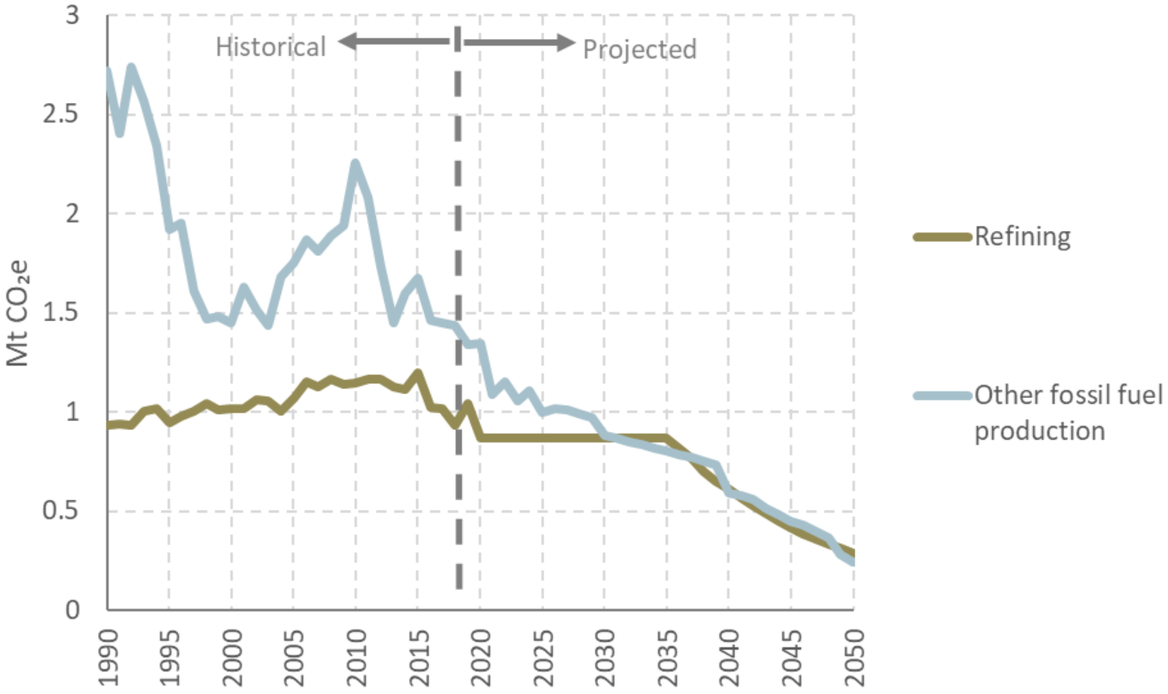

Figure 12.30: Fossil fuel production emissions for the Tailwind scenario

Source: Commission analysis

Domestic refining of crude oil to produce petroleum products for transportation is projected to decrease in the scenarios as transport electrifies. However, this only begins to occur beyond 2035 when the demand for fuel drops below the capacity of the Marsden Point refinery.

Heavy industrial processes

Achieving emissions reductions in some industries will be a considerable challenge for global decarbonisation efforts, requiring radical conversion of industrial processes and use of alternative feedstocks. These scenarios reflect these challenges by having generally conservative assumptions around the potential to reduce emissions for certain industrial process.

In the Further Technology and Tailwinds scenarios, domestic steel making converts to a zero emission process in 2040. In the model the process converts to green hydrogen-based steel making, but this could be one of a number of zero emission steel processes which are on the horizon. We assume no such conversion for cement and lime production as we judge alternative technologies as less ready. The 2050 emissions for these heavy industrial sectors are shown in Figure 12.31 below.

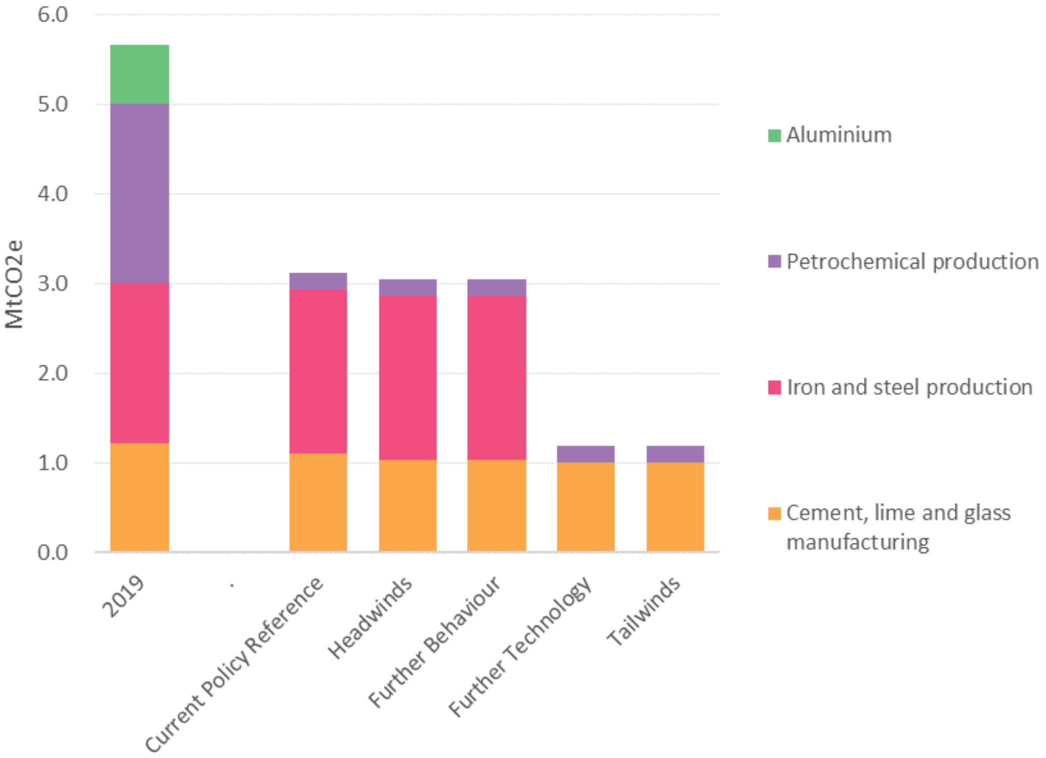

Figure 12.31: Emissions in 2050 from heavy industries relative to 2018 and the Current Policy Reference case

Source: Commission analysis

Box 12.4: Hydrogen use in industry
The use of hydrogen as an emissions reduction opportunity for the iron and steel manufacturing sector has been modelled in the Tailwinds and Further Technology scenarios. Emissions from iron and steel manufacturing stem from fossil fuel combustion to generate high temperature process heat and from industrial process reactions such as the reduction of iron sand using coal. Over 80% of emissions from the sector are process emissions. The scenarios are ambitious and assume green hydrogen-based steel making achieves full decarbonisation of the sector by 2040, reducing the emissions of Aotearoa by nearly 2 $MtCO_2$.

This application of hydrogen has been explicitly modelled as it offers significant emissions reduction and it has been judged likely to be technically achievable globally before 2050. There are other niche industrial opportunities for hydrogen which have not been modelled but would likely be required to achieve deep decarbonisation in other sectors. For example, urea production can be decarbonised by utilising green or blue hydrogen as a chemical feedstock. Industrial applications which require high temperature heat may also convert to hydrogen if the use of fossil gas and coal is to cease. It is estimated that the additional opportunity for reducing emissions from the use of hydrogen in Aotearoa is around 1 $MtCO_2$ per year.

Off-road vehicles and machinery

The use of petrol and diesel in off-road vehicles and machinery reduces considerably in all modelled scenarios. This use of motive power occurs primarily in the mining, construction, agriculture, forestry and fishing sectors. There are a diverse set of fuel uses in these sectors. However, we assume that generally these motor applications would electrify in the long term and can use low carbon liquid fuels in the interim.

For these scenarios it is assumed that motive power in these applications electrifies at the same rate as heavy trucks. Heavy trucks are assumed to be a slow type of transport to electrify due to their weight and the long distances they travel. This is therefore a conservative assumption for off-road vehicles and machinery but is a practical proxy given the diverse energy uses in this these applications. Although some applications could electrify faster than heavy trucks, the remoteness or activities and particular requirements would likely make many difficult to electrify.

Figure 12.32 shows the emissions in 2050 from off-road vehicles and machinery across the scenarios compared with the Current Policy Reference case. A 3% per year increase in energy for mining and construction activities is assumed in these projections. The electrification of these applications achieves an approximately 50% reduction in emissions by 2050 relative to the Current Policy Reference. The Further Technology and Tailwinds scenarios deploy biofuels blended with conventional diesel to achieve greater emissions reductions.

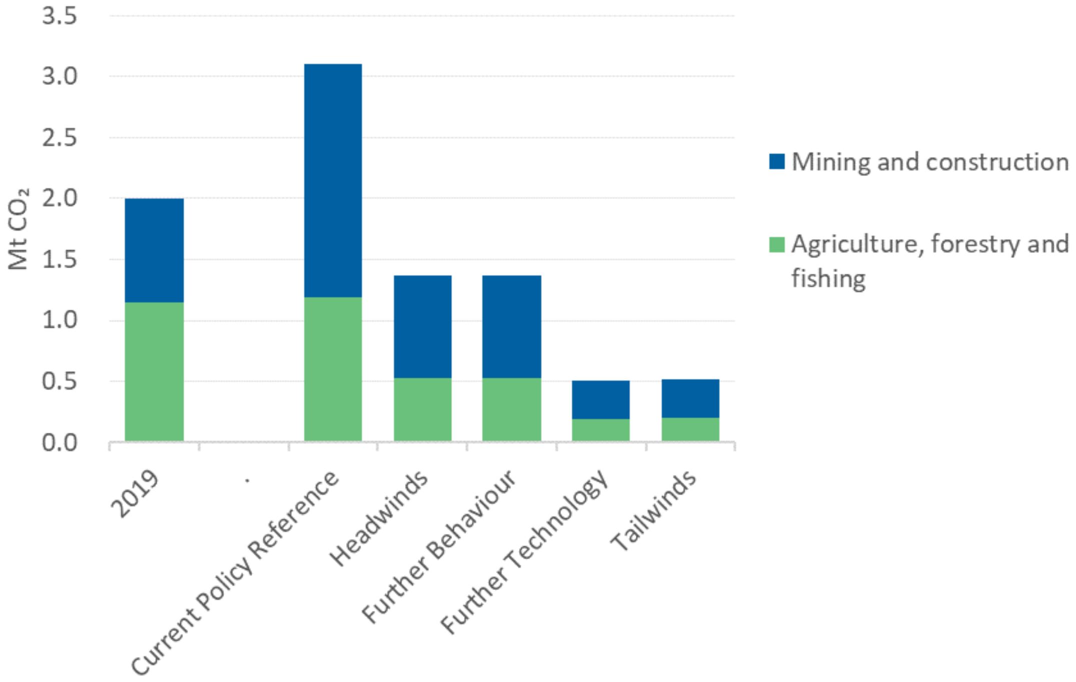

Figure 12.32: Emissions from off-road vehicles and machinery in 2050 across the scenarios compared with the Current Policy Reference case and 2019 emissions

Source: Commission analysis

Box 12.5: The future of fossil gas

The use of fossil gas decreases considerably under all modelled scenarios as is shown in Figure 12.33. As was the case for the Current Policy Reference projection, the large portion of gas currently used for methanol production is assumed to stop by 2040. By around 2025 the requirement for fossil gas for electricity generation has also reduced due to the displacement of baseload generation with new renewable projects. However, gas generation remains a necessity for covering dry year conditions and peaking requirements.

Other industrial uses of fossil gas and fossil gas use in buildings also reduces in all scenarios. This is due to electrification of heating and conversion to biomass with total conversion of low to medium temperature process heat by 2050.

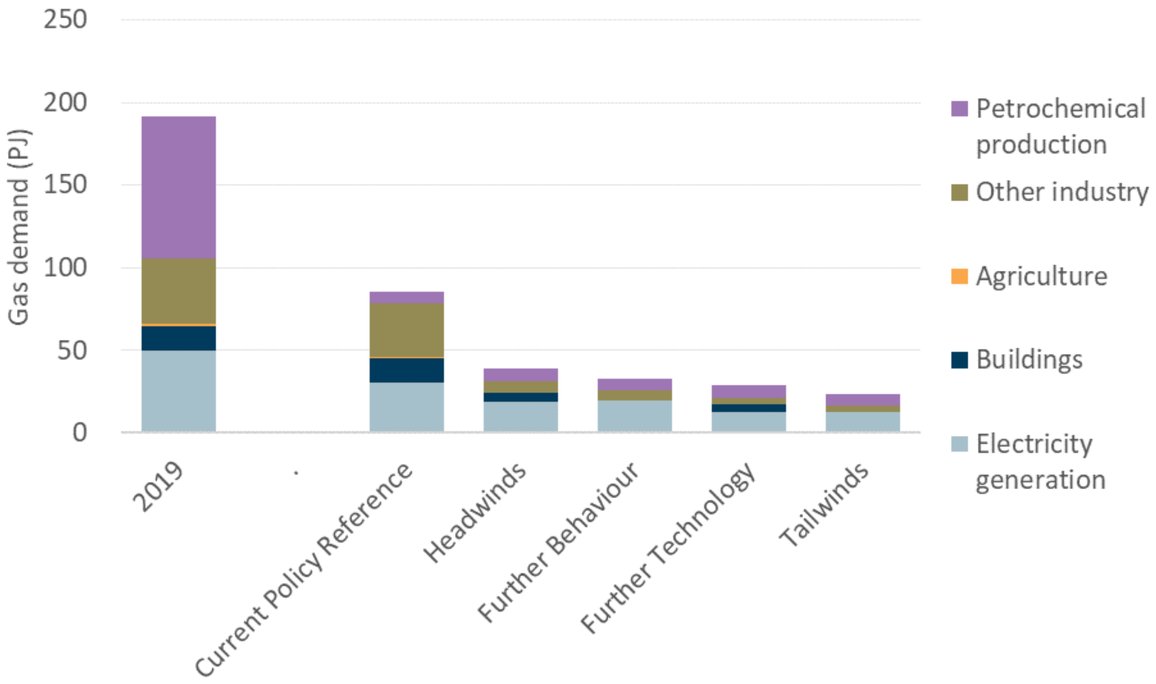

Figure 12.33: Fossil gas demand in 2050 across the scenarios and Current Policy Reference case relative to 2019 totals

Source: Commission analysis

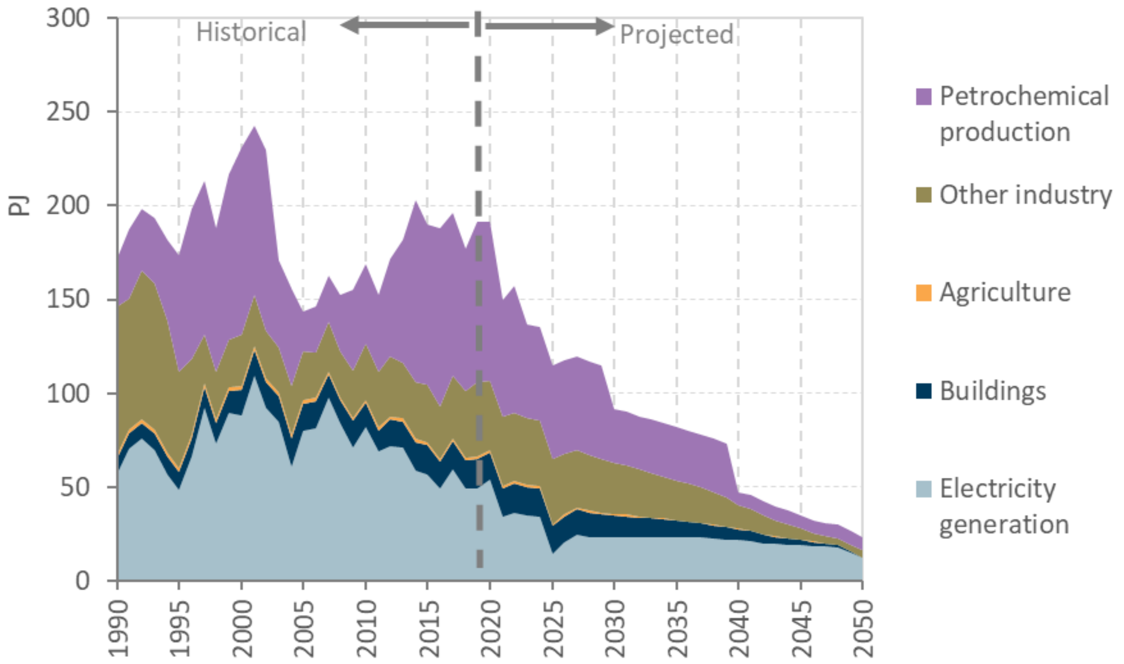

Figure 12.34: Projected fossil gas demand in in the Tailwinds scenario

Source: Commission analysis

These are the modelled scenarios and there are layers of uncertainties around the future of fossil gas in Aotearoa. The Government restrictions on offshore oil and gas exploration[12] announced in 2018 may limit future production pending a significant new find. Although a general shrinking trend in production and consumption towards 2050 has been projected, there are some market specifics that make forecasting emissions from fossil gas challenging, especially with regard to timing. We have considered the role of players within the market, the uses of gas and the options for lower emissions alternatives.

The importance of Methanex

Methanex produce methanol from fossil gas and export the majority overseas. They are a significant export earner and employer in Taranaki. They also underpin the domestic fossil gas market by purchasing most of the domestic supply. In 2019 Methanex consumed 40% of domestic fossil gas. This large demand provides sufficient incentive for fossil gas producers to continue upstream investment to secure supply. This is important to sustaining the domestic market longer-term. Methanex may no longer operate in Aotearoa if it cannot access sufficient fossil gas, or fossil gas at a price at which they can profitably produce methanol.

Methanex provide critical flexibility as a fossil gas user and can reduce parts of their production at times of scarcity. The flexibility they offer in varying their requirements by altering their production levels enables security of supply for other users – for example, Methanex can on sell their gas to electricity generators to provide cover for dry year relief. Although they perform this arbitraging role, Methanex would prefer to focus on their core business of methanol production where it provides a higher profit margin.

Methanex currently hold fossil gas supply contracts extending to 2029.[13] It is not clear whether contracts would be extended. This depends on several factors including global methanol prices, plant refurbishment requirements and gas supply in Aotearoa. However, in these projections it is assumed that they secure new contracts and continue operating until 2040.

Because of the anchor role and flexibility that Methanex play in the domestic fossil gas industry, if they were to stop production in Aotearoa then this could have significant impacts for other gas users.

Fossil gas supply in Aotearoa

The fossil gas used in Aotearoa is supplied from onshore and offshore fields in the Taranaki region and the supply industry is of significant scale. Existing offshore permits for oil and gas exploration issued prior to 2018 may result in substantial new production. There are potential new onshore permits, for example, Block Offer 2020 is ongoing. We have set aside this possibility as an uncertainty that would require further analysis.

The offshore Maui and Pohokura fields have been the largest producers historically. However, their output has reduced as they approach the end of their operational life. Although the total amount of fossil gas in permitted fields is reducing, there are still reserves that could be produced through continued operation. This production requires continued investment.

Figure 12.35 below shows a modelled projection of future gas supply, mostly from existing fields in the Taranaki region. This projection assumes that the existing reserves would be produced. However, commercial decision around production economics and future demand would determine whether the gas is brought to market. The projection shows that the offshore Pohokura field would continue to produce until around 2035. Given that this is an offshore field with high operating costs, it might not make commercial sense for the fields owners to produce in this manner. It is not possible to model these dynamics.

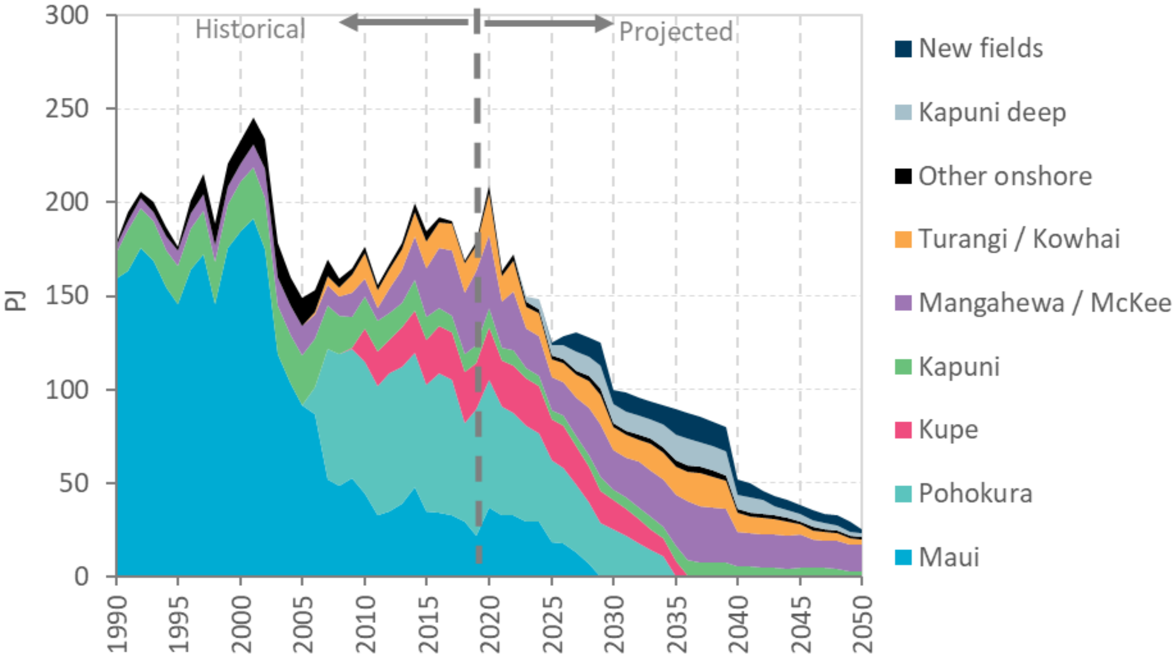

Figure 12.35: Fossil gas supply in the Tailwinds scenario

Source: Commission analysis

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[12] (New Zealand Government, 2018)

[13] (Methanex, 2018)

It is plausible that a market for fossil gas continues to exist, but domestic production is not able to meet it because wells are nearing their end of life. The wells may not produce sufficient gas and may also not be adjustable in terms of being able to increase and reduce production to meet variation in demand. In a situation without Methanex, solutions would be required to meet occasional users' needs for large amounts of gas. Options include storing large volumes of gas or supplementing domestic production with flexible supply in the form the form of imported LNG.

These outcomes are likely to result in higher supply costs then current wholesale fossil gas prices which could increase energy costs for users and could result in higher electricity prices. Using the EnergyLink modelling tools we investigated the impact of significantly higher gas price on the wholesale electricity price. We assumed that in 2029 the price of gas for electricity generation jumps from $8/GJ to $14/GJ which causes a wholesale electricity price increase of 20% or around $15-20/MWh. If such a price increase was to occur then this could slow and add cost to the transition to electricity as a low-emissions fuel for industry, business and households.

12.5.4 Forests

Our scenarios feature significantly less exotic afforestation and more native afforestation compared with the Current Policy Reference case. Figure 12.36 below compares the annual and cumulative areas of native and exotic afforestation.

The overall level of afforestation in our scenarios is similar to the Current Policy Reference, at 1.1 to 1.3 million hectares from 2021-2050. But native forests on less productive land would account for about 40-55% of this in our scenarios, compared with 10% in the Current Policy Reference case.

The total area of new native forest ranges from 440,000 to 670,000 hectares by 2050. Higher rates of native afforestation are assumed in the Further Behaviour Change and Tailwinds scenarios. The upper bound of 0.7 million hectares is informed by recent analysis from Manaaki Whenua on the potential area suitable for regenerating native forests.[14] The scenario trajectories consider practical limits on how fast native forest planting could be ramped up, particularly nursery capacity.[15]

The total area of new exotic forest in the scenarios ranges from 570,000 to 760,000 hectares by 2050. This is comparable to the total area planted between 1990 and 2020.

The exotic afforestation trajectories were designed by following the Current Policy Reference case up until 2030 and then ramping down to a level sufficient to meet and sustain net zero long-lived gas emissions by 2050. In the Headwinds scenario, an additional 35,000 hectares of land-use change from sheep and beef to forestry (or a different low-emissions use) was required in the 2020s in order to meet the 2030 biogenic methane target.

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[14] (The Aotearoa Circle, 2020)

[15] (New Zealand Plant Producers Incorporated (NZPPI), 2019)

Box 12.6: Modelling land use and forestry

Land areas are an input assumption in all our modelling. The starting point for all scenarios is the Current Policy Reference case, informed by projections from the Ministry for Primary Industries (MPI) (see *Chapter 11: Where are we currently heading?* for more information).

For each scenario, we specify annual areas of exotic and native afforestation and deforestation. We assume native afforestation can be established through a combination of reversion and planting. The change in forest land area relative to the Current Policy Reference case is calculated and corresponding adjustments are made to other land-use categories. Exotic forestry is assumed to compete with productive sheep and beef farmland; for example, a decrease in exotic afforestation relative to the Current Policy Reference case leads to increased land available for sheep and beef farming. New native forest is assumed to be established on less productive land and have a smaller impact on livestock numbers and production: we assume that each hectare of native forest reduces the effective grazed area by 0.2 hectares.

We have developed assumptions on levels of afforestation based on evidence and judgement (see *Chapter 9: Removing carbon from our atmosphere*). In the case of exotic forestry, we have used a manual refinement process to 'goal seek' and ensure the net zero target for long-lived gases is met by 2050 or earlier.

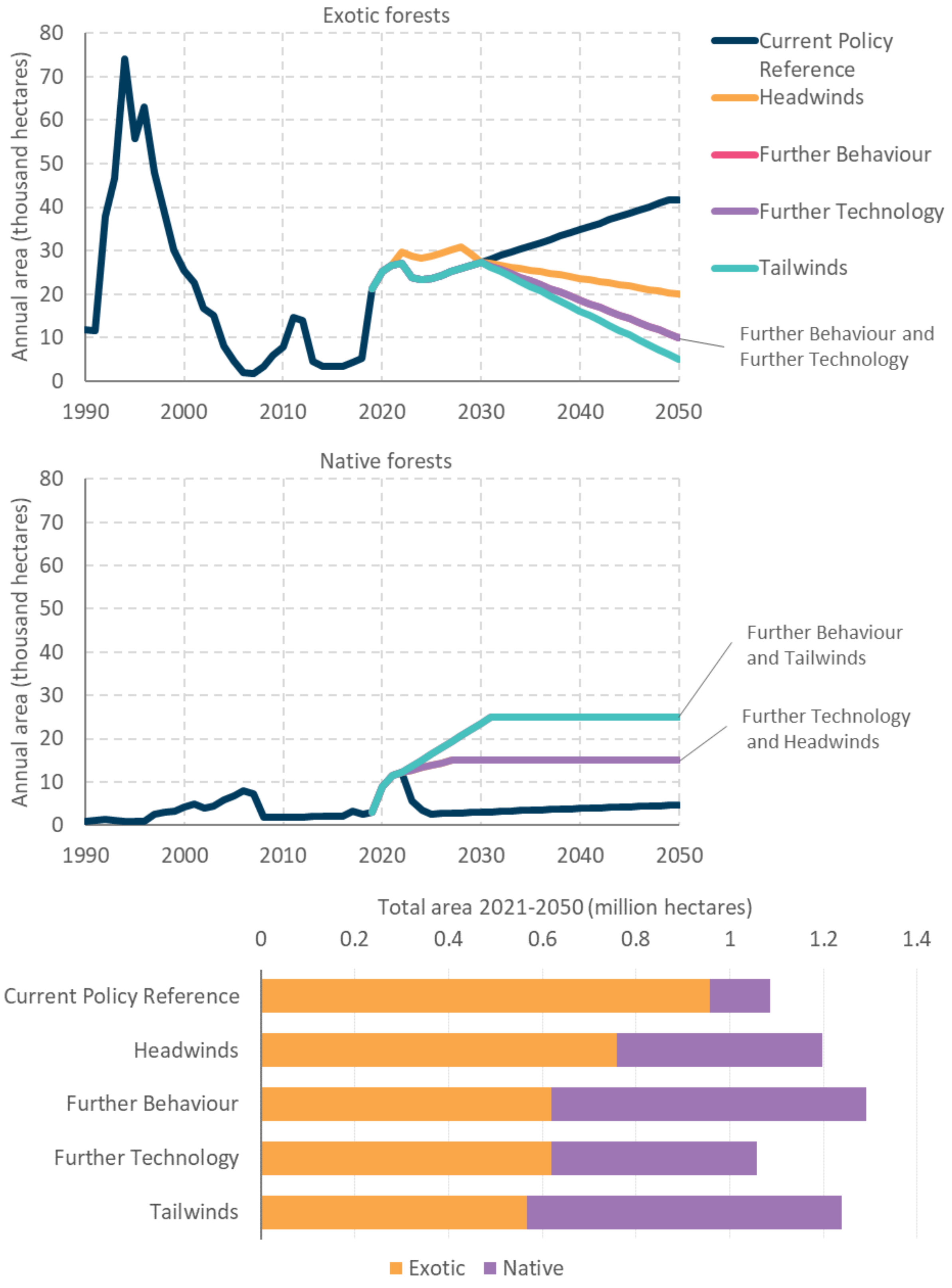

Figure 12.36: Annual exotic afforestation (top), annual native afforestation (middle), and cumulative total areas in 2050 (bottom) by scenario

Source: Commission analysis

Figure 12.37 shows the resulting net forestry emissions out to 2050. Differences across the scenarios are relatively small, but greater variation would be seen after 2050 due to the diverging rates of exotic afforestation (post-2050 implications were explored in *Section 12.4.4, Looking beyond 2050* earlier in this chapter).

Early differences are partly due to different deforestation assumptions across the scenarios, all of which have reduced deforestation compared with the Current Policy Reference case. In the Further Behaviour and Tailwinds scenarios, deforestation is almost eliminated from 2026 except for a small annual area of post-1989 exotic forest.[16]

In 2050, native forests deliver annual net carbon removals of 3.7 Mt CO_2 in the Headwinds and Further Technology Change scenarios and 5.9 Mt CO_2 in the Further Behaviour Change and Tailwinds scenarios.

The annual rate of carbon removals in the scenarios peaks around 2040, about 10 years after the peak in exotic forest planting. Cumulative net carbon removals from 2021 to 2050 range from 432-468 Mt CO_2, which is equal to or higher than in the Current Policy Reference case. However, the rate of removals is still growing in 2050 in the Current Policy Reference case due to the assumption exotic afforestation continues at an increasing rate.

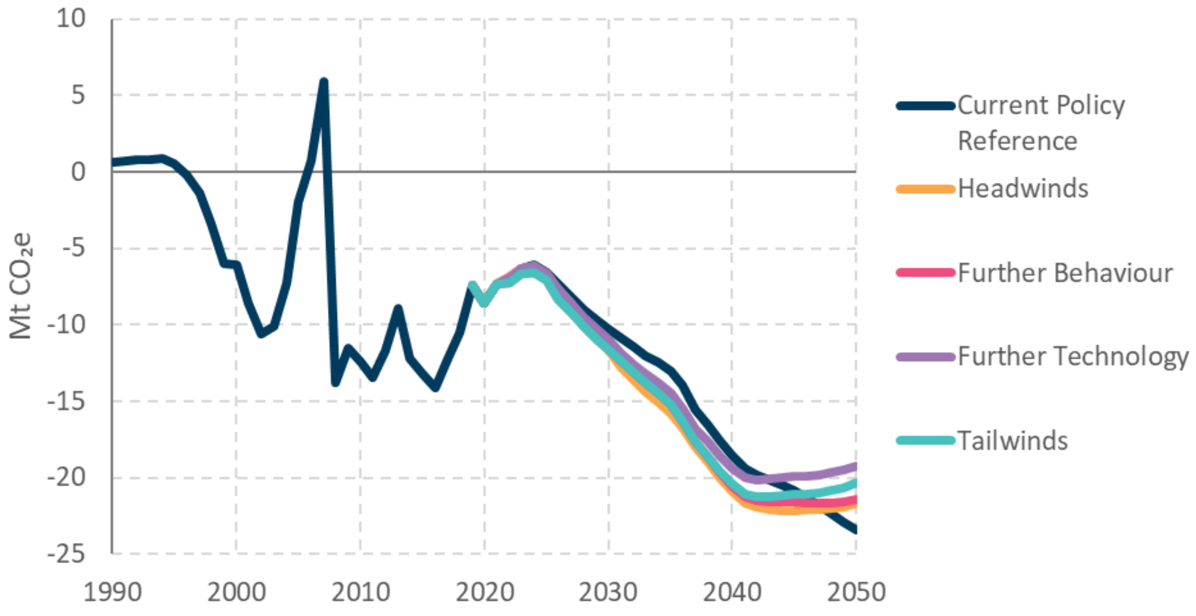

Figure 12.37: Net forestry emissions from 1990 to 2050 across the scenarios

Source: Commission analysis

12.5.5 Agriculture

Land use

All scenarios see a reduction in the total area of land used for food production from 2019 to 2050 (Figure 12.38). However, the reduction is smaller than in the Current Policy Reference case

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[16] This allows for some continued pre-1990 exotic forest deforestation with offsetting with carbon equivalent forest.

presented in *Chapter 11: Where we are currently heading?*. Compared with the Current Policy Reference case, the scenarios feature:

- A smaller reduction in sheep and beef land due to lower rates of conversion to exotic forestry. Pasture used for sheep and beef farming reduces from 7.99 million hectares in 2019 to between 6.89 and 7.04 million hectares in 2050 (compared to 6.75 million hectares in the Current Policy Reference case).[17] The largest reduction occurs in the Headwinds scenario, which requires higher land-use change to meet both the net zero long-lived gas target and the biogenic methane target.
- There was the same change in dairy land area in the Headwinds and Further Technology Change scenarios, reducing from 1.74 million hectares in 2019 to 1.66 million hectares in 2050. The Further Behaviour Change and Tailwinds scenarios assume a further 5% of current dairy land (around 87,000 hectares) is converted to horticulture by 2050. This would almost double the existing horticulture area by 2050, compared with a 17% increase in the Current Policy Reference case.
- Significantly greater native afforestation on less productive land, as discussed above.[18]
- The same assumption on retirement of agricultural land into other uses.

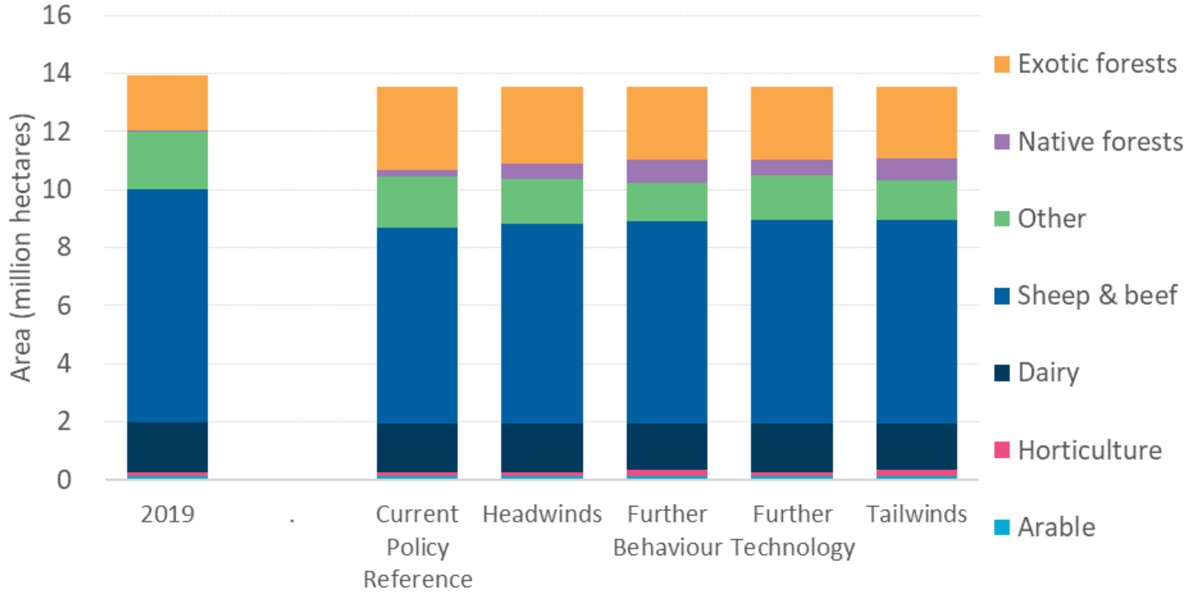

Figure 12.38: Agriculture and forestry land area in 2050 compared with 2019

Source: Commission analysis

Changes to farm management practices

Chapter 7: Reducing emissions from agriculture discusses shifts in farm management practices which can reduce total feed inputs and emissions. Different approaches will be better suited to different individual farms, given the diversity of farm situations, farmer preferences and objectives. Rather than making assumptions about adoption of individual practice changes, our scenarios consider the

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[17] This includes the assumed impact of native afforestation on productive pasture land as described in Box 12.6: Modelling land use and forestry.

[18] In the figure this is shown as taking land from the 'Other' category, which does not contribute to production. Some could also occur on land that is not classified as agricultural land, such as lifestyle blocks.

overall changes to livestock numbers and production that could result from a range of practice changes being adopted across different farms.

The different practice changes have different implications for livestock numbers and production, as summarised in Table 12.7. Some changes could allow farmers to maintain production levels from fewer animals, which is likely to improve profitability. Others would see production levels reduced, which could either reduce or improve profitability depending on the associated changes in inputs (such as feed and labour). Within some options there is potential for a rebound effect, where unutilised pasture or feed could be used to increase stock numbers or consumed elsewhere. For these options to lead to a reduction in emissions, it may require an associated change in land use, such as putting some low-producing pasture into native forest or other uses.

Table 12.7: Impacts of potential farm practice changes on animal numbers, production and emissions

		Production per animal[19]	Stock numbers	Total production	Feed inputs and emissions
Improving animal performance while decreasing stocking rates		Increase	Reduce	Maintain	Reduce
Moving to lower input farm system		Maintain or slightly reduce	Reduce	Reduce	Reduce
Once a day milking	***No rebound***	Reduce	Maintain	Reduce	Reduce
	Rebound effect	Reduce	Increase	Maintain or slightly reduce	Maintain or slightly reduce
Reducing breeding and replacement animals	***No rebound***	Increase	Reduce	Maintain	Reduce
	Rebound effect	Increase	Maintain	Increase	Maintain

Our scenarios explore two distinct futures from potential changes in farm management practices. Historic and future changes in livestock numbers, animal productivity and total milk and meat production are shown below in Figure 12.389.[20]

In the ENZ model and in all figures presented here, sheep and beef farming is treated as an aggregated sector. Total sheep and beef animal numbers are expressed using a weighted population metric which accounts for the approximate relative feed intake and emissions: one beef cattle animal is assumed equivalent to five sheep. This weighting is constant across time.

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[19] This refers to total production divided by total population, including breeding and replacement animals.

[20] These charts do not show the Further Technology Change and Tailwinds scenarios as they are almost identical to the Headwinds and Further Behaviour Change scenarios respectively. Small differences in livestock numbers and production arise due to the scenarios' different assumptions on the level of afforestation.

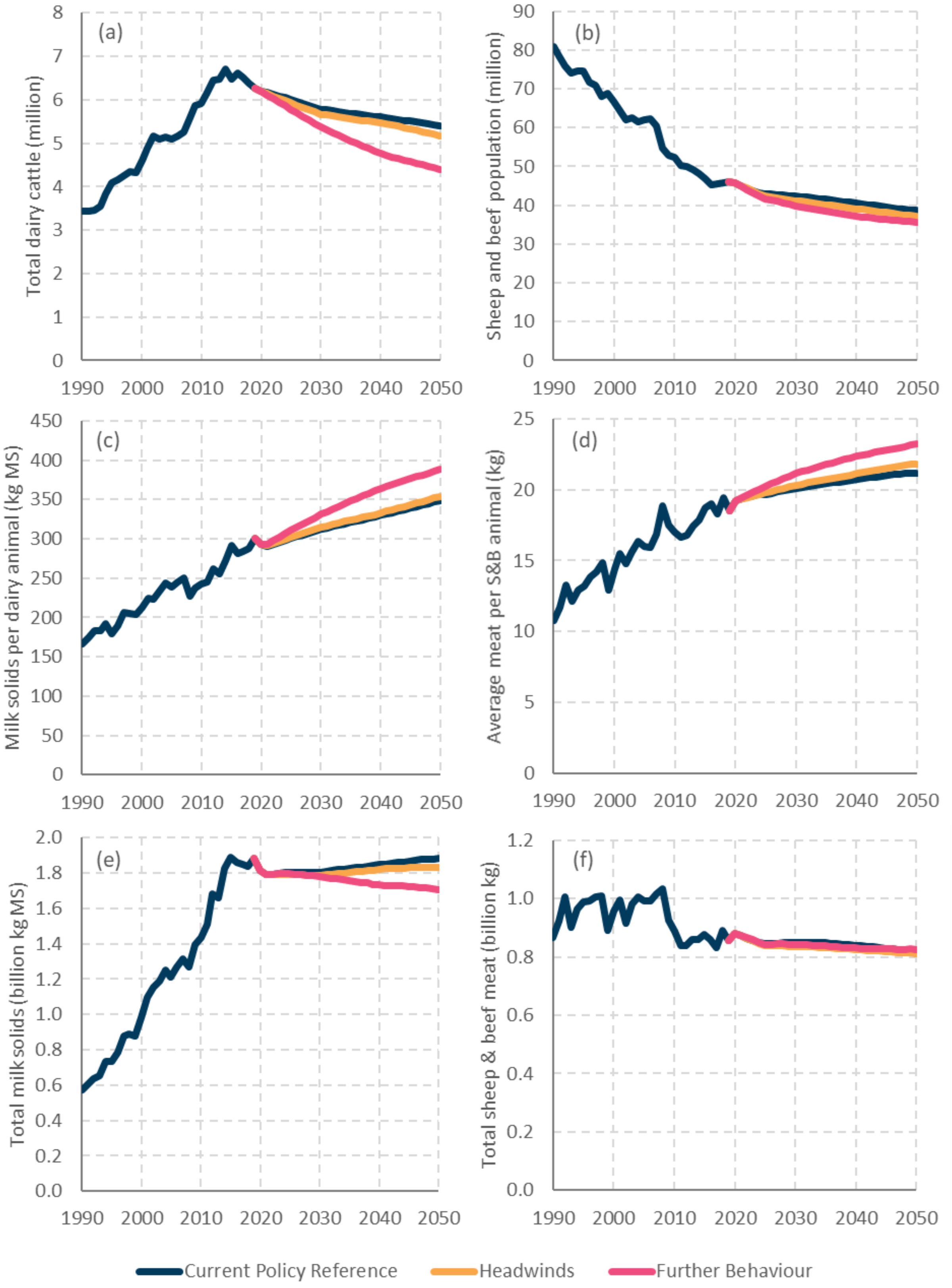

Figure 12.389: Scenario assumptions and outputs for (a) total dairy cattle; (b) sheep and beef population (in weighted units); (c) milk solids per dairy cattle; (d) meat per sheep & beef animal; (e) total milk solids production; (f) total sheep and beef meat production.

Source: Commission analysis

The Headwinds scenario assumes modest additional reduction in livestock numbers relative to the Current Policy Reference case, with only small corresponding increases in animal performance. As a result, total production is slightly reduced compared with the Current Policy Reference, but still roughly the same as current levels. The lower level of land use change to exotic forestry in our scenarios compared with the Current Policy Reference helps to maintain production levels.

This scenario could represent a future in which some farmers deliberately choose to adopt practice changes that result in lower production, without necessarily reducing profitability. Alternatively, it could represent a future where farmers are attempting to maintain production while reducing stocking rates but some are less successful in their efforts to improve animal performance, meaning there is limited potential without significant profitability impacts.

By contrast, the Further Behaviour Change scenario represents a future where animal performance can be significantly improved, allowing deeper reductions in livestock numbers while maintaining similar production levels. This scenario sees additional reductions in the dairy herd due its explicit assumption that 5% of current dairy land is converted to other uses such as horticulture. Total milk solids production is 10% lower in 2050 than in the Current Policy Reference, while horticulture production would increase by nearly 70%.

We have looked at how the productivity improvements in this scenario could be achieved through specific mechanisms (for example, improved milking cow performance and lambing rates) based on the work for the Biological Emissions Reference Group (BERG) and other research. Our assumptions are broadly in keeping with those used for the BERG in its future scenario analysis and in other contributing research.[21] For dairy, several studies using farm system models and farmlet trials have demonstrated the potential to reduce emissions through lowering stocking rates while maintaining production.[22] Realising these improvements depends on increasing the genetic merit of animals, advancing skills to manage pasture quality with fewer grazing animals, and other factors. Reducing replacement rates could also contribute to producing more milk from a smaller total herd.

Figure 12.38 shows that our assumed productivity improvements in the Further Behaviour scenario are similar to rates achieved historically for dairy, and slower than past rates for sheep and beef. The latter reflects market constraints around further increases in carcass weights, which has been an important driver of historic productivity gains. However, continuing to improve growth rates and bringing slaughter dates forward could be an additional source of emissions reductions that we have not included in our modelling. For dairy we have looked at historic trends by region to assess how much the conversion of highly productive irrigated land in Canterbury and Southland to dairy contributed to increased production per cow at the national level. Our analysis showed that this can account for at most 11% of the national increase over the last 20 years, and that production per cow has increased significantly in every region.

Figure 12.390 and Figure 12.401 below show the resulting methane emissions intensity for dairy and sheep and beef respectively. These results include the effects of technology adoption (discussed

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[21] We have revised our assumptions around sheep and beef production since our *Draft Advice for Consultation* based on subsequent analysis and new information received from the Ministry for Primary Industries. This led to significantly slower baseline productivity improvements in the Current Policy Reference case. We also revised our assumptions on the potential for additional productivity gains in the more conservative direction, after reassessing these against the BERG reports and other work.

[22] (de Klein & Dynes, 2017)

below), but the effect of changes in farm management practices can be seen in the difference between the Headwinds and Further Behaviour scenarios.

Technological changes

The scenarios include assumptions on the adoption of several emerging technologies. The Headwinds and Further Behaviour scenarios assume small impacts from low-emissions breeding for sheep and beef only, and from methane inhibitors for dairy only. The Further Technology and Tailwinds scenarios assume high impacts from low-emissions breeding, including for dairy, and from methane inhibitors and vaccines that could also be adopted on sheep and beef farms. The assumptions used in each scenario are laid out in Table 12.8 below. Figure 12.390 and Figure 12.401 show the impacts of these technology assumptions on methane emissions per unit of product.

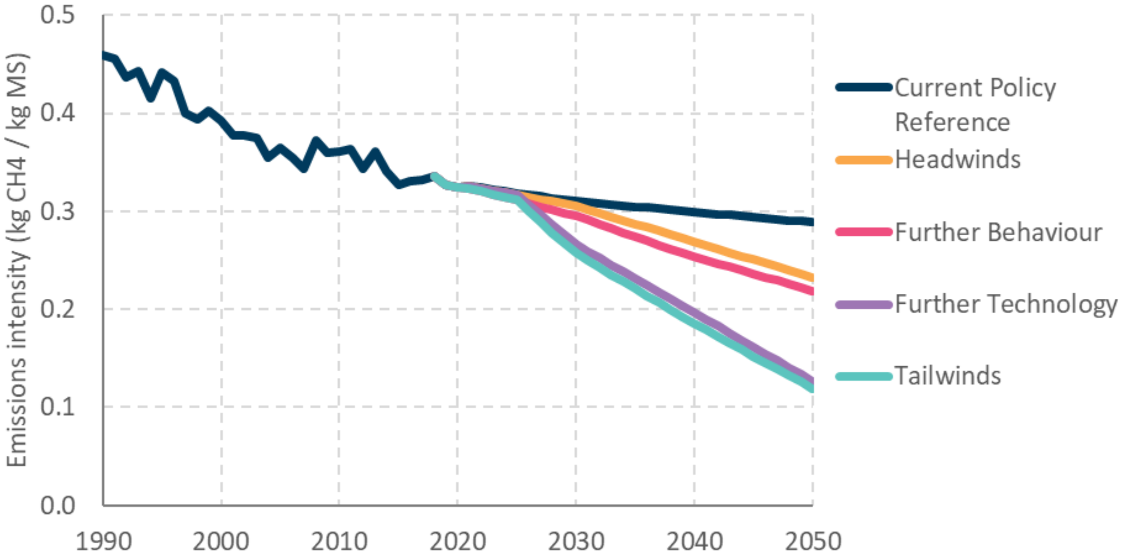

Figure 12.390: Dairy biogenic methane emissions intensity 1990-2050

Source: Commission analysis

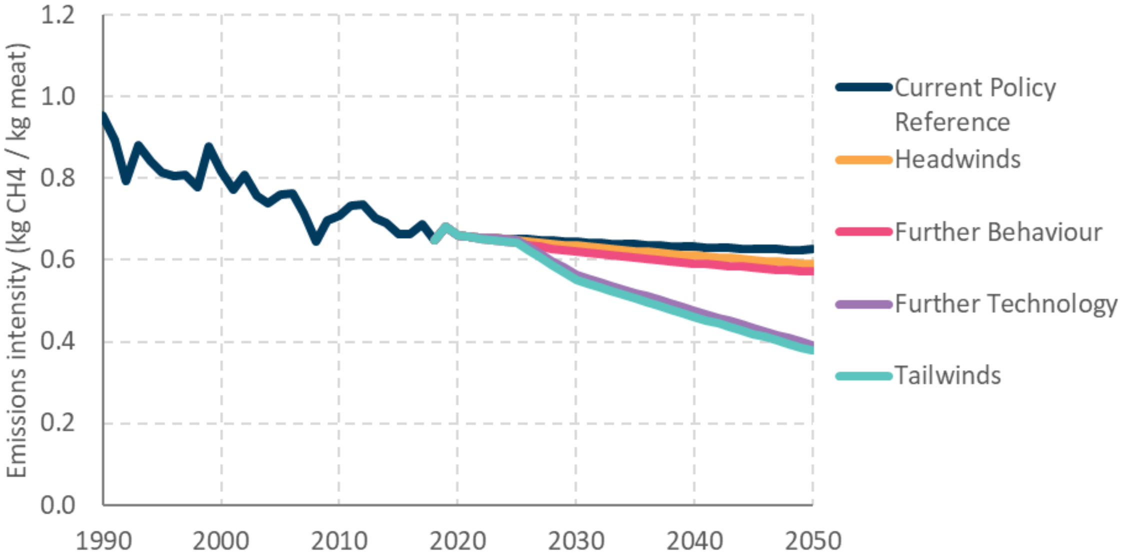

Figure 12.401: Sheep and beef biogenic methane emissions intensity 1990-2050

Source: Commission analysis

Table 12.8: Scenario assumptions on agriculture mitigation technologies

		Low effectiveness and adoption (Headwinds and Further Behaviour scenarios)	High effectiveness and adoption (Further Technology and Tailwinds scenarios)
Low methane breeding	Dairy	Available from 2030. Enteric methane emissions reduction increases linearly to 7.5% in 2050 (15% effectiveness x 50% adoption).	Reduction of 13.5% in 2050 (15% effectiveness x 90% adoption).
	Sheep and beef	Available from 2025. Enteric methane emissions reduction increases linearly to 4.5% in 2050 (15% effectiveness x 30% adoption).	Reduction of 7.5% in 2050 (15% effectiveness x 50% adoption).
Methane inhibitor	Dairy	Available from 2025. Enteric methane emissions reduction of 1% by 2030 (10% effectiveness x 10% adoption) and 12% by 2050 (30% effectiveness x 40% adoption).	Reduction of 12% by 2030 (30% effectiveness x 40% adoption) and 37.5% by 2050 (50% effectiveness x 75% adoption).
	Sheep and beef	None	Enteric methane reduction of 1.5% by 2030 and 20% by 2050 (50% effectiveness x 40% adoption).
Methane vaccine[23]	Dairy	None	Additional enteric methane reduction of 3% by 2030 (30% effectiveness x adoption of 10%) and 4.5% by 2050 (30% effectiveness x adoption of 15%) on top of those from inhibitor.
	Sheep and beef	None	Additional enteric methane reduction of 10.5% by 2030 (30% effectiveness x adoption of 35%) and 12% by 2050 (30% effectiveness x adoption of 40%) on top of inhibitor.
Nitrification inhibitor	Dairy	Available from 2030. Nitrous oxide emissions reduction of 2.5% by 2035 (60% effectiveness x 10% adoption x application in 5/12 months) and 12% by 2050 (60% effectiveness x 20% adoption with year-round application).	Reduction of 7.5% by 2035 (60% effectiveness x 30% adoption x application in 5/12 months) and 30% by 2050 (60% effectiveness x 50% adoption with year-round application).

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[23] Methane inhibitors and vaccines are assumed to be mutually exclusive, so cannot both be applied to the same animal. Combined adoption of inhibitor and vaccine in 2050 in the Further Technology Change and Tailwinds scenarios is 90% for dairy and 80% for sheep and beef.

	Sheep and beef	None	None

Biogenic methane emissions

Figure 12.412 shows the agricultural biogenic methane emissions breakdown in 2050 across the scenarios compared with the Current Policy Reference case and with emissions in 2019. Relative to 2017 (the base year for the biogenic methane target), the scenarios see reductions of 23-55% by 2050. Figure 12.423 shows the emissions trajectory for all scenarios.

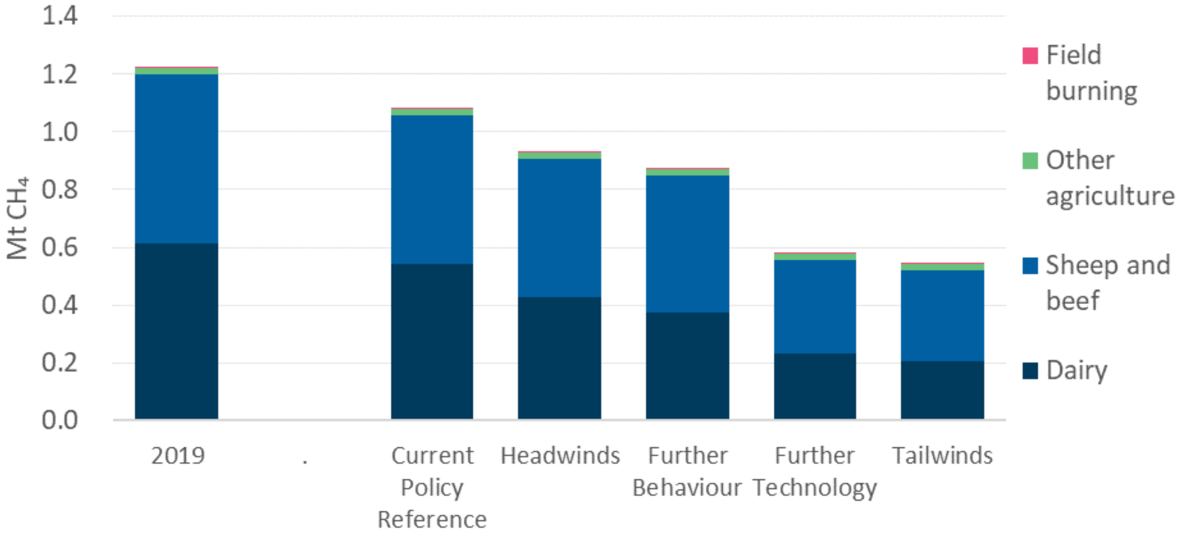

Figure 12.412: Agriculture biogenic methane emissions in 2050 compared with 2019

Source: Commission analysis

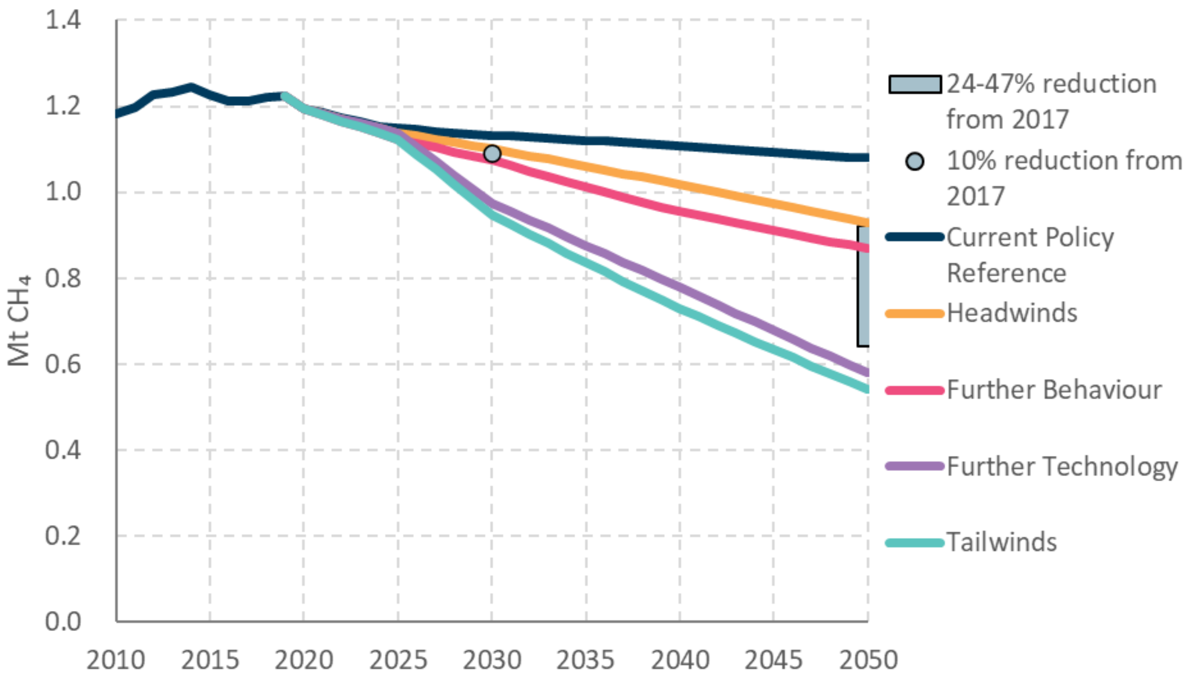

Figure 12.423: Agriculture biogenic methane emissions 2010-2050 across the scenarios

Source: Commission analysis

Nitrous oxide emissions

Figure 12.4 shows a breakdown of nitrous oxide emissions in 2050 across the scenarios compared with the Current Policy Reference and with 2019. Within this, we have split out the contributions from livestock excreta, nitrogen fertiliser use, and other sources. Figure 12.435 shows the emissions trajectories over time.

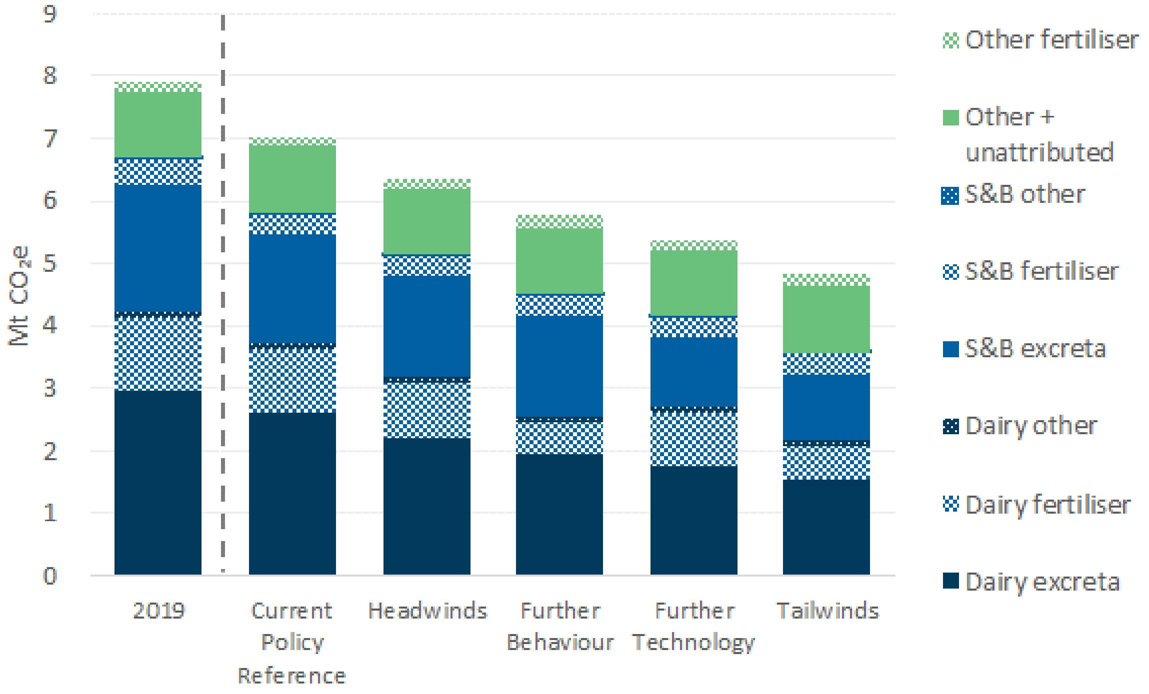

Figure 12.44: Agriculture nitrous oxide emissions in 2050 compared with 2019.

Source: Commission analysis

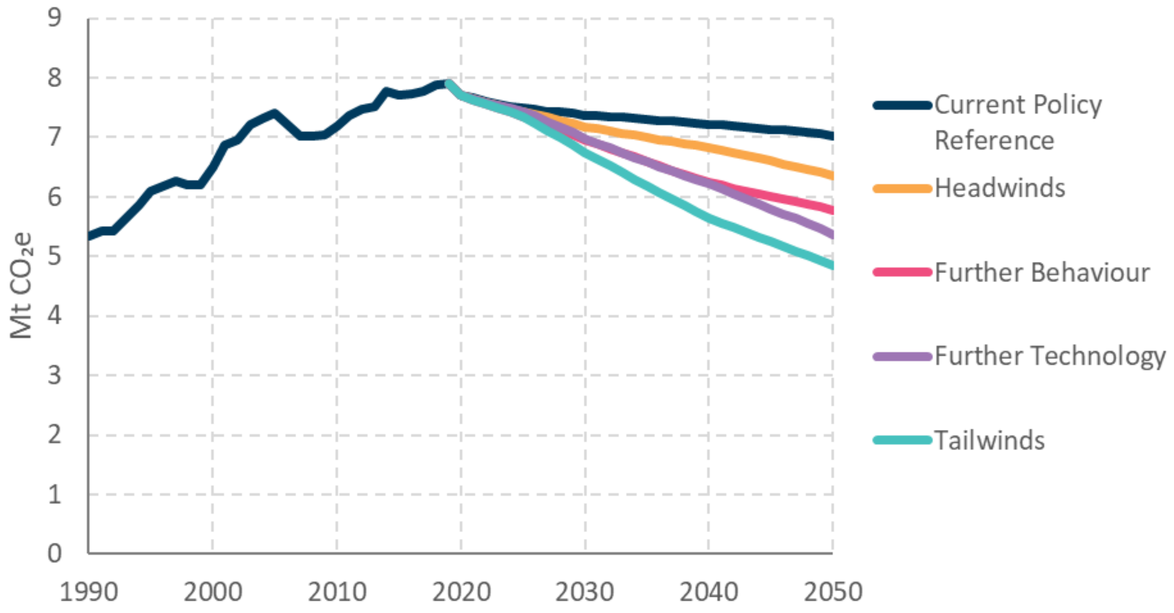

Figure 12.435: Agriculture nitrous oxide emissions 2010-2050 across the scenarios

Source: Commission analysis

Nitrous oxide emissions reductions in the scenarios come from a combination of land-use change, reductions in livestock numbers, modelled reductions in nitrogen fertiliser, increased use of urease inhibitor, and uptake of nitrification inhibitors. Figure 12. shows that most nitrous oxide emissions are caused by urine and dung deposited by livestock, but meaningful reductions could also come from reduced fertiliser use. In the Further Behaviour and Tailwinds scenarios, total nitrogen fertiliser use reduces by around 15% by 2030 and 35% by 2050 relative to 2019, mainly from farm practice changes.[24]

12.5.6 Waste

Future emissions from waste span a wide range across our four scenarios (Figure 12.446). The reductions in the Headwinds scenario are in line with the targets for total biogenic methane emissions, while the other scenarios outperform these targets.

In the Headwinds scenario, biogenic methane emissions reduce by 19% by 2030 and 32% by 2050, compared to 2017. The Further Behaviour scenario sees much larger reductions occurring over time, to 55% below 2017 levels by 2050. Despite large and fast cuts in the amount of organic waste sent to landfill in this scenario, the emissions reductions occur more gradually as organic matter already in landfills continues to release methane for many years. This demonstrates the inertia associated with the waste decay process.

Improvements to landfill gas capture in the Further Technology and Tailwinds scenarios lead to sharper reductions of 38% and 42% by 2030, and 67% and 75% by 2050 respectively. This highlights the opportunity landfill gas capture provides to drive faster emissions cuts. This is because installing

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[24] ENZ models changes in nitrogen fertiliser use on dairy farms in response to changes in dry matter intake per hectare. For more information see Appendix 1 of *Chapter 11: Where are we currently heading?*

landfill gas capture to sites with high volumes of legacy organic waste reduces the methane emissions from historic as well as future waste deposited at the landfill.

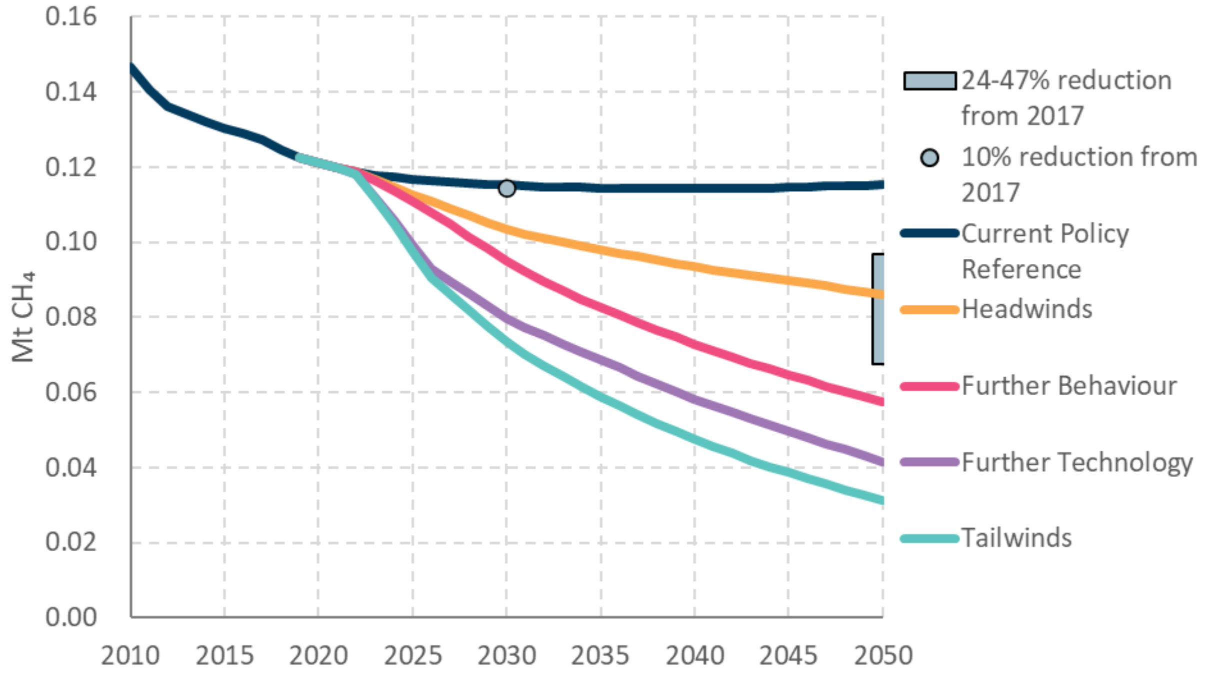

Figure 12.446: Biogenic methane emissions from waste by scenario

Source: Commission analysis

Waste Generation

All scenarios see a reduction in waste generation out to 2050 for municipal food and paper waste, with further reductions to other waste types in scenarios with greater behaviour change.

In comparison to the Current Policy Reference Case, waste generation settings in the different scenarios are:

- In Headwinds and Further Technology Change: municipal food and paper waste are 15% lower by 2050. All other waste types across all disposal sites have the same level of waste generation as baseline.
- In Further Behaviour Change and Tailwinds: paper waste is 35% lower, food waste is 30% lower, and all other waste types are 15% lower for municipal landfills by 2050. Garden and wood waste are 15% lower for non-municipal landfills, and all other waste types across non-municipal landfills and farm fills are 10% lower by 2050. The only exception is sludge waste which remains at baseline.

Waste Recovery

Overall waste recovery is higher in all scenarios in comparison to the Current Policy Reference, with the degree of increased recovery and the balance of recovery options varying by scenario. Different types of recovery options are more suitable towards different types of waste. For example, food waste is a more suitable feedstock for composting and wood waste is a more suitable feedstock for use as boiler fuel.

Waste recovery settings in the different scenarios are:

- In Headwinds and Further Technology Change: 60% of food waste, 38% of garden waste, 34% of paper waste, 25% of wood waste, 15% of textile waste and 18% of construction waste is recovered by 2050. Composting is the most common recovery option for recovered food and garden waste. Recycling and reusing is the most common recovery option for textile, paper and construction waste. Use as boiler fuel is the most common recovery option for wood waste.
- In Further Behaviour Change and Tailwinds: 90% of food waste, 90% of garden waste, 92% of paper waste, 62% of wood waste, 50% of textile waste and 58% of construction waste is recovered by 2050. Food waste is evenly recovered across recycling, composting and anaerobic digestion. Garden waste is evenly recovered across composting and anaerobic digestion. Recycling and reusing remains the most common recovery option for construction, paper and textile waste and use as boiler fuel is still the most common recovery option for wood waste.

Figure 12.457 shows the combined effect of reduced waste generation and waste recovery on the amount of organic waste sent to landfill in the Further Behaviour scenario.

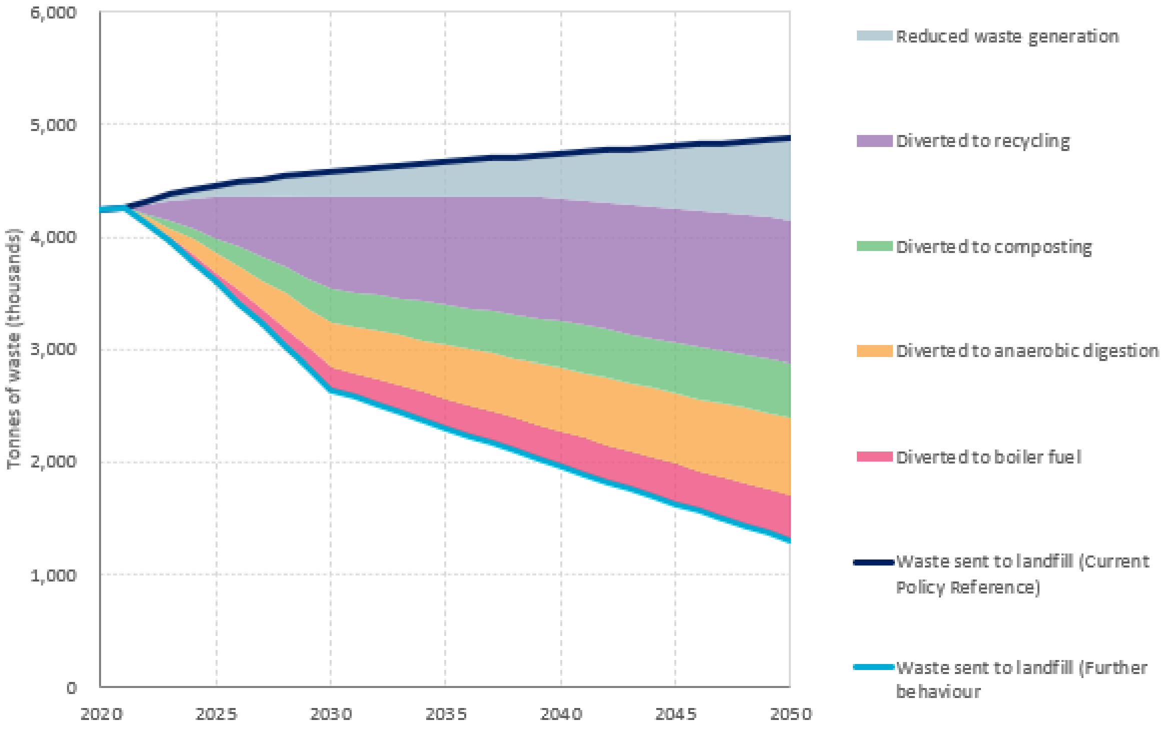

Figure 12.457: Total organic waste sent to landfill in the Further Behaviour scenario compared with the Current Policy Reference case, showing the effect of reduced waste generation and waste recovery

Source: Commission analysis

Total reduction of waste to landfill

The overall impact of decreasing waste generation at source and increasing resource recovery will be to decrease the amount of waste going to landfill. Table 12.9 below shows the percentage of overall waste recovered from landfill split across waste streams.

Table 12.9 Overall waste recovery rate across waste stream split by scenario

	2030		2040		2050	
	Headwinds	**Tailwinds**	**Headwinds**	**Tailwinds**	**Headwinds**	**Tailwinds**
Food	34%	64%	50%	80%	66%	93%
Garden	15%	66%	24%	85%	38%	91%
Paper	21%	57%	33%	79%	43%	95%
Wood	8%	31%	17%	52%	25%	67%
Textile	5%	33%	10%	46%	15%	57%
Nappies	2%	24%	4%	37%	6%	66%
Sludge	10%	37%	20%	60%	30%	89%
Construction and demolition	6%	36%	12%	48%	18%	62%
Bulk	5%	30%	10%	40%	15%	52%
Industrial	5%	28%	10%	38%	15%	50%
Total organic	11%	42%	20%	59%	28%	73%

Landfill gas generation and landfill gas capture

As organic waste breaks down it produces biogenic methane. The level of biogenic methane generated depends on a complex number of variables including waste type, landfill temperature, existing waste at landfill, depth of landfill and other variables. The raw amount of biogenic methane generated at this stage, before gas capture, is referred to as 'methane generation’.

The two key variables in landfill gas capture are the efficiency of landfill gas capture and the portion of methane generated subject to gas capture. The efficiency of landfill gas capture refers to the portion of methane gas captured over the lifespan of the landfill gas capture system and the portion of methane generated subject to gas capture refers to the percentage of waste emissions with landfill gas capture in that particular category. Methane produced after it has been subject to gas capture is referred to as 'methane emissions.’

In comparison to the Current Policy Reference case, landfill gas capture efficiency and portion of sites with landfill gas capture in the different scenarios are:

- In Headwinds and Further Behaviour Change: Landfill gas capture efficiency is the same as in baseline with 68% being the assumed for existing municipal landfills with gas capture and 52% for other sites through to 2050. Around a quarter of methane generated from sites with no gas capture (except farm fills) are now subject to gas capture.
- In Tailwinds and Further Technology Change: Landfill gas capture efficiency for all open landfills increases to 90% by 2050. In addition, 90% of methane generated from sites with no gas capture (except farm fills) are now subject to gas capture.

Increasing the amount of methane emissions subject to gas capture can be achieved through either installing landfill gas capture at sites that currently do not have it or by diverting waste away from landfills without gas capture to landfills with gas capture.

The importance of landfill gas capture is illustrated in Figure 12.48 below which compares methane generation in the Current Policy Reference compared to methane emissions in the Further Technology Change scenario.

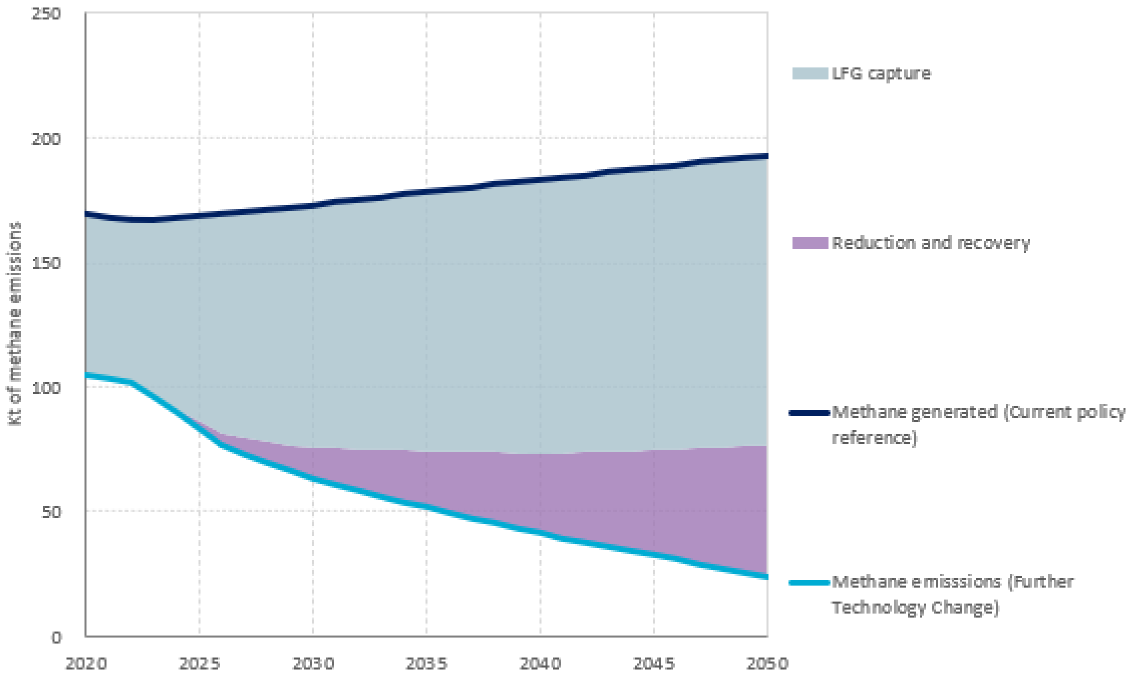

Figure 12.468: Landfill gas capture compared across Current Policy Reference and Further Technology Change

Source: Commission analysis

Even in scenarios with conservative assumptions about landfill gas capture, it still prevents substantial levels of methane which has been generated from being emitted. Figure 12.49 demonstrates the role of landfill gas capture, but also illustrates that as waste generation decreases, so does methane generation and the potential emissions prevented by landfill gas capture.

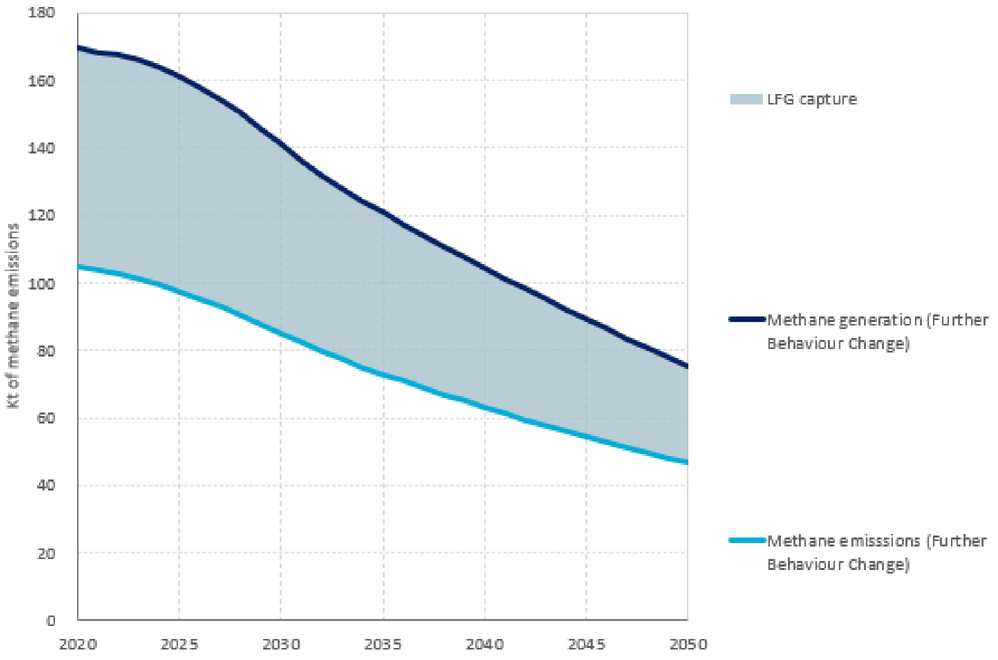

Figure 12.479: Methane generation compared to biogenic methane emissions in the Further Behaviour Change scenario.

Source: Commission analysis

12.5.7 F-gases

F-gas emissions are largely from the leakage and improper disposal of HFCs in refrigeration and air conditioning equipment. Two projections for F-gas emissions are demonstrated in these scenarios:

- In the Headwinds and Further Technology scenarios emissions are reduced below the Current Policy Reference by increased capture and destruction of HFCs from end-of-life products.
- The Further Behaviour and Tailwinds Scenario achieve greater amounts of capture and destruction to reduce emissions further. In addition to this, in these scenarios the importation of certain products containing high-GWP refrigerants are restricted – this reduces emissions from product leakage in subsequent years.

The emissions projections for these scenarios are shown in Figure 12.480 below. The plot shows the considerable potential of reducing emissions by improving recovery and destruction. Note that there is considerable uncertainty in estimates and projections of emissions from HFCs as quantities have to be inferred from a model which balances known imports and reported recovery with assumed leakage from an operational ‘bank’. This contrasts with fossil fuel emissions where the fuel quantity is known at the point of combustion.

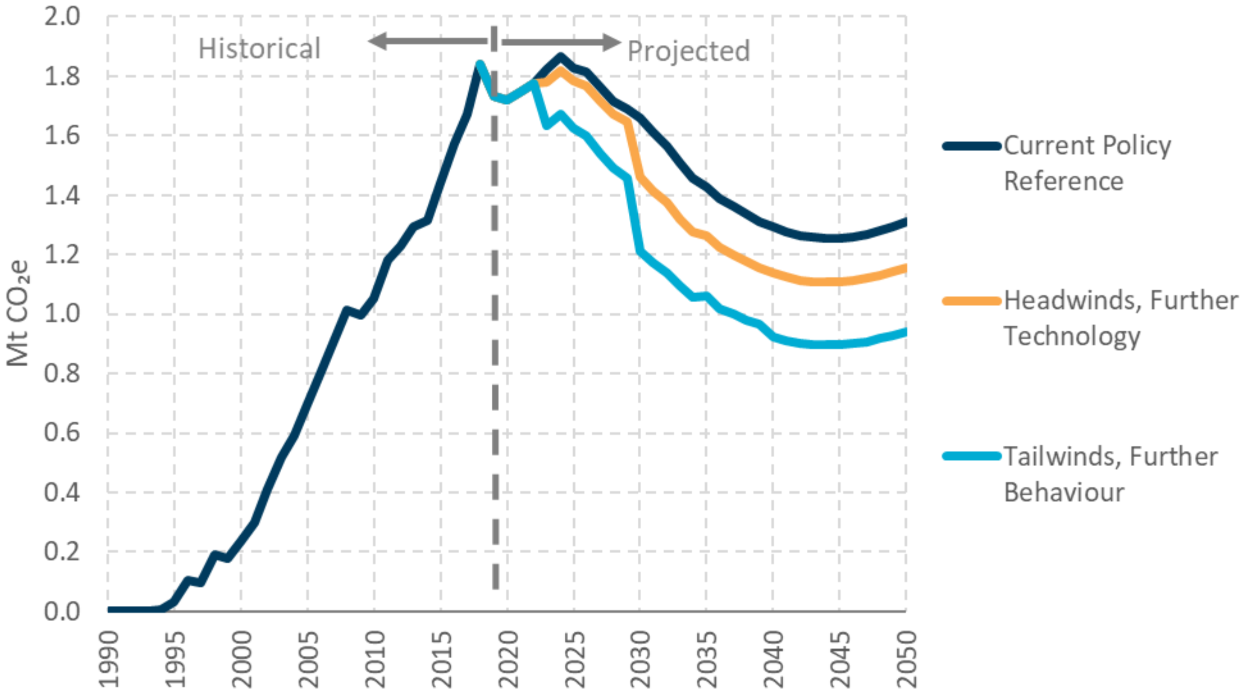

Figure 12.48: HFC emission projections across the scenarios

Source: Commission analysis

12.6 Cross sector implications

12.6.1 The role of bioenergy

Bioenergy can be used in the form of woody biomass, liquid biofuels and biogas. It needs to be used sustainably and co-managed with forestry and waste workstreams. These scenarios assume that all bioenergy is domestically produced and consumed.

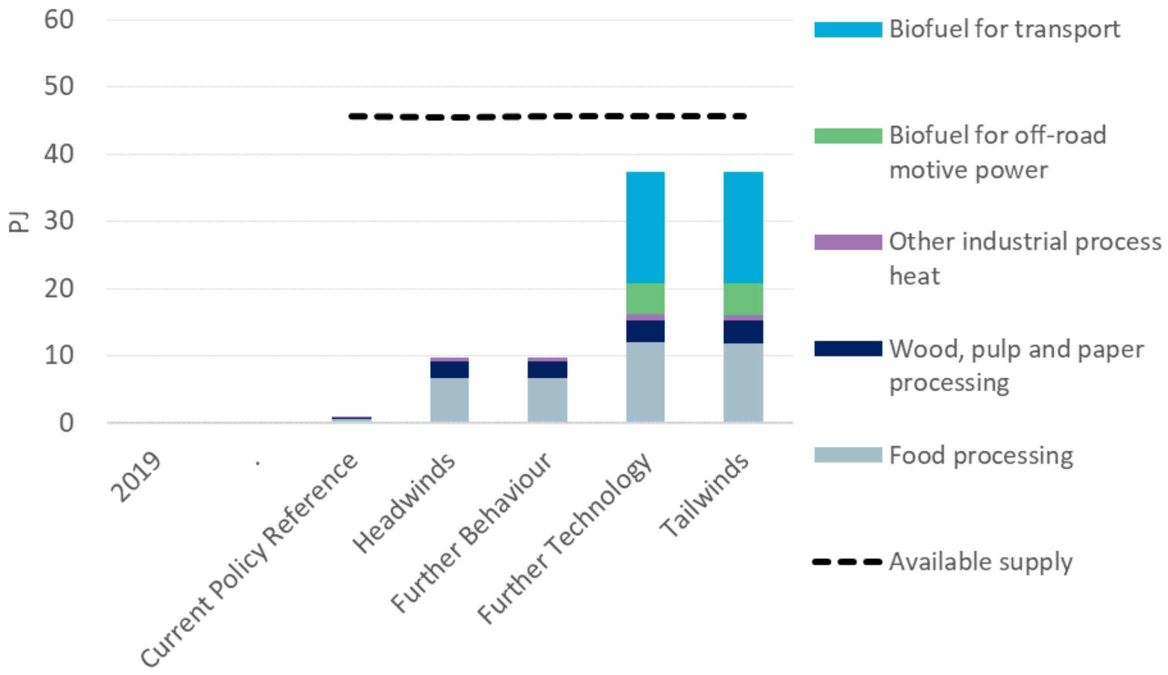

Figure 12.491: Additional biomass demand in 2035 across the scenarios and relative to 2019

Source: Commission analysis

These scenarios show that woody biomass can be expected to play a significant role in decarbonising process heat. Usage in the food, wood, pulp and paper sectors increases considerably with 2035 consumption totals around 10-15 PJ and increasing to up to 20 PJ by 2050, as shown in Figure 12.50. When available, woody biomass is the lowest cost fuel for these applications and this future requires the mobilisation of significant woody biomass resource.

The Further Technology and Tailwinds scenario used further biomass resource to produce liquid biofuels for hard to electrify uses such as the heavy transport fleet, off road vehicles and machinery, and aviation and shipping. Increasing domestic production of biofuels would require large quantities of feedstock and increased commercial scale production facilities. These scenarios see biofuels production scaling up to 9.5 PJ of fuel per year – this is equivalent to 270 million litres of fuel. For scale, Z Energy's currently mothballed biodiesel plant in Wiri has a capacity of 20 million litres per year.

The entirety of the biomass resource used in these scenarios is woody biomass from existing forests. Figure 12.502 shows that the scenarios take some time to ramp up demand to meet the available supply – this reflects time to convert plants and establish supply chains. The available bioenergy resource is currently underused.

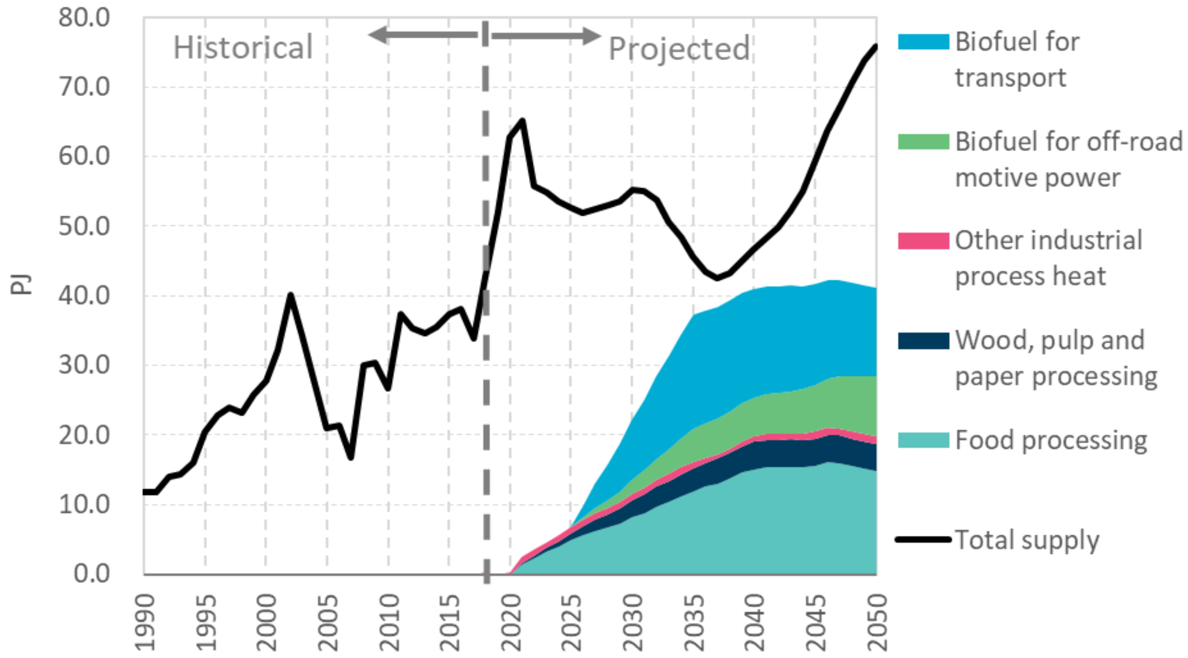

Figure 12.502: Biomass for energy demand for the Tailwinds scenario. Note that this is additional bio energy to the amount already consumed.

Source: Commission analysis

In these scenarios bioenergy supply and demand are regionally constrained for process heat use. This however has not been replicated for liquid fuel production. It is acknowledged that the high cost and practicality of transporting biomass can be a barrier to use. Additional analysis could be done on geographical location optimisation, for example, on centralised refineries around forestry resources. There is a link to the long-term regional perspectives on bioenergy carbon capture and storage (*Chapter 9: Removing carbon from our atmosphere*) which may also require a geographic and industry specific lens. This has not been modelled in the scenarios.

Under the scenario modelling the use of woody biomass is from forestry waste streams and low value product. No land-use change has been assumed and no dedicated energy crops are required under these assumptions. It is assumed that some low value export pulp logs are used as a biomass resource. The modelling includes a small increase in timber processing domestically as forestry expands, however the wood processing residue has not been quantified and deployed in the model.

Biogas harnessed from landfills and other waste streams presents an additional opportunity which is not included in these scenarios. At present, biogas currently represents a very small proportion of energy supply in Aotearoa, but there is further potential to use it as a resource for niche applications that are located close to landfills. Liquid biofuels could also be produced from tallow or imported from overseas.

Box 12.7: ***Opportunities and challenges for a bioeconomy***

Increased use of wood products in the built environment could assist the development of a bioeconomy. More timber could be used in domestic buildings, increasing the amount of stored carbon in the built environment and reducing the demand for emissions-intensive materials such as steel or concrete. Increased demand for timber and/or more domestic timber processing could also increase the availability of biomass residues which can be used for energy.

There are multiple barriers to the development of a sustainable bioeconomy and risks that need to be managed. Uncertainty regarding the long-term supply of bioenergy resources could impede decision-making and investment in bioenergy technologies. The lack of robust and recent data coupled with changes in forestry and wood processing market conditions such as log and lumber prices, transport costs, and exchange rates, could impact the cost and availability of bioenergy resources. This has not been an area of government focus of commitment to date.

While the use of bioenergy could be significantly increased, it is important to note the potential scarcity of bioenergy resources in the future, due to the long-term supply decisions, large areas of land required and its competing uses. It may be appropriate to focus the use of bioenergy on opportunities which offer considerable emissions reductions which cannot be easily or cheaply achieved by competing technologies. Liquid biofuels for aviation may be an example of this.

12.6.2 Hydrogen

Hydrogen could be described as the ‘missing link’ in achieving full decarbonisation of our energy system and some hard to abate sectors. With a planned approach, it is possible the use of green hydrogen[25] would enable Aotearoa to reach lower emission levels by 2050 than could be achieved without it.

Hydrogen can complement electrification in industry and transport. In particular, green hydrogen could play a valuable role in decarbonising long-haul transport (heavy trucks, ships, and aviation) and could enable a switch away from fossil fuels in high-temperature industrial processes that require both physical and chemical properties of molecule-based fuels. Green hydrogen also offers the potential for medium- to long-term energy storage of surplus renewable electricity and could boost domestic energy security by reducing our reliance on energy imports.

Over the longer-term, Aotearoa has the potential for a green hydrogen economy because of our abundance of renewable energy, water, infrastructure potential, and highly skilled workforce. Various transition pathways for hydrogen can be envisaged. The pace and pathway of a domestic green hydrogen economy depend on:[26]

- The potential scale up of hydrogen production - based on international markets and technological innovation influencing production costs (including the cost reduction curve of electrolysers and the ability to integrate abundant low-cost renewable electricity generation with efficient hydrogen production)
- Level of government leadership and support (e.g. policy to deploy and grow jobs, clear and enduring regulation, growth in financial incentives)
- Industry investment and knowledge sharing in different applications to grow expertise
- A social licence to scale up the hydrogen economy through awareness and public acceptance.

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[25] Green hydrogen – hydrogen produced with zero carbon emissions from renewable energy sources like wind, solar or hydro via water electrolysis, or from biomass (and nuclear energy sources) through a gasification process.

[26] (Pflugmann & De Blasio, 2020, p. 9; Venture Taranaki, 2018, p. 14)

Blue hydrogen could be used in the transition to a zero carbon economy. However, its reliance on carbon intensive gas supplies and carbon capture and storage (CCS) technology mean it may not be an appropriate long-term solution for climate change mitigation in Aotearoa. Blue hydrogen production economics are influenced by:

- The availability of fossil gas reserves and cost competitive gas supply
- The potential to economically utilize or store large volumes of captured carbon dioxide
- The size of an accessible market to support larger volumes enabling economies of scale in production facilities

12.6.3 Alternative carbon dioxide removals

In these scenarios there are residual emissions stemming from hard to abate sectors such as carbon dioxide from cement and lime manufacturing and nitrous oxide from agriculture. In order to achieve net zero emissions, these scenarios offset residual emissions with forestry removals.

Carbon capture and storage or utilisation (CCSU) is an alternative form of emissions removal. CCSU involves capturing the emissions associated with an activity, for example burning coal or an industrial process, transporting them to a storage facility and permanently locking them away in a reservoir or utilising them in another process. Variations of CCSU include direct air capture with carbon capture and storage (DACCS) or bioenergy with carbon capture and storage (BECCS).

In Aotearoa, CCS technology has not progressed beyond the concept stage. The low cost of forestry as an alternative removal technology and the limited requirement for removals from the energy industry in Aotearoa has restricted interest in CCS.

CCS is an expensive technology with highly variable, site-specific costs. The effectiveness, applicability, uptake and realisable emissions reduction potential of CCS in Aotearoa is uncertain. International project designs may not be applicable to our unique circumstances. Additionally, the technological readiness of CCS as an emissions removal option is markedly different compared to forestry as an emissions removal option. As such, CCS has not been included in the scenario modelling at this time.

CCS may play a role in our contribution to global efforts to limit warming to 1.5°C above pre-industrial levels in the latter half of the century. To maintain this optionality for the future, it would be beneficial to retain and leverage capabilities, skills and workforce in forestry, oil and gas, and geothermal energy in Aotearoa to support efforts of other countries in meeting their commitments under the Paris Agreement.

CCS may have broader implications around the potential role of land use in carbon dioxide removals. Where new infrastructure needs to be built to enable CCS, there may be ecosystem, biodiversity and other resource considerations. For BECCS in particular, there may be increased competition for land and biomass resources.

12.7 References

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Appendix 1: Demonstration path sensitivity test parameters

Table A.1 presents the assumptions and sources used in our sensitivity tests of the demonstration path. The results of this are presented in *Chapter 7: Demonstrating emission budgets are achievable* of our final advice, *Inaia Tonu Nei*.

Table A.1: Assumptions used in sensitivity testing of the demonstration path

Variable	**Demonstration path value/setting**	**Sensitivity assumptions**		**Source/basis for sensitivity assumptions**
		Low	***High***	
Population (average growth rate 2020-2035)	1.0%	0.5%	1.4%	Low and high cases used in 2020 government emissions projections. Assumes: • 10th / 90th percentile population projections from StatsNZ • Labour productivity growth of 1.0% (base) / 0.6% (low) / 1.4% (high)
GDP (average real growth rate 2020-2035)	2.4%	2.1%	2.7%	
Aluminium production	Closure at end of 2024	N/A	Continues at full output	Illustrative
Steel production	Continues at full output	Closure for last two years of each budget period	N/A	Illustrative
Refinery production	Continues at full output	Closure for last two years of each budget period	N/A	Illustrative
Methanol production	Waitara Valley train closes end of 2021; Motunui train No. 2 closes end of 2029.	All trains close for last two years of each budget period	Waitara Valley train reopened from 2026; all trains continue at full output	Illustrative
Dryer/wetter hydro years	Mean hydro years	Standard deviation in emissions based on historic hydro variability		Electricity emissions calculated from E-market modelling with 90-year historic record of hydro in-flows

Exotic afforestation level (annual average 2020-2030)	25,400 hectares per year	22,300 hectares per year	30,200 hectares per year	Ministry for Primary Industries 2020 afforestation projections, low and high cases
Deforestation of post-1989 forests	Budget 1: 620 hectares per year Budgets 2-3: 310 hectares per year	310 hectares per year	1,410 hectares per year	Ministry for Primary Industries 2020 deforestation projections, low and high cases
Used EV supply constraint	Total of 198,000 used light EVs imported 2021-2030	N/A	Total of 93,000 used light EVs imported 2021-2030	Used EV uptake rate constrained to same as current policy reference scenario
EV costs	Costs fall, light passenger EVs reach purchase price parity with ICE vehicle by 2031	Costs fall faster, light passenger EVs reach purchase price parity with ICE vehicle by 2028	Costs fall slower, light passenger EVs reach purchase price parity with ICE vehicle by 2035	CCC assumptions
Oil price	Increases from 40 USD/bbl in 2020 to 60 USD/bbl 2023, then constant	Decreases to 35 USD/bbl by 2030	Increases to 70 USD/bbl by 2023, then 90 USD/bbl by 2030	CCC assumptions informed by IEA World Energy Outlook and other projections
New renewables costs (annual capital cost reduction)	Wind 0.8% Solar 3.0% Geothermal 0.1%	Wind 1.2% Solar 4.5% Geothermal 0.15%	Wind 0.53% Solar 2.0% Geothermal 0.07%	CCC assumptions
Biomass price (delivered)	Residues $10/GJ Pulp chip $12.8/GJ	Residues $12/GJ Pulp chip $17.5/GJ	Residues $7.5/GJ Pulp chip $10.4/GJ	CCC assumptions