Chapter 8:

What our future could look like

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 target.

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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 target.

8.1 Introduction

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

To this end, we have developed detailed long-term scenarios to explore and demonstrate how the 2050 target can be met. These scenarios build on the analysis of emissions reduction options (*Chapter 4: Reducing emissions – opportunities and challenges across sectors*) and our current path (*Chapter 7: Where are we currently headed?*) using our bottom-up modelling framework. The analysis presented in this chapter supports our advice on how the emissions budgets and ultimately the 2050 target may realistically 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
- Comparison to global 1.5 °C pathways and other international pathways.

8.2 Key findings from the scenario analysis

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

Meeting the net zero long-lived gases target:

- Aotearoa can achieve net zero emissions of long-lived gases by 2050 with significantly lower levels of forestry planting than previous studies have suggested. Our scenarios also show how it would be possible for Aotearoa to maintain net zero after 2050 with relatively little additional effort, either through additional afforestation, further reductions in long-lived gases, or other forms of carbon dioxide removals.

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 existing farm management practices and a combination of waste reduction and diversion from landfills.

- Developing and widely adopting new technologies to reduce agricultural methane emissions would enable Aotearoa to reach 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 lower agricultural production from livestock and more land use change.

Transport

- Through switching to electric vehicles, road transport, including heavy vehicles, can be almost decarbonised by 2050. This requires a rapid increase in electric vehicle sales so that nearly all vehicles entering the fleet in Aotearoa are electric by 2035. The switch to electric vehicles is expected to deliver significant cost savings while also reducing air and noise pollution and replacing imported fuels with local renewable electricity.

Heat, industry and power

- Wider electrification of energy use is an essential part of the transition and this would 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. Our analysis indicates that these costs could range up to $250 per tCO_2e reduced but would be less than this where heat pumps or biomass can be used.
- Sustainable biomass supply constrains the deployment of biofuels out to 2050, particularly if we seek to produce biofuels for international aviation and shipping.

Forestry

- 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 such as agricultural nitrous oxide.
- Exotic plantation 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 target could be met with a significantly smaller area of new exotic forestry than would occur under current policy settings.

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, only a small fraction of the vehicle fleet turns over each year, so even if all newly registered vehicles could become 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.

8.3 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 also explore 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.

The four scenarios are described in Table 8.1 and illustrated in Figure 8.1.

Table 8.1 Scenario descriptions

Headwinds	In this scenario there are higher barriers to uptake of both technology and behaviour changes across key measures. 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. It makes assumptions about the technologies which are developed and deployed which could allow faster emissions reductions to occur. 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 changes in people's and businesses' preferences encourage more behaviour changes away from high emitting activities and practices. There are conservative improvements in technology as per the Headwinds scenario, but barriers to adoption of existing technologies are lower as people and businesses make greater efforts to adopt them.
Tailwinds	This scenario combines further technology and further behaviour change assumptions to provide a potential upper bound for how far and how quickly emissions could be reduced based on current evidence and judgements.

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[1] (IPCC, 2018)

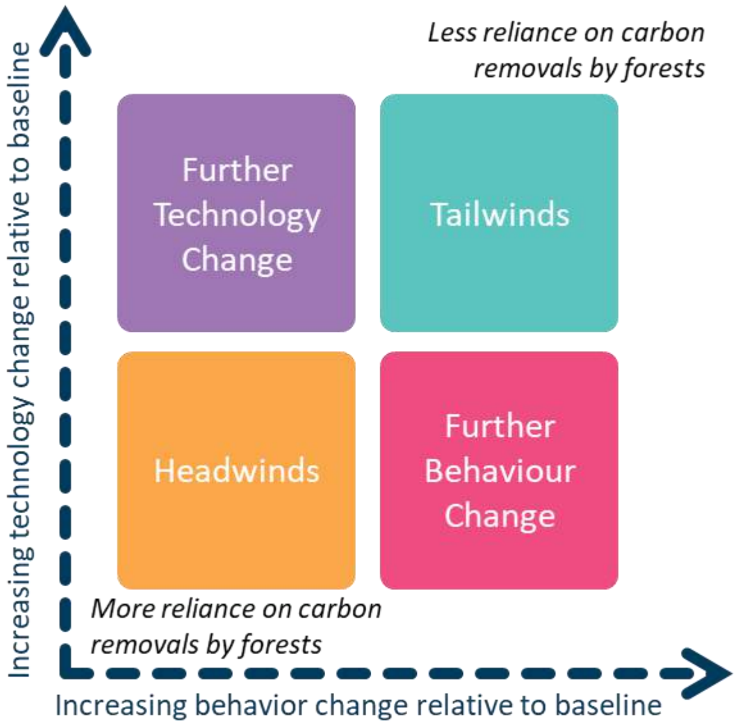

Figure 8.1: Scenario structure

8.3.1 How our scenarios differ from the Current Policy Reference case

As we outlined in *Chapter 7: Where are we currently headed?* current government policies and settings do not put Aotearoa on track to meet the targets in the Climate Change Response Act. This is not surprising, given these policies were largely set before the 2050 target in the Act came into force. Our analysis of current policies is set out in our Current Policy Reference case. It indicates that emissions of long-lived gases would not reach net zero by 2050 and biogenic methane emissions would only be reduced by around 12% below 2017 levels by 2050.

Our scenarios have been developed to test how the targets in the Act 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.

8.3.2 Locking in net zero

The scenarios have been developed to examine different ways in which the 2050 target and the 2030 biogenic methane target can be met. In doing so, the we have applied the principles laid out in the Commission's Advice Report. Of importance is the long-term perspective to ensure that our path to meeting the 2050 target does not impose unfair burdens on 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 gases in a way which can be sustained indefinitely with minimal further effort required after 2050. If Aotearoa choses a path that 'locked in net zero' by 2050, this would require two key transformations:

- decarbonising the sources of long-lived gas emissions as far as possible, and
- 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.

8.3.4 Scenario design and assumptions

Within the bottom-up model, ENZ, many emissions reduction actions are imposed by assumption. We have arrived at assumptions for effectiveness and adoption in each scenario based on an assessment of available evidence and engagement with experts and stakeholders. These assumptions take into account likely costs and benefits of the reduction options and judgements about realistically achievable rates of change. These assumptions are set out in the appendix to this chapter.

Emissions values

The model 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 for process heat and the choice of vehicle technology (internal combustion engine or electric) for vehicles entering the fleet. The emissions values in the scenarios have been set at a level to achieve deep decarbonisation of these areas, particularly heat, by 2050.

For agriculture, forestry and waste, explicit emissions values are not used. 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 target is met.

The path of emissions values was constructed by choosing a value in 2050 ($250), discounting this back using a 3% discount rate to a value in 2030 (~$140) and drawing a straight line to this from estimated NZ ETS prices in 2020 ($30). This is similar to the UK Government's approach to setting '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 target.

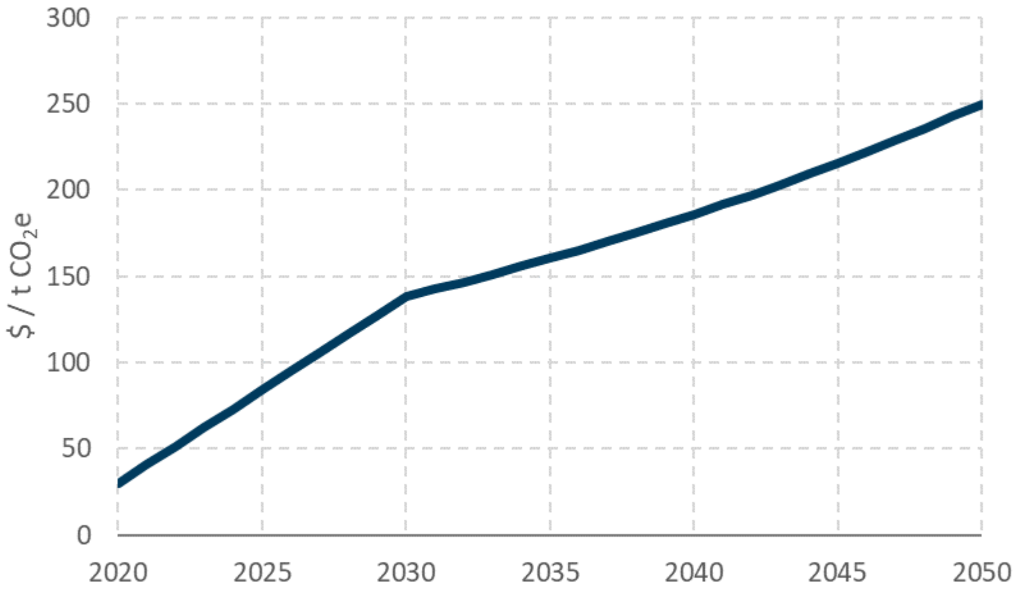

Figure 8.2: Emissions values used in the bottom-up scenario modelling in ENZ. These apply to the energy and transport sectors only.

Box 8.1: Role of forestry

Even if the primary goal is to reduce gross emissions by 2050 as far as possible, it may not be feasible to completely eliminate all gross emissions. Therefore, some carbon dioxide removals would be required to reach and maintain net zero emissions.

Relying on forests to reach net emissions targets poses challenges. Perhaps the greatest risk is that of it being a temporary measure, with forests being vulnerable to extreme events such as fires, floods or pest infestations and other issues, particularly as the physical impacts of climate change intensify and can cause a re-release of stored carbon. The impacts of afforestation vary widely depending on where it occurs and what type of forests are established. Positive impacts can include generating business opportunities and promoting biodiversity, while potential negative impacts of large-scale afforestation include disruption to local employment in rural communities. Further discussion of these impacts is contained in *Chapter 13: Households and impacts* and *Chapter 14: Environment and ecology.* We see a role for a diverse range of forests which provide emissions removals to help achieve emissions budgets and targets, with active management of risks and impacts.

Native afforestation can help develop an enduring source of emissions removals which could offset remaining emissions beyond 2050. They can offer significant co-benefits such as for biodiversity, mahinga kai, water quality, culture, recreation and provide forest products such as honey and medicines. Permanent native forests can be established on marginal land and thereby provide these benefits without displacing other economic activity and with limited negative impacts on local communities. The slow growth of native forests means they store carbon at a relatively slow rate, but unlike production exotic forests they would continue to do so for at least 50 years, possibly even centuries.

Exotic forests grow rapidly and can contribute significant emissions removals, including by 2030 and therefore for the first NDC. Rapid growth and sequestration mean they can serve as a flexibility mechanism to ensure emissions budgets and the 2050 target are met. Production forests have well established markets for their products, generate jobs and exports. They ensure Aotearoa has a sustainable supply of wood products, now and in the future. However, they contribute only medium-term emissions removals under the current Government's averaging accounting for forests.

Policies have provided incentives for the planting of exotic forests and to a lesser extent for native forests. More recently the incentives are more focused on native afforestation and reversion. Achieving a desirable balance of forests would require early action to remove barriers to native afforestation on marginal land so there is time to build a large emissions sink by 2050. There are challenges to increasing the rates of planting of native forests. In our modelling we have assumed these challenges can be overcome through policy or other interventions.

The planting trajectory for exotic forests captured in the Current Policy Reference case should be maintained until 2030 to help achieve emissions budgets and the first NDC. Consideration should be given to managing a declining reliance on emissions removals from exotic forests after 2030 as the native forests become established and deeper reductions in gross emissions are achieved.

Forestry would also support other parts of a low emissions Aotearoa through the use of residues for biofuel and timber in the built environment. There is significant potential for diversifying forestry e.g. through better integration of trees on farms, developing native forestry, continuous cover forestry and shortening harvesting rotation lengths. These should be explored as ways of maximising the benefits of forests while minimising potential negative impacts of large-scale afforestation.

8.4 Economy-wide emissions results

8.4.1 Long-lived gases

Figure 8.3 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. Figure 8.4 shows a breakdown of the emissions path by sector for the Headwinds and Tailwinds scenarios.

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 highlight that the assumed technology changes have a greater overall impact on the emissions trajectories than the assumed behaviour changes.

Gross emissions of long-lived gases in 2050 range from 9.6 Mt CO_2e in the Tailwinds scenario to 17.6 Mt CO_2e in Headwinds, compared with 45.7 Mt CO_2e in 2018 (Figure 8.5). The Further Technology Change and Tailwinds scenarios reach net zero emissions earlier and with less reliance on removals.

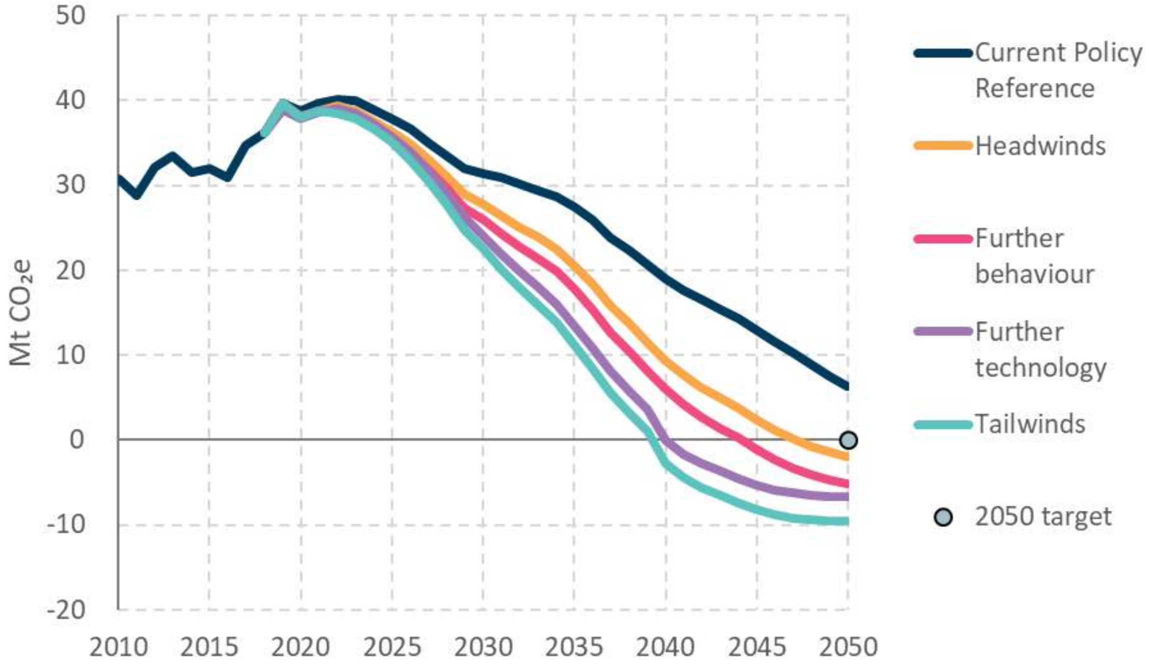

Figure 8.3: Net long-lived gas emissions from 2010-2050

Source: Commission analysis.

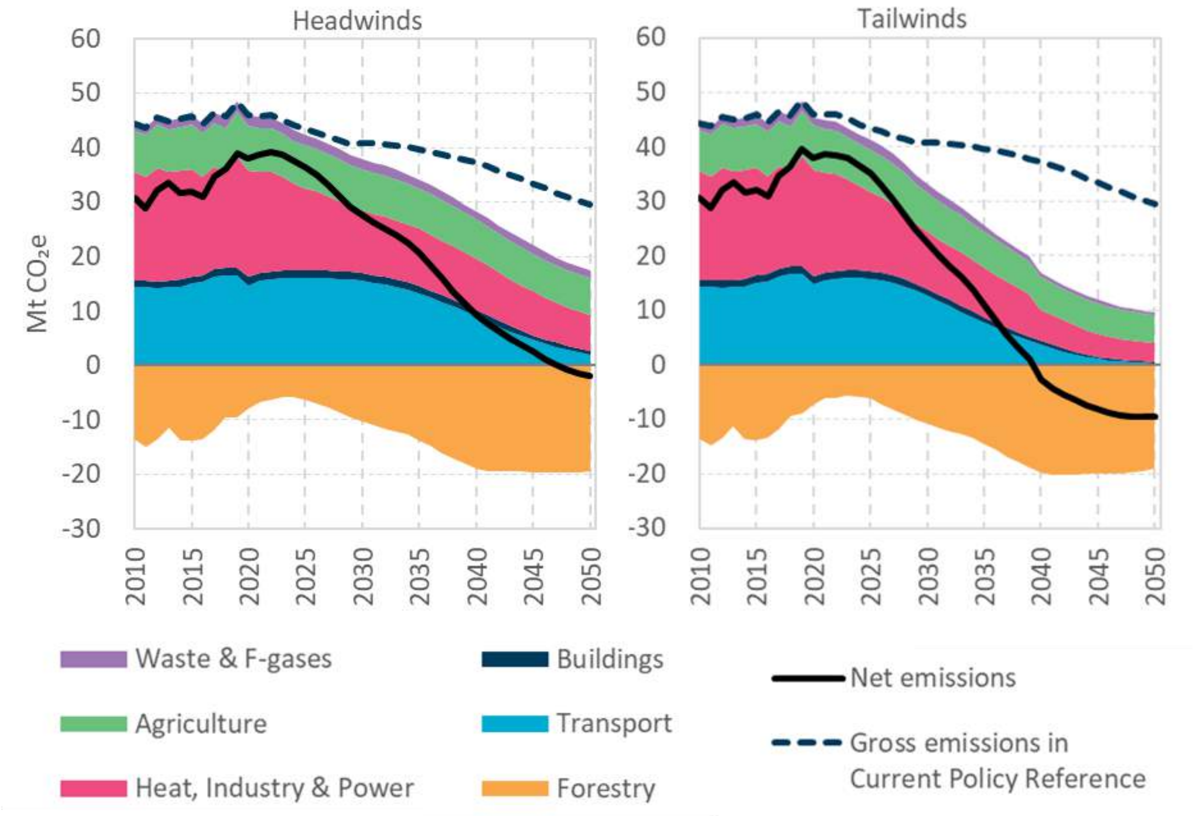

Figure 8.4: Long-lived gas emissions by sector in the Headwinds and Tailwinds scenarios

Source: Commission analysis.

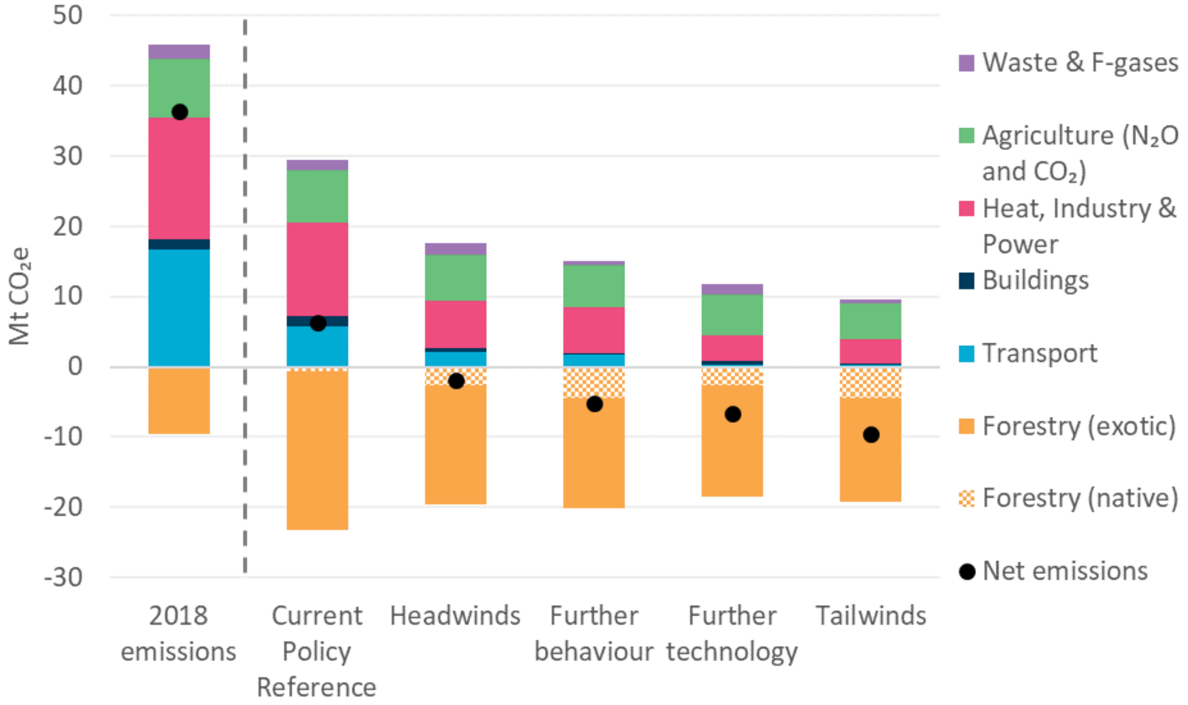

Figure 8.5: Long-lived gas emissions by sector in 2050 compared with 2018

Source: Commission analysis.

8.4.2 Biogenic methane

The scenarios all meet the 2030 and 2050 targets for biogenic methane but display a wide range in their emissions paths (Figure 8.6). This reflects the different assumptions around the availability, effectiveness and uptake of technologies to reduce enteric methane emissions from ruminant livestock. The Headwinds and Further Behaviour Change scenarios indicate that it is possible to meet the less ambitious end of the 2050 target range with very limited contribution from technologies reducing enteric methane emissions and with less land use change to exotic forestry than in the Current Policy Reference case.

The Further Technology Change scenario indicates that it could be possible to meet or exceed the more ambitious end of the 2050 target range should the optimistic assumptions on methane-reducing technologies eventuate.

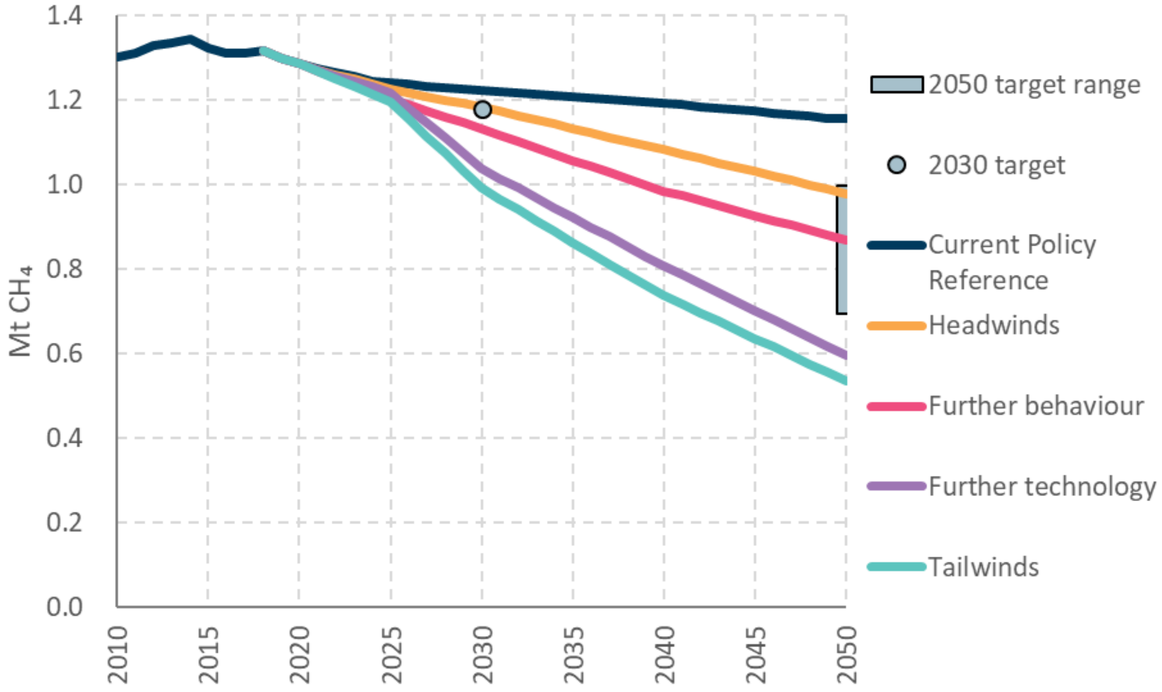

Figure 8.6: Biogenic methane emissions from 2010-2050

Source: Commission analysis.

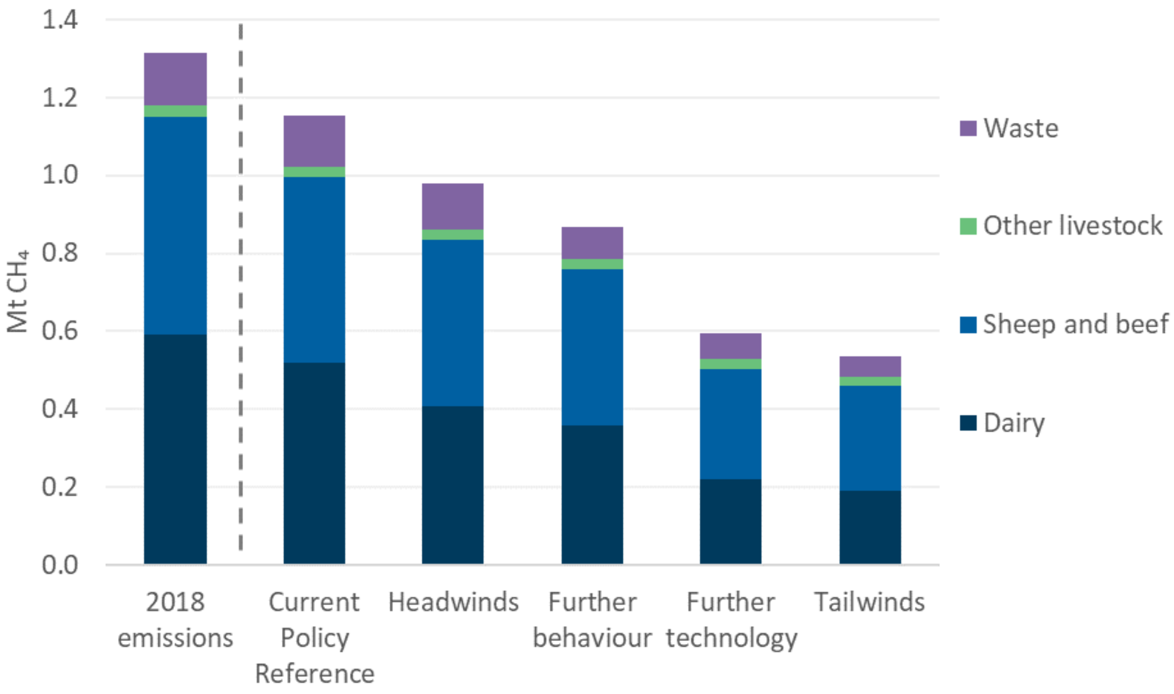

Figure 8.7: Biogenic methane emissions by sector in 2050 compared with 2018

Source: Commission analysis.

Table 8.2: Summary emissions results for the scenarios

		Headwinds	**Further Behaviour Change**	**Further Technology Change**	**Tailwinds**
Long-lived gases					
Year net zero reached		2048	2045	2040	2040
Gross emissions in 2050 (MtCO$_2$e)		17.6	15.0	11.8	9.6
Net emissions in 2050 (MtCO$_2$e)		-1.9	-5.2	-6.6	-9.5
Cumulative gross emissions 2021-2050 (MtCO$_2$e)		954	901	800	759
Cumulative net emissions 2021-2050 (MtCO$_2$e)		558	488	408	351
Change in gross emissions 2018-2030	CO$_2$	-19%	-21%	-29%	-30%
	N$_2$O	-7%	-11%	-10%	-13%
	F-gases	-12%	-26%	-12%	-26%
Change in gross emissions 2018-2050	CO$_2$	-73%	-76%	-87%	-89%
	N$_2$O	-20%	-28%	-32%	-39%
	F-gases	-30%	-83%	-30%	-83%
Per capita emissions in 2050 (tCO$_2$e/person)	CO$_2$	1.5	1.4	0.8	0.6
	N$_2$O	1.0	0.9	0.8	0.8
	F-gases	0.2	0.1	0.2	0.1
Biogenic methane					
Change in emissions 2017-2030		-10%	-14%	-21%	-24%
Change in emissions 2017-2050		-25%	-34%	-55%	-59%
Per capita emissions in 2050 (in tCO$_2$e/person)		3.9	3.5	2.4	2.1

Source: Commission analysis.

8.4.3 Emissions reductions by sector

Figure 8.8 shows changes in emissions from 2018-2050 across sectors in the Headwinds and Tailwinds scenarios, alongside the Current Policy Reference case. Below we give a broad summary of the major drivers of change in each sector.

Figure 8.8: Change in emissions from 2018-2050 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 electric vehicle sales reach critical mass and then steadily take over the fleet. This leads to road travel, as well as rail and domestic shipping, being almost fully decarbonised by 2050. Reduced travel demand and shifting passenger and freight transport to lower emissions modes help to deliver earlier emissions cuts. Domestic aviation emissions do not reduce at all in the Headwinds scenario, while in the Tailwinds scenario these are heavily reduced by 2050 through electrification of shorter trips and use of low carbon liquid fuels.

Heat, Industry and Power

The Current Policy Reference case sees significant reductions in electricity and manufacturing emissions by 2030 as a result of the construction of new renewable generation and the assumed closure of aluminium and methanol plants (*Chapter 7: Where are we currently headed?*). Further manufacturing emission reductions in the four scenarios come from fuel switching and additional efficiency in food processing and other medium temperature process heat uses.

Tailwinds also sees the steel plant converting to emissions-free production by 2050. Further emissions reductions come from electrification of off-road vehicles and machinery, assumed to occur at a similar pace to electrification of heavy trucks and the use of liquid biofuels.

Buildings

Tailwinds sees building heat almost fully decarbonised by 2050 while in Headwinds around half of current gas use remains.

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 high technology impact, improved farm management and some land use change from dairy into horticulture or other low emission uses. The widespread adoption of methane inhibitors and vaccines in the Tailwinds scenario has a particularly large impact.

Waste

The Headwinds scenario sees very modest reductions in methane emissions from waste, under-delivering relative to the 2030 and 2050 biogenic methane targets. By contrast the Tailwinds scenario, with deep reductions in waste to landfill along with comprehensive landfill gas capture, would significantly outperform the targets. Nitrous oxide emissions increase slightly compared with the Current Policy Reference due to increased composting.

8.4.4 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 8.9 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 2018. Meanwhile, 0.7 million hectares of new native forest would lead to a long-term carbon sink of over 4 $MtCO_2$ per year, similar in size to the residual nitrous oxide emissions.

After 2050, emissions would still bounce back above net zero to around 1 $MtCO_2e$ in 2075 without new actions to reduce 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 negative emissions indefinitely (dotted black line).

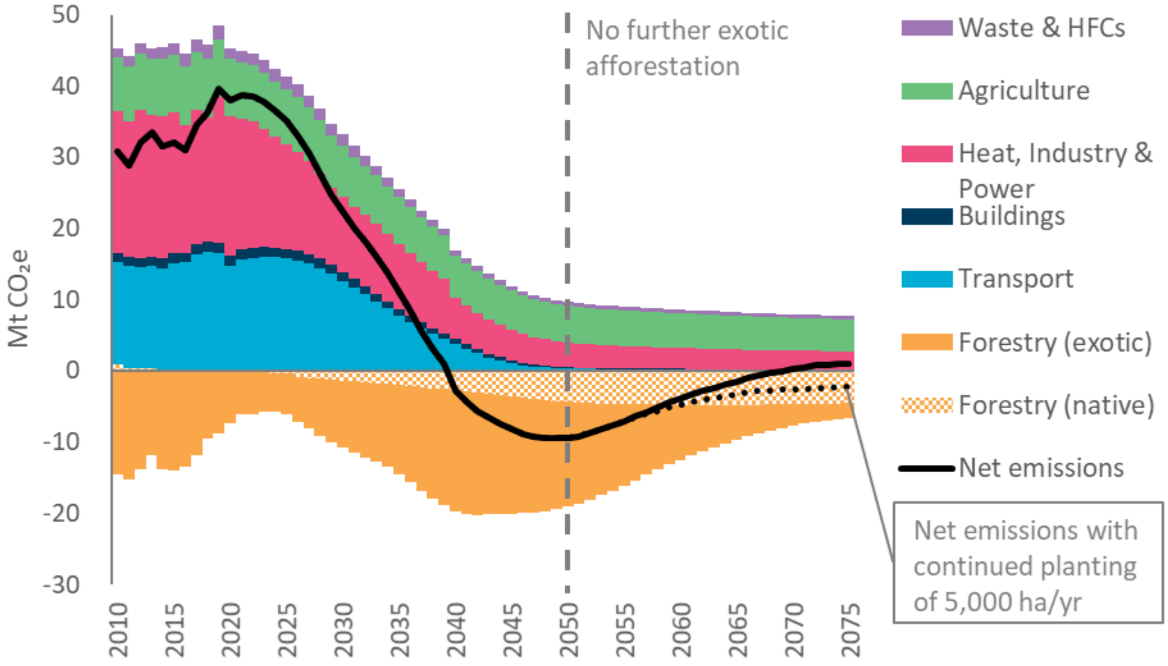

Figure 8.9: Long-lived gas emissions to 2075 in the Tailwinds scenario, with and without further afforestation after 2050

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.

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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.

Box 8.2: Sustaining net zero

Chapter 3 of the advice report: The path to 2035 sets out our approach to meeting the 2050 target, guided by the considerations in the Climate Change Response Act. Our approach has focused on reducing gross long-lived gas emissions and seeking to 'lock in net zero' by 2050.

We have tested to understand how different our approach is to the approach used previously that focusses on only on net emissions. We found that increasing the NZ ETS price from $35 under the Current Policy Reference case to $50 would be sufficient to meet the 2050 net zero target for long-lived gases (Figure 8.10).The higher NZ ETS emissions price would encourage only a small reduction in gross emissions but would encourage much higher planting of exotic forestry (an increase of 8.5 Mt from the Current Policy Reference case).

Significant further afforestation and land-use change would be required every year after 2050 to maintain net zero long-lived gas emissions. Figure 8.10 shows that if there were no further afforestation or policy changes net emissions would bounce back above zero by 2067 as the temporary exotic forest carbon sink declines. This would be despite gross emissions reducing significantly after 2050 due to continued turnover of the road vehicle fleet to electric vehicles and reductions in gas use as supply runs out.

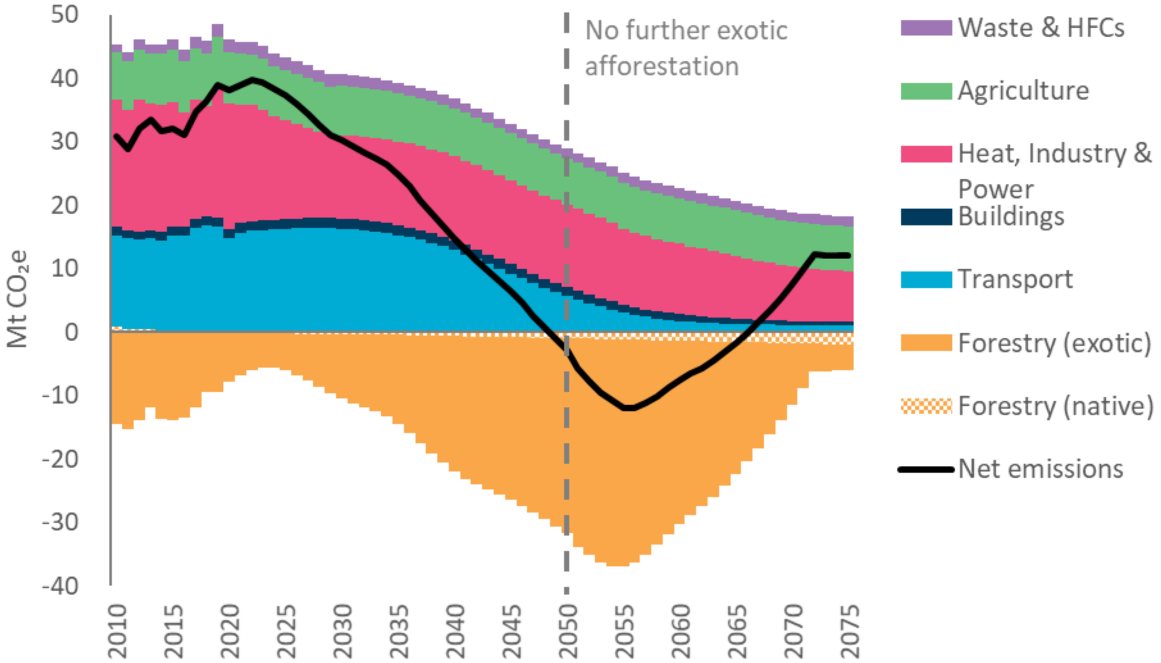

Figure 8.10: Long-lived gas emissions in the Modified Current Policy scenario, with a $50 emissions value applied to forestry, energy and transport

Source: Commission analysis.

8.5 Sector assumptions, results and insights

8.5.1 Total primary energy use

The scenarios show that for Aotearoa to achieve a low emission 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 8.11 for the Further Behaviour scenario, takes Aotearoa to a position where total primary energy source is between 80-90% from renewable sources by 2050.

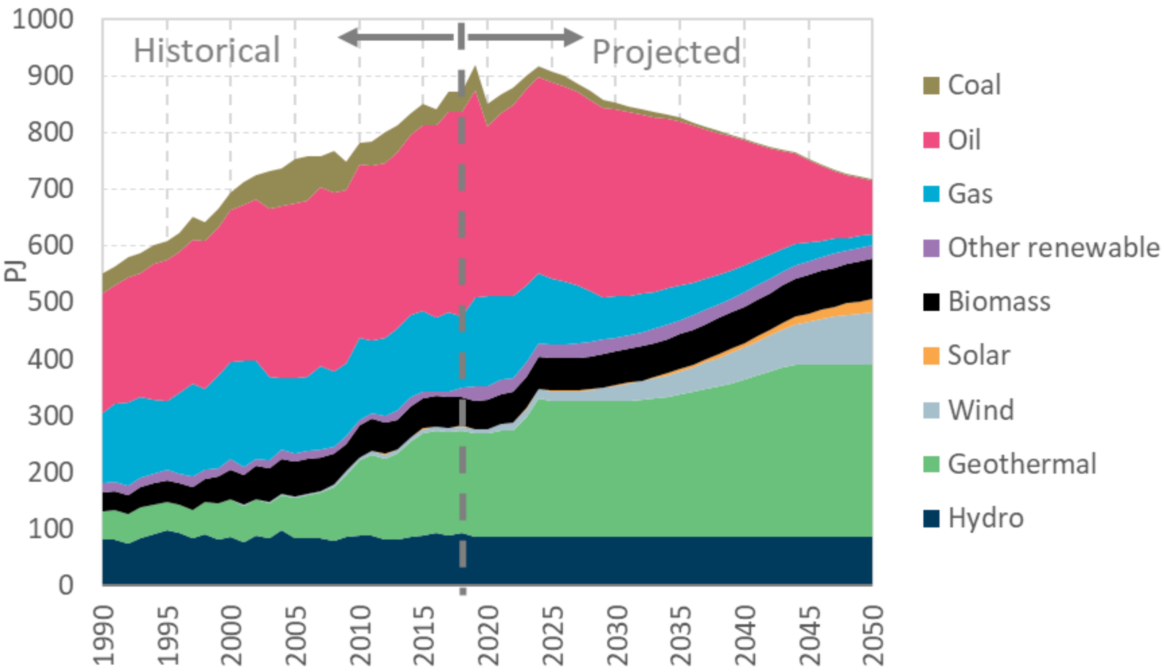

Figure 8.11: Total primary energy for the further behaviour scenario

Source: Commission analysis.

Improvements in energy efficiency mean that the total energy required in 2050 is around 25% less than 2018. This reduction is largely due to the replacement of internal combustion engines with electric motors.

Table 8.3: Renewable percentage of total primary energy

	2018	2035	2050
Current Policy Reference	40%	49%	61%
Government projections	40%	54%	80%
Further behaviour	40%	57%	84%
Further technology	40%	64%	85%
Tailwinds	40%	65%	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%. 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.

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, in the UN Sustainable Development Goals, have been set by looking at final consumption shares.

8.5.2 Transport

Transport emissions fall dramatically in the later years in all our scenarios as is shown in Figure 8.12. In the Tailwinds and Further Technology scenarios emissions fall to near zero by 2050, while Headwinds and Further Behaviour Change have approximately 2 $MtCO_2$ remaining.

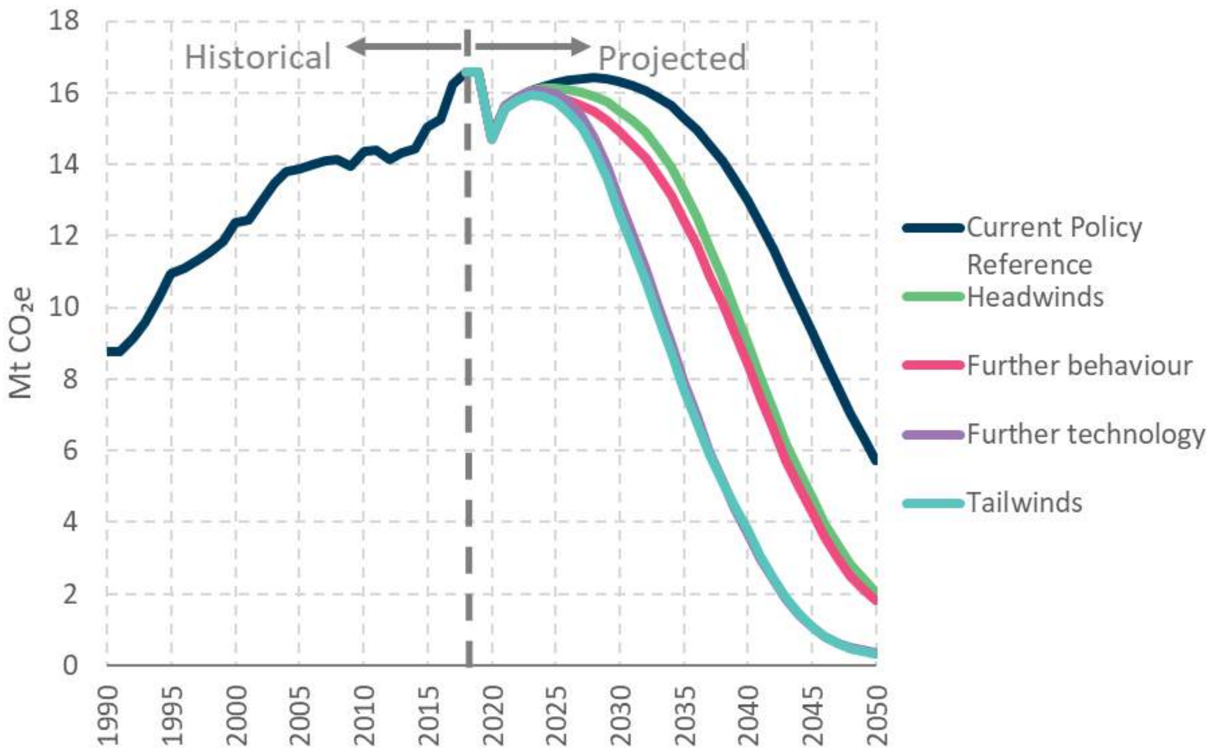

Figure 8.12: Total Transport Emissions by Scenario

Source: Commission analysis.

The reduction in transport emissions primarily comes from the electrification of road transport, which currently makes up the largest share of transport emissions. There is some limited electrification of air and rail as well as the use of liquid biofuels to target transport types which are difficult to electrify. Figure 8.13 below shows the total domestic transport emissions in 2050 under four scenarios compared to 2018.

The take up of electric vehicles drives the rapid decline of transport emissions across all scenarios. The take up of electric vehicles is considerably faster in the Headwinds scenario compared to the Current Policy Reference case, while uptake in the Tailwinds scenario is faster still.

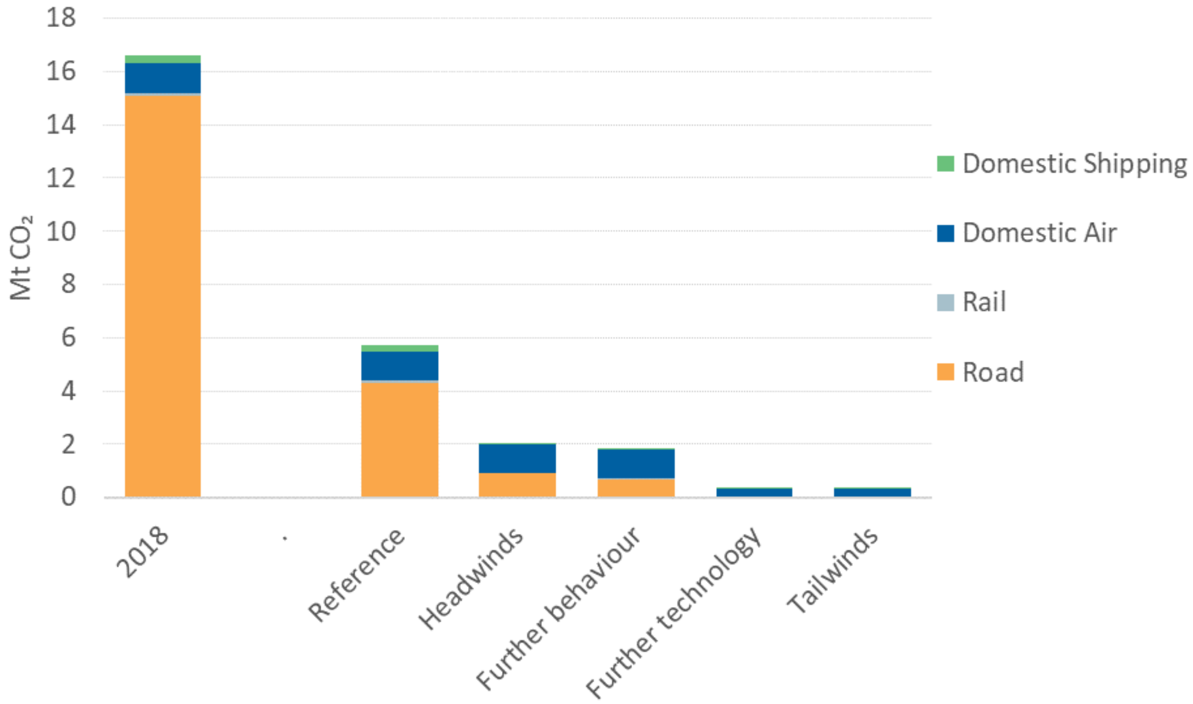

Figure 8.13: Transport emissions in 2050 compared to 2018

Source: Commission analysis.

Light vehicles (cars, SUVs, vans and utes)

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 8.14 shows the percentage of newly registered light vehicles that are electric for the scenarios and the Current Policy Reference case. Because vehicles have a long operational life and the fleet is slow to turn over, the proportion of electric vehicles in the total vehicle fleet lags behind these uptakes. The bottom chart in Figure 8.14 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, although the Tailwinds scenario gets very close.

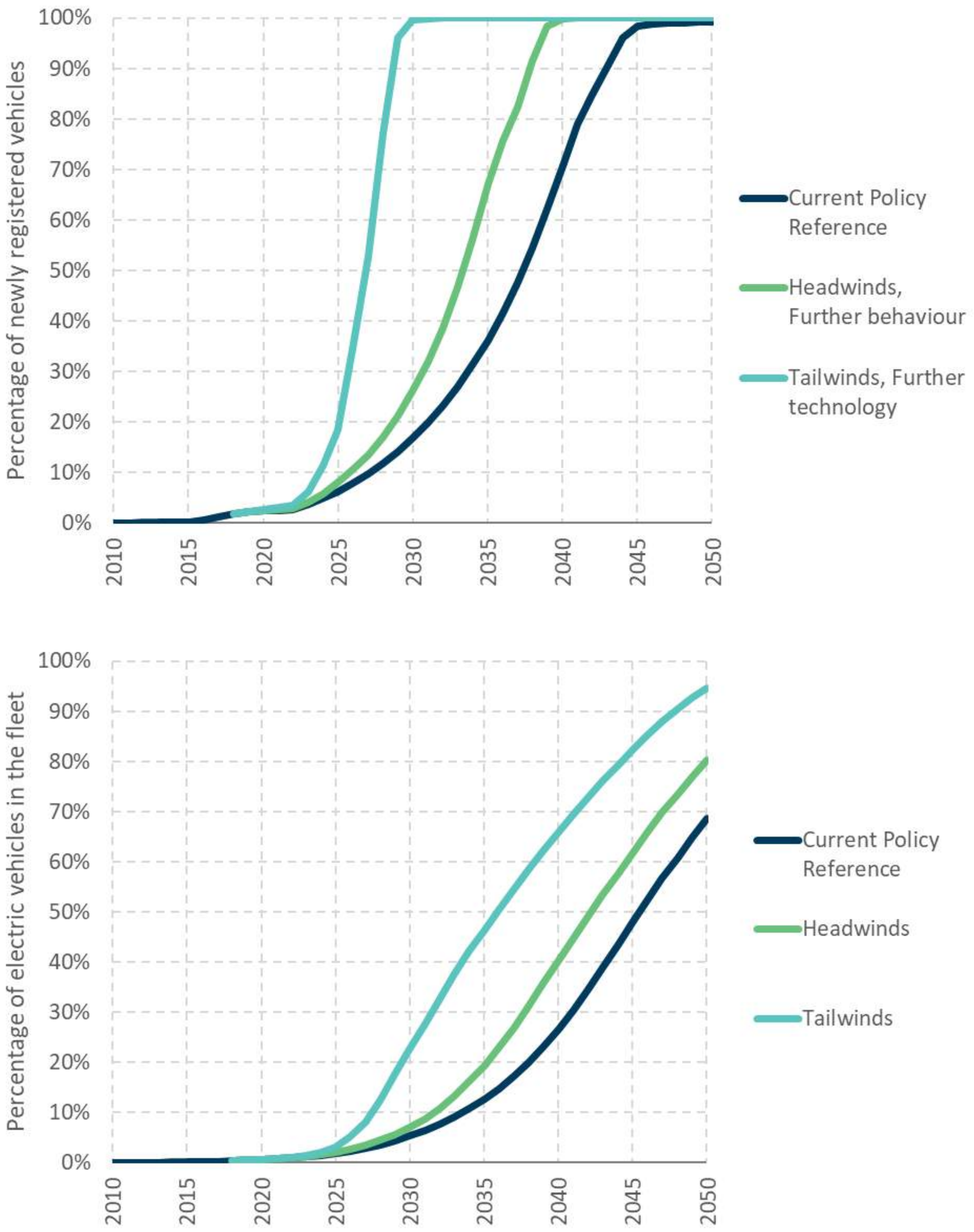

Figure 8.14: Percentage of newly registered light passenger vehicles that are electric by scenario (top) and percentage of total light passenger vehicle fleet that are electric (bottom)

Source: Commission analysis.

Table 8.4: Percentage of newly registered light passenger vehicles that are electric by scenario

	2018	2030	2040	2050
Current Policy Reference	2%	17%	72%	99%
Headwinds and Further Behaviour	2%	26%	100%	100%
Tailwinds and Further Technology	2%	100%	100%	100%

Table 8.5: Percentage of light passenger vehicles in the fleet that are electric by scenario

	2018	2030	2040	2050
Current Policy Reference	0%	5%	27%	69%
Headwinds	0%	7%	41%	81%
Tailwinds	0%	22%	65%	95%

Vehicle efficiency

Figure 8.15 shows the assumed changes in emissions per kilometre travelled by internal combustion vehicles for the two classes of light vehicles: light passenger vehicles (cars/SUVs) and light commercial vehicles (vans/utes). The assumed emissions per vehicle-kilometre are the same in all scenarios with a modest improvement over time. The assumed efficiency improvements account for the increased adoption of conventional hybrid vehicles. Although conventional hybrid vehicles are at least partly powered by electric motors, they are still internal combustion engine vehicles as their batteries cannot be charged from the grid.

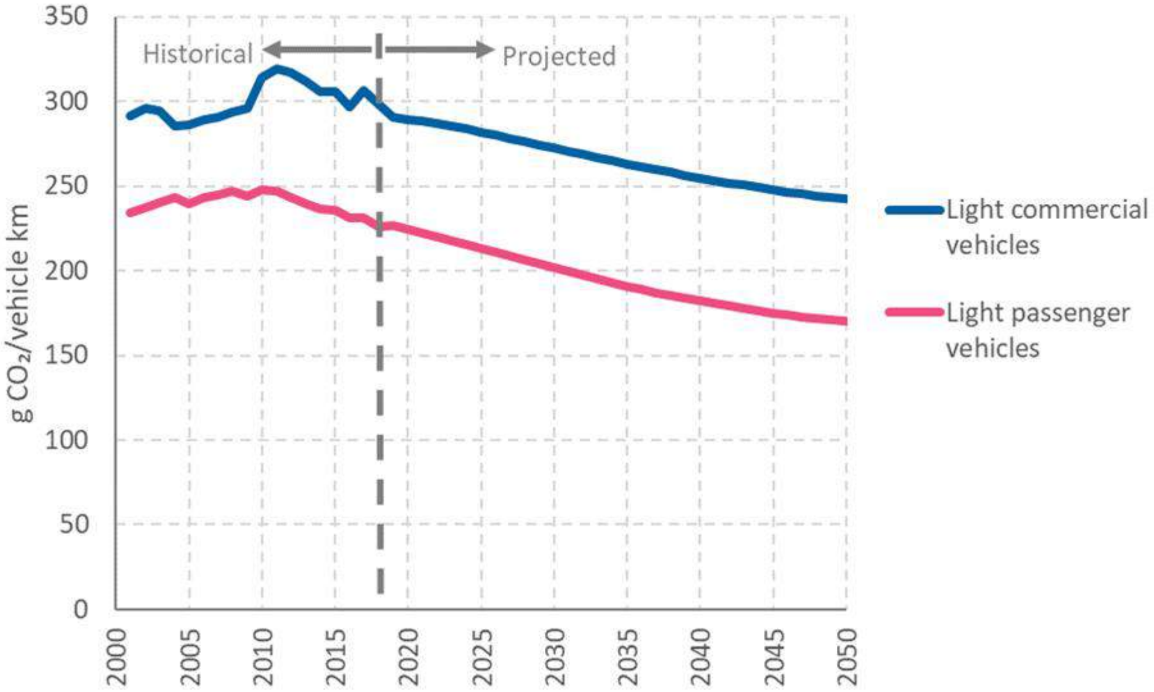

Figure 8.15: Emissions per vehicle kilometre travelled by internal combustion vehicles

Source: Commission analysis.

Reducing the vehicle kilometres travelled by light vehicles

Figure 8.16 shows the vehicle-kilometres travelled by light vehicles in the scenarios compared with the Current Policy Reference case. These vehicle kilometres include commercial as well as household travel. The figure again shows the impact that behavioural changes, including reduced need for travel and change in type of transport, can have on vehicle kilometres.

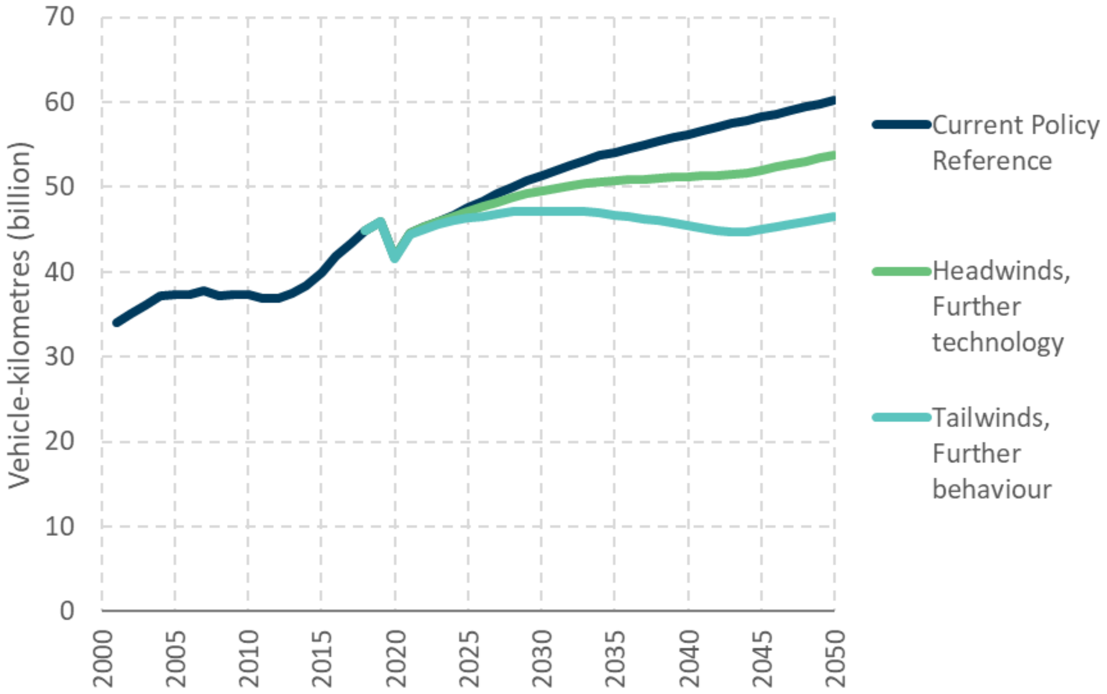

Figure 8.16: Vehicle-Kilometres travelled by light vehicles

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. For example:

- By 2030, cycling is up 100% compared to the Current Policy Reference case. By 2040 cycling is up 400%.
- By 2030, public transport is up 50% compared to the Current Policy Reference case. By 2040 public transport is up 125%, with proportionate reductions in vehicle driver and vehicle passenger travel.

Other Road Transport

Trucks and buses are also increasingly electrified in these scenarios. However, because of suitability and costs the uptake is different for these vehicle types. This variation is shown in comparison to light vehicles in Figure 8.17 for the Tailwinds and Further Technology scenarios.

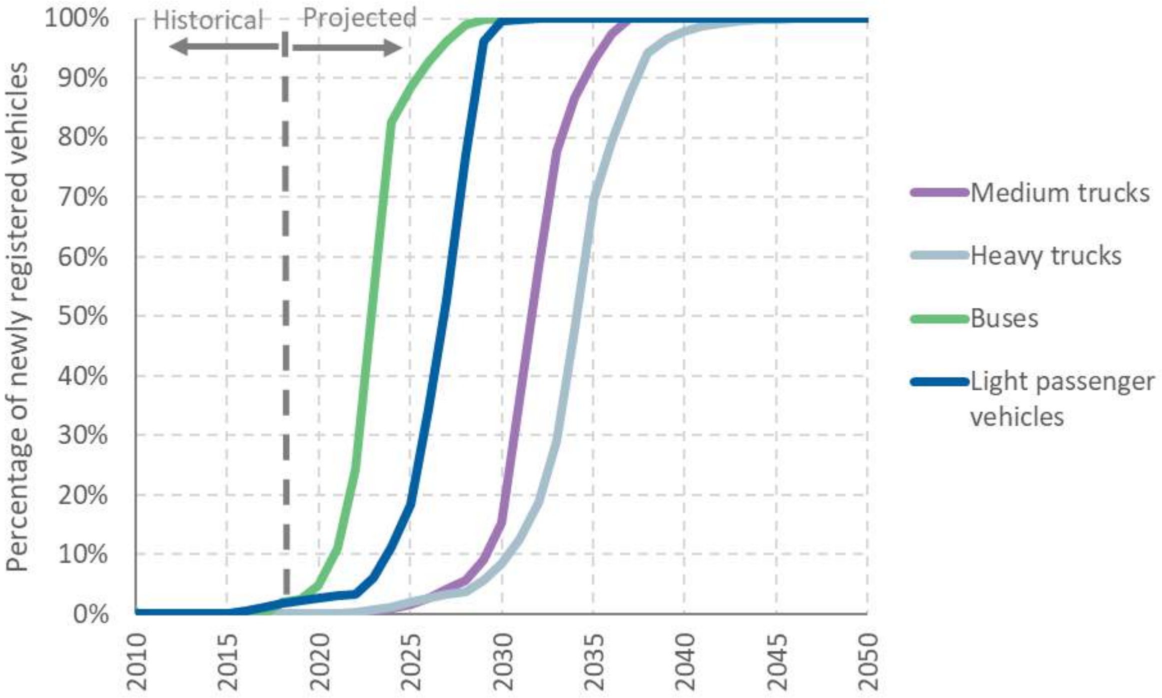

Figure 8.17: Percentage of newly registered trucks and buses that are electric for the Tailwinds and Further Technology scenario

Source: Commission analysis.

Trucks are slower to convert to electric propulsion than light vehicles due to their higher power requirements. Medium trucks are defined here to have a fully loaded weight less than 30 tonnes.

Heavy trucks 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. Heavy trucks are defined here to have a fully loaded weight greater than 30 tonnes.

Table 8.6: Year by which 100% of newly registered vehicles are electric for all road vehicle classes

	Headwinds & Further Behaviour	**Tailwinds & Further Technology**
Light passenger vehicles	2041	2032
Medium trucks	2047	2037
Heavy trucks	after 2050	2048
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 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 20% increase in rail and coastal shipping freight tonne-kilometres by 2042 compared to the Current Policy Reference case due to diversion of freight from trucks. This diversion starts with an 8% increase in rail and coastal shipping freight by 2027. Our Tailwinds and Further Behaviour Change scenarios assume a 67% increase in rail and coastal shipping tonne-kilometres by 2042 compared to the Current Policy Reference case due to diversion of freight from trucks. The diversion starts with a 14.5% increase by 2027.

Aviation

Options to limit emissions from domestic aviation beyond what is assumed in the Current Policy Reference case are currently limited. Electrification of aircraft is challenging due to the weight of the batteries. There are currently no electric aircraft in commercial operation anywhere in the world, although at least two manufacturers are currently planning to offer small electric aircraft suitable for short-distance commercial flights.

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 10% 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. By 2050, these 270 million litres enable a reduction in domestic liquid fossil fuel use and associated emissions, of about 43%.

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.

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. Recall, however, that international aviation emissions are not included in the Commission’s initial emission budgets.

Domestic Coastal Shipping and Cook Strait Ferries

All four alternative scenarios assume existing ships are replaced by plug-in hybrids as they reach normal end-of-life. The batteries on these ships could be upgraded in future years as battery technology continues to improve. The upgraded batteries would allow the ships to reduce the fraction of their travel that is fossil fuel powered. In the Headwinds and Further Behaviour Change scenarios, this results in 1% of coastal shipping and Cook Strait ferries tonne-kilometres being handled by electric propulsion in 2026, with the share rising by 1% each year to 25% by 2050. In the Tailwinds and Further Technology Change scenarios, 4% of coastal shipping and Cook Strait ferries tonne-kilometres are handled by electric propulsion in 2026, with the share rising by 4% each year to 100% by 2050.

On the demand side, coastal shipping benefits from a diversion of freight from trucks, discussed above under 'Trucks and freight transport'.

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 Headwinds and Further Behaviour 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 2031. Complete electric operations would then be possible between five major cities on the North Island. The Tailwinds and Further Technology Change scenarios move the completion date for this project up to 2026.

There is also a long-term opportunity to use battery-powered locomotives on non-electrified rail lines. This technology is, however, still in the early stages of development and we have not assumed its use in our scenarios.

On the demand side, rail freight benefits from a diversion of freight from trucks, discussed above under 'Trucks and freight transport'.

Box 17.4: Hydrogen for transport

Hydrogen has not been modelled as an emissions reduction option in the scenarios presented here. We have modelled the uptake of battery electric vehicles. If we had also modelled hydrogen vehicles, the model would have always picked battery electric vehicles over hydrogen vehicles. This is because, due to the conversion losses involved in producing hydrogen from renewable electricity and then converting the hydrogen back to electricity in the vehicle, it takes almost three times as much renewable electricity to power a hydrogen vehicle compared to a battery electric vehicle.

There are, however, segments of the transport sector which are difficult to power with battery electric vehicles. 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 that 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, which could be used in conventional internal combustion engine vehicles. Electrofuels, or 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 is evolving rapidly, it is not possible to say which could emerge as the winner.

We have specified a modest uptake of low carbon liquid fuels for all travel types in our Further Technology Change and Tailwinds scenarios, but none in the Headwinds or Further Behaviour Change scenarios. This low carbon liquid fuel could equally well be interpreted as hydrogen. Due to their high costs, the market is unlikely to implement any of these low carbon technologies in the first three budget periods without supporting policies. However, it is important that Aotearoa gains experience with emerging low carbon technologies to spur market development, innovation and learnings which can be drawn-upon in future budgets.

8.4.3 Buildings

Emissions from the combustion of fossil fuels for heating and cooking in buildings decrease significantly in all scenarios relative to 2018 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 8.18 shows the historical share of building energy supply and a future transition from natural gas to electricity for the Tailwinds scenario. The plot also shows that total energy demand can remain constant despite an increasing population due to improvements in energy efficiency.

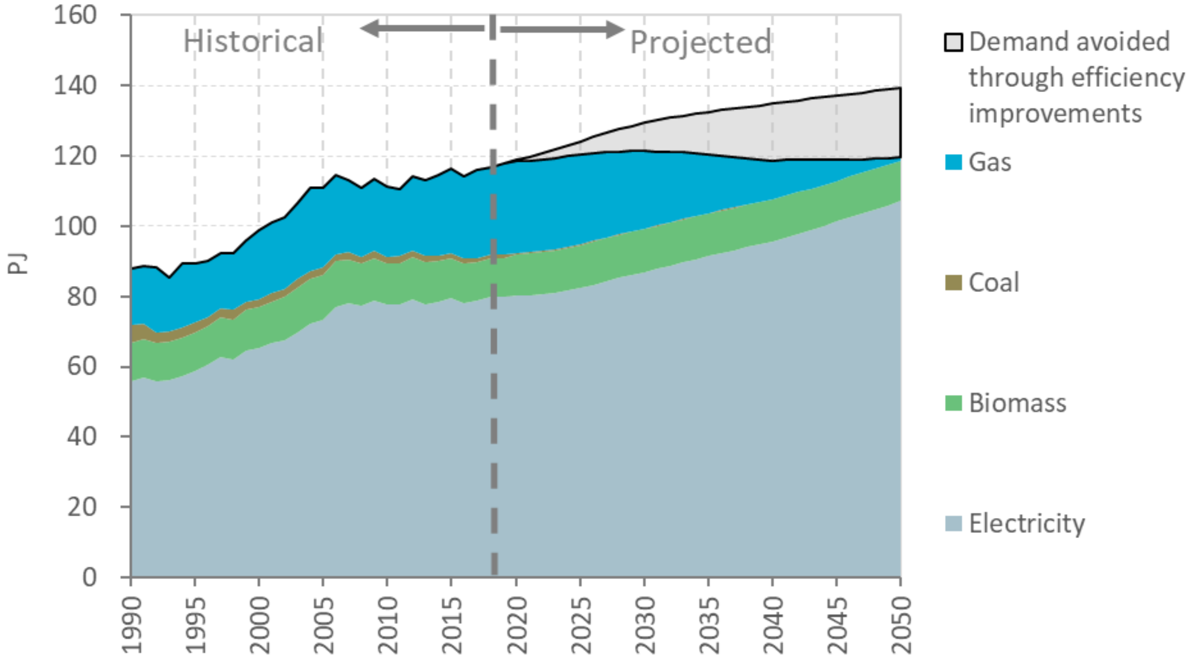

Figure 8.18: Historical and projected supply of energy in buildings for the Tailwinds scenario. The demand avoided wedge shows the energy avoided through improvements in efficiency relative to the Current Reference Policy case efficiency improvements.

Source: Commission analysis.

In all scenarios the adoption of natural gas and bottled LPG in new builds stops before 2040 and the Further Behaviour and Tailwinds scenario achieve the largest emissions reduction by transitioning the use of gas in all buildings to electricity or biomass by 2050. The use of coal for heating is eliminated in all scenarios by 2030. The reduction in emissions for the Tailwinds scenario is shown in Figure 8.19 below.

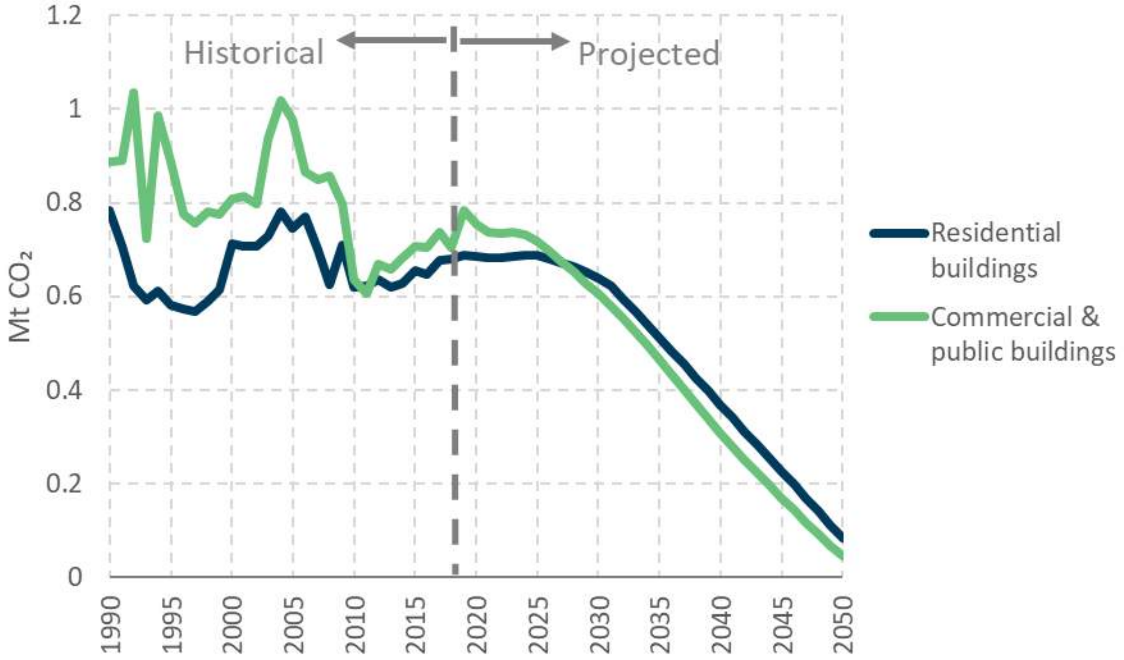

Figure 8.19: Historical and projected emissions from fossil fuel combustion in buildings in the Tailwinds scenario

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 8.20 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[3] and liquid fuel use for commerical motors.

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[3] 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.

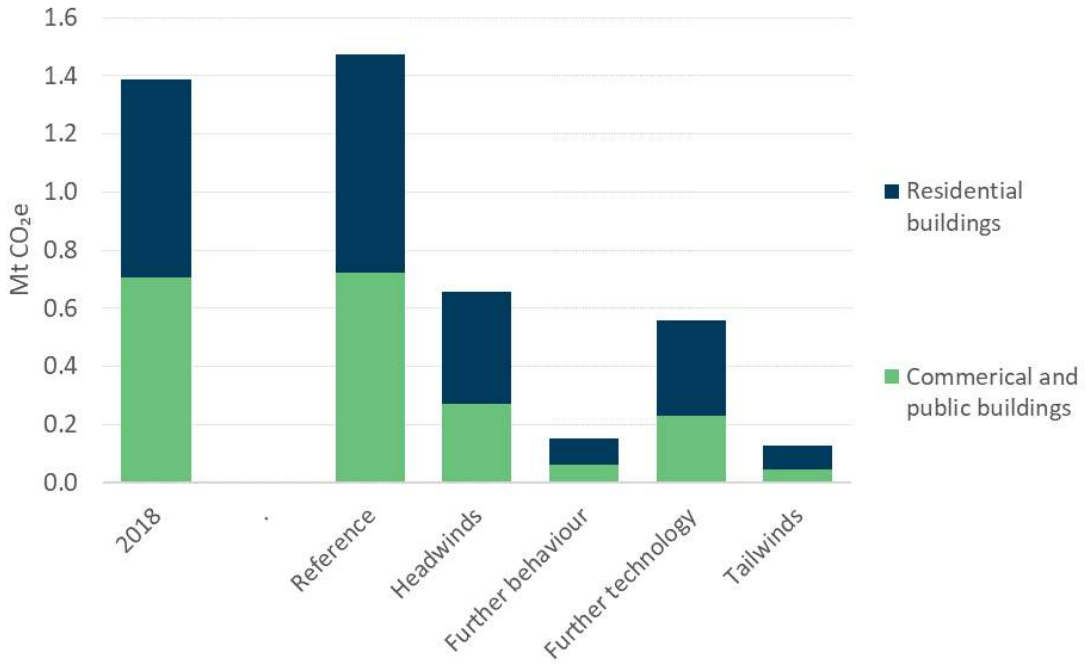

Figure 8.20: Fossil fuel combustion emissions in buildings in 2050 across the modelled scenarios

Source: Commission analysis.

8.4.4 Heat, Industry and Power

Electricity demand, generation and emissions

Electricity is increasingly relied upon as a carrier of energy in these scenarios. Despite increasing demand across all scenarios, emissions from the generation of electricity are projected to decrease from 4.2 $MtCO_2e$ in 2018 to 1.5 - 1.9$MtCO_2e$ by 2035 and 0.8 - 1.4$MtCO_2e$ by 2050 as is shown in Figure 8.21 below.

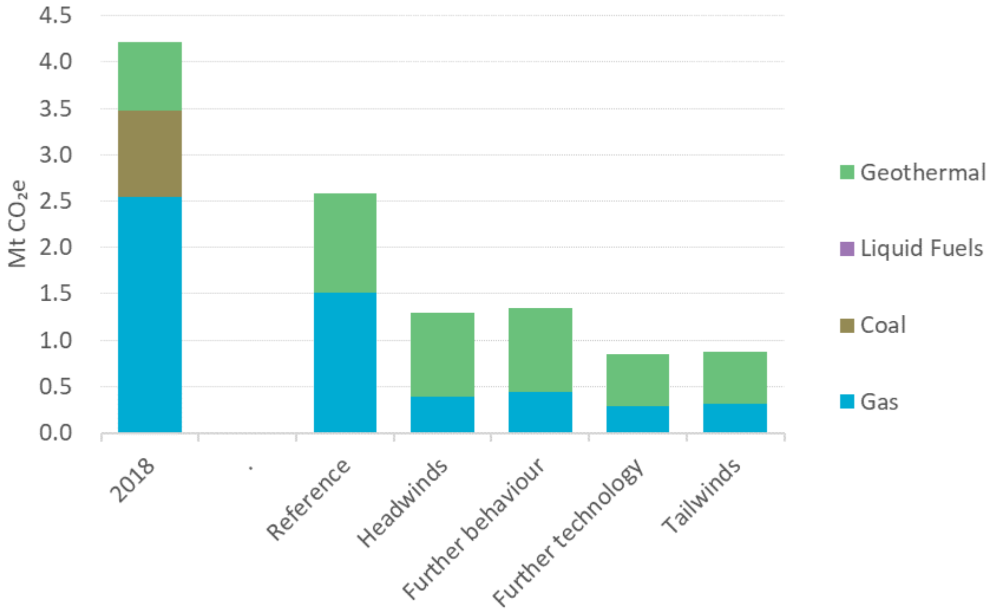

Figure 8.21: Electricity generation emissions in 2050 compared with 2018

Source: Commission analysis.

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 targets. Annual demand for electricity would increase from 40 GWh in 2018, to 43–47 GWh by 2035 and to around 63 GWh by 2050. This demand growth is shown below.

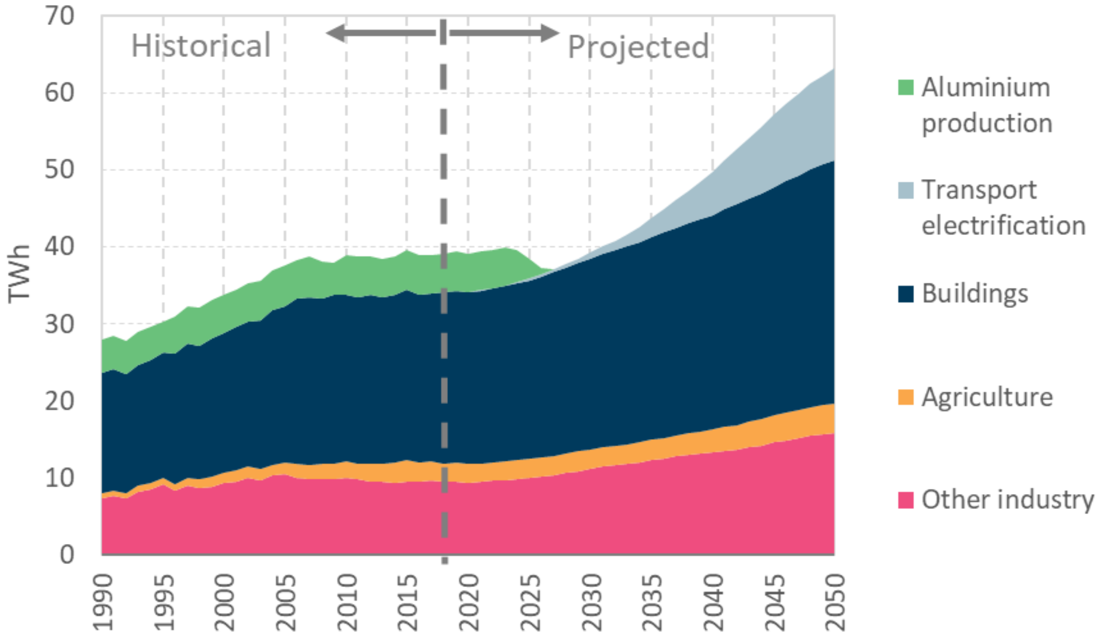

Figure 8.22: Electricity demand growth in the Further Behaviour scenario

Source: Commission analysis.

In these scenarios, the maximum rate at which electricity demand increases 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. Most of the demand growth in the scenarios is met by new wind generation, the installed base increases by 1500% to 6–7 GW. In addition to this, by 2050 new geothermal generation contributes 4 - 5 TWh per annum of generation and utility solar, mostly built beyond 2040, contributes 6 - 11 TWh per annum. The change in the electricity generation by generation type is shown in Figure 8.23 below.

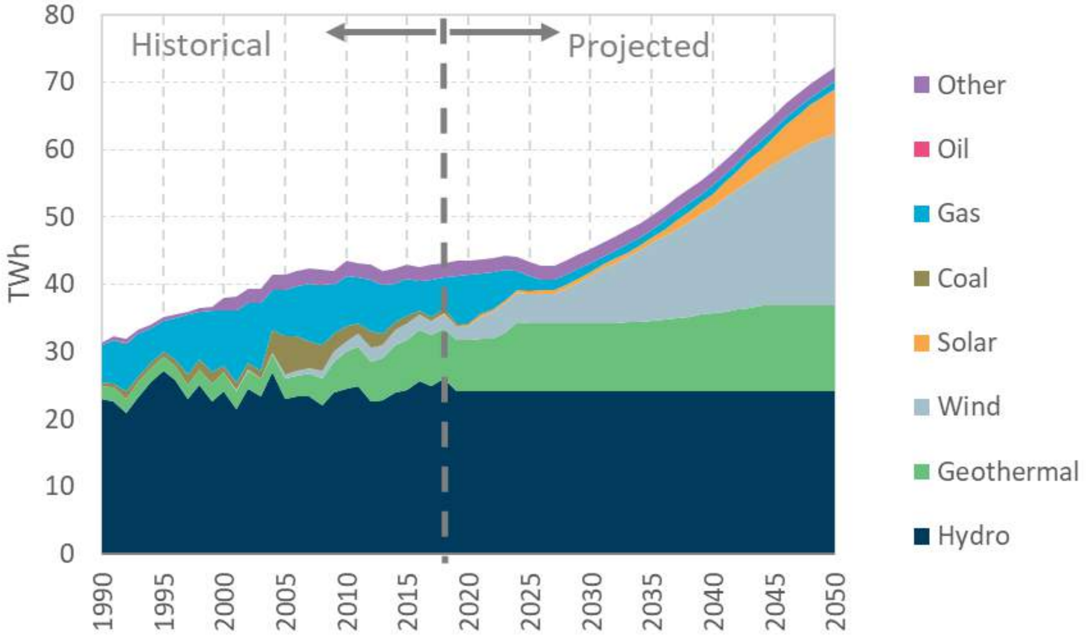

Figure 8.23: Electricity generation growth in the Further Behaviour scenario

Source: Commission analysis.

Electrification also requires considerable expansion and increases in capacity of electricity transmission and distribution infrastructure, 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 contribute 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.

The use of gas for electricity generation is projected in the scenarios to fall and during the early 2040s the total emissions from gas generation would fall below those from geothermal generation. Emissions from geothermal generation vary widely from field to field, with the worst emitting fields being comparable to gas generation. While it may be possible to reduce emissions by capturing and reinjecting them, it is anticipated that the worst emitting geothermal plants would close before 2030 as they may not be economic to operate at the emission pricing faced during this period.

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 as shown in Figure 8.21.

Box 8.6: 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 (ICCC) 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 is to evaluate the viability of pumped hydro. The project will consider this solution against alternative methods to resolve New Zealand's storage problem 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 5TWh 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 8.24 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 0.6TWh of thermal generation per year. This is equivalent to 0.3Mt CO_2 of emissions per year.

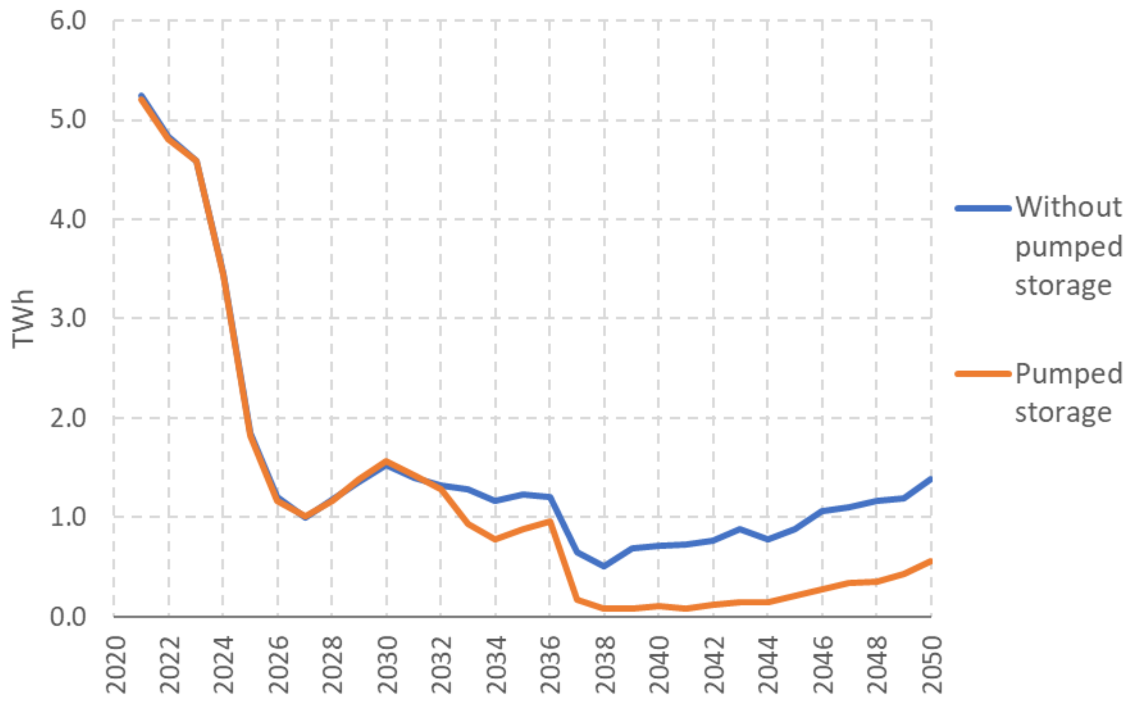

Figure 8.24: Total annual thermal generation in electricity system with and without a pumped storage scheme. This is for a demand profile representative of the Headwinds scenario; the totals are averages across a full record of hydrological years and do not include cogeneration. The Step reduction in 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 the Ministry of Business, Innovation and Employment (MBIE) will make recommendations as to whether this is a solution that Aotearoa should pursue.

Low and medium temperature process heat

In all scenarios the food processing sector is expected to almost completely decarbonise by achieving widespread energy efficiency improvements and switching heating from coal, 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 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 between 20% - 40% reduction 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.[4] No domestic uses of timber are diverted for this energy resource.

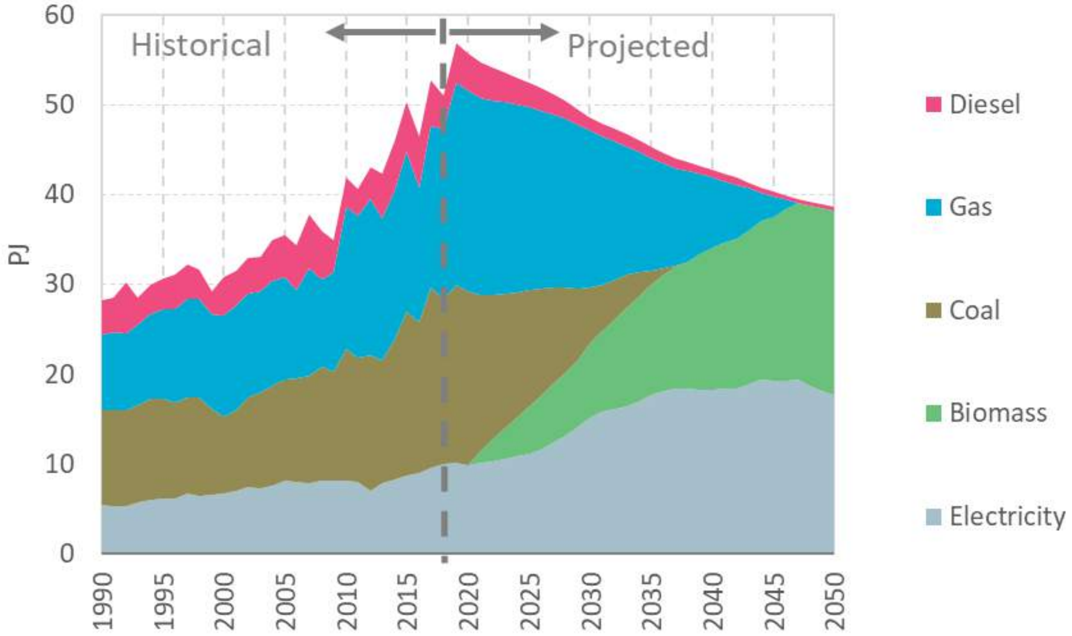

Figure 8.25: Food processing fuel use in the Further Technology scenario

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. For example, in Canterbury, a region which has limited forestry resource, 50% of coal heating has been converted to electrode boilers by 2035 in the Further Technology scenario.

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,

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

decarbonisation of the sector is slower in the scenarios where the biomass supply is restricted. This is shown in Figure 8.26.

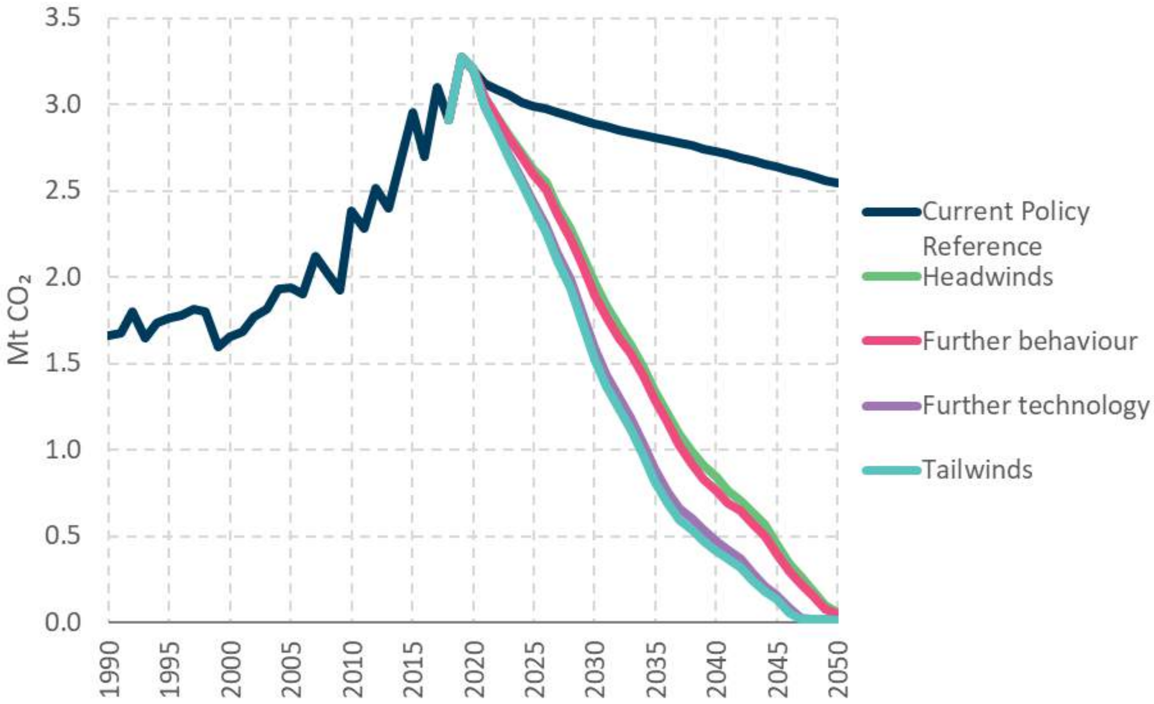

Figure 8.26: Food processing emissions across the modelled scenarios.

Source: Commission analysis.

In these scenarios, improvements in energy efficiency and fuel switching to biomass or electricity combine to achieve a reduction in the use of coal of up to about 1.5PJ 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[5] and at this rate coal is eliminated from food processing by 2040. In total the use of 20PJ 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 natural 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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[5] Fonterra converted the 40MW boiler at their Te Awamutu plant in 2020 to run off wood pellets. The coal that this displaced is equivalent to around 1PJ.

Fossil fuel production

The scenarios show emissions from the production of fossil fuels are projected to decrease from 2MtCO$_2$ today to less than 1MtCO$_2$ by mid-century. We have assumed a proportional reduction in the emissions from fossil fuel production (vented and flared carbon dioxide and fugitive methane emissions) as overall demand for natural gas reduces.

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 as reduction requires radical conversion of industrial process 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 scenario 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 8.27 below.

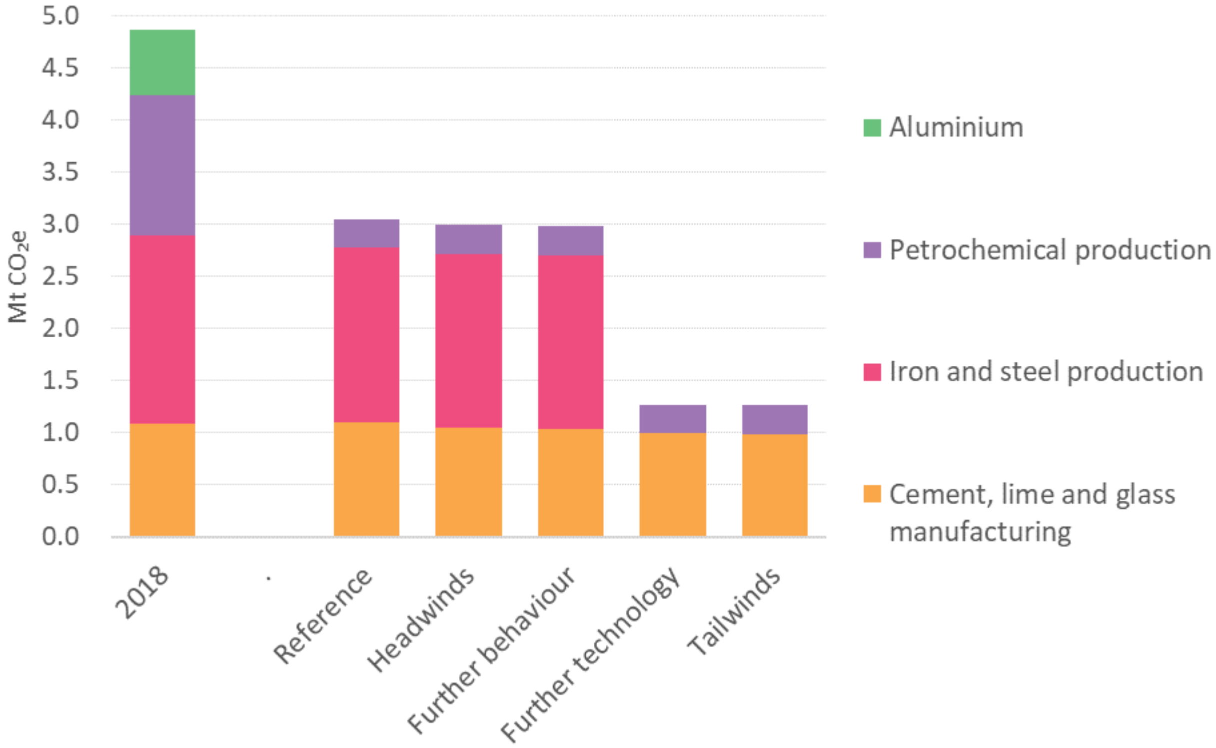

Figure 8.27: Emissions in 2050 from heavy industries relative to 2018 and the Current Policy Reference case

Source: Commission analysis.

Although the model demonstrates the potential for radical technological transformation by decarbonising steel production, it is not realistic to assume that domestic industries would achieve this type of conversion in isolation. Achieving decarbonisation in these difficult to abate industries may require a coordinated long-term partnership between the industry, government and researchers, along with the development of new supporting industries and infrastructure.

Box 8.7: 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 natural 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 8.28 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. The Further Technology and Tailwinds scenarios deploy biofuels blended with conventional diesel to achieve greater emissions reductions.

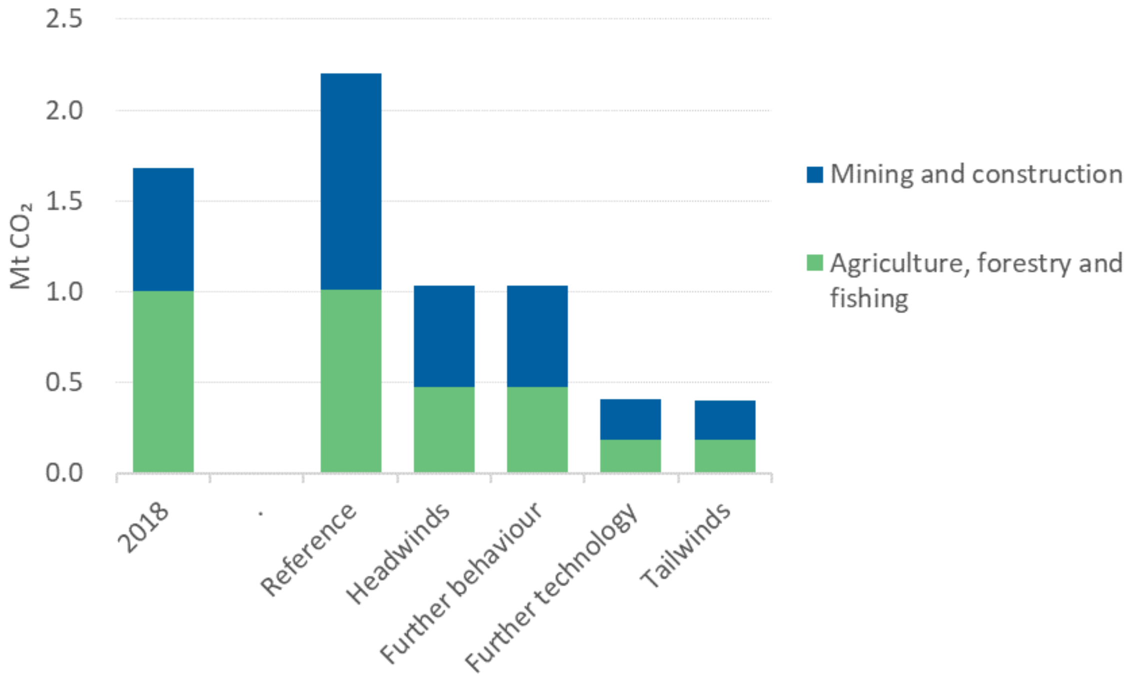

Figure 8.28: Emissions from off-road vehicles and machinery in 2050 across the scenarios compared with the Current Policy Reference case and 2018 emissions

Source: Commission analysis.

Box 8.8: The future of gas

The use of gas decreases considerably under all modelled scenarios as is shown in Figure 8.29. 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 2029. By this time the requirement for 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 gas and 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.

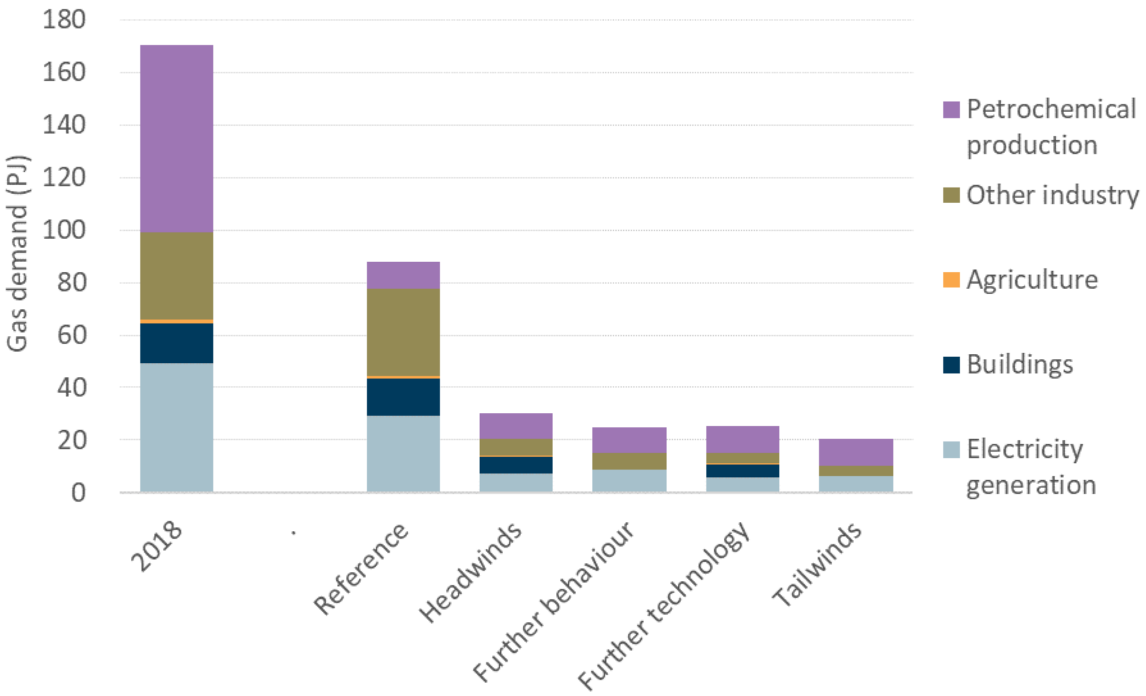

Figure 8.29: Gas demand in 2050 across the scenarios and Current Policy Reference case relative to 2018 totals

Source: Commission analysis.

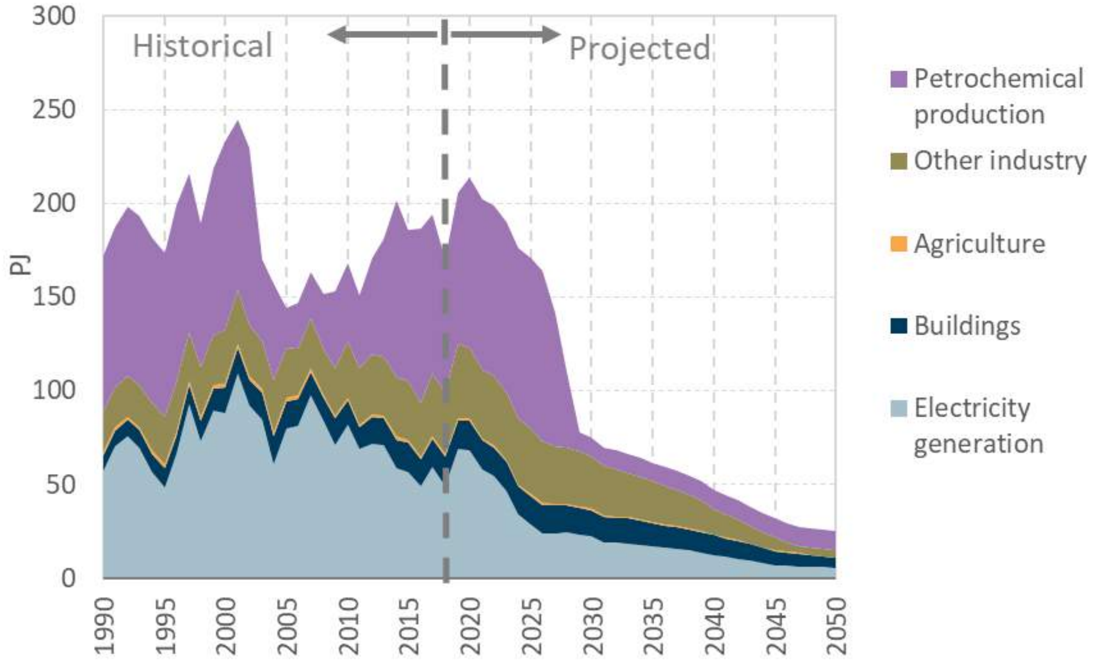

Figure 8.30: Projected gas demand in in the Further Technology scenario

Source: Commission analysis.

These are the modelled scenarios and there are layers of uncertainties around the future of gas in Aotearoa. The Government restrictions on offshore oil and gas exploration[6] 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 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 natural gas and export the majority overseas. They are a significant export earner and employer in Taranaki. They also underpin the domestic gas market by purchasing most of the domestic supply. In 2019 Methanex consumed 40% of domestic gas. This large demand provides sufficient incentive for 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 gas, or gas at a price at which they can profitably produce methanol.

Methanex provide critical flexibility as a 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 gas supply contracts extending to 2029.[7] 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.

Under our modelling, it is assumed that Methanex would cease domestic production in 2029 when the current gas contract expires. We have consulted extensively with industry players in the gas market about the size and cost of future gas supplies. We note the uncertainty around the assumption and welcome feedback.

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

Natural gas supply in Aotearoa

The natural 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. We welcome feedback on this.

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 natural gas in permitted fields is reducing, there are still reserves that could be produced through continued operation. This production requires continued investment.

Figure 8.31 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 beyond 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.

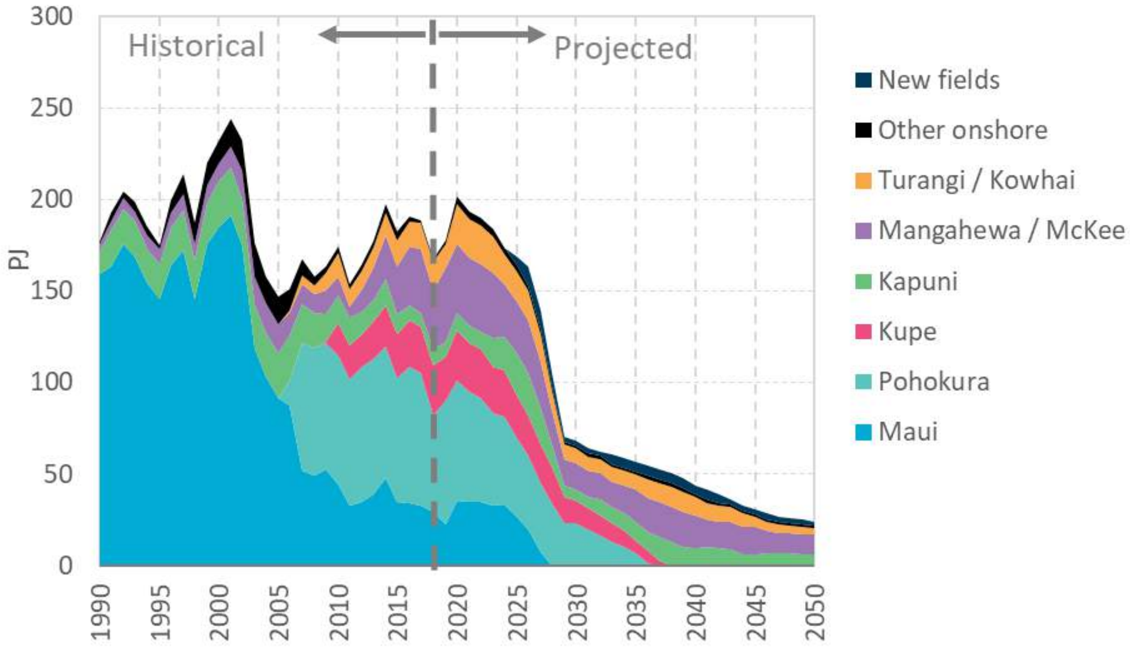

Figure 8.31: Natural gas supply in the Further technology scenario

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[6] (New Zealand Government, 2018)

[7] (Methanex, 2018)

Source: Commission analysis.

It is plausible that a market for gas continues to exist, but domestic production is not able to meet it because wells are nearing the 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 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 following Methanex's departure 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 emission fuel for industry, business and households.

8.4.5 Forestry

Box 8.9: 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 7: Where are we currently headed?* for more information).

For each scenario, we specify annual areas of exotic and native afforestation and deforestation. 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 unproductive land and have no impacts on livestock numbers or production.

We have developed assumptions on levels of afforestation based on evidence and judgement. 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 8.32 below shows the trajectories and total areas of native and exotic afforestation in the scenarios and the Current Policy Reference case.

The scenarios feature significantly less exotic afforestation and more native afforestation compared with the Current Policy Reference case. The overall level of afforestation is similar, at 1.1 to 1.3 million hectares by 2050, but native forest on less productive land would account for about 40 to 55% of this.

The total area of new native forest ranges from approximately 0.4 to 0.7 million 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.[8] The scenario trajectories consider practical limits on how fast native forest planting could be ramped up, particularly nursery capacity.[9]

The total area of new exotic forest in the scenarios ranges from 0.6 to 0.7 million hectares by 2050. This is comparable to the total area planted between 1990 and 2010. 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.

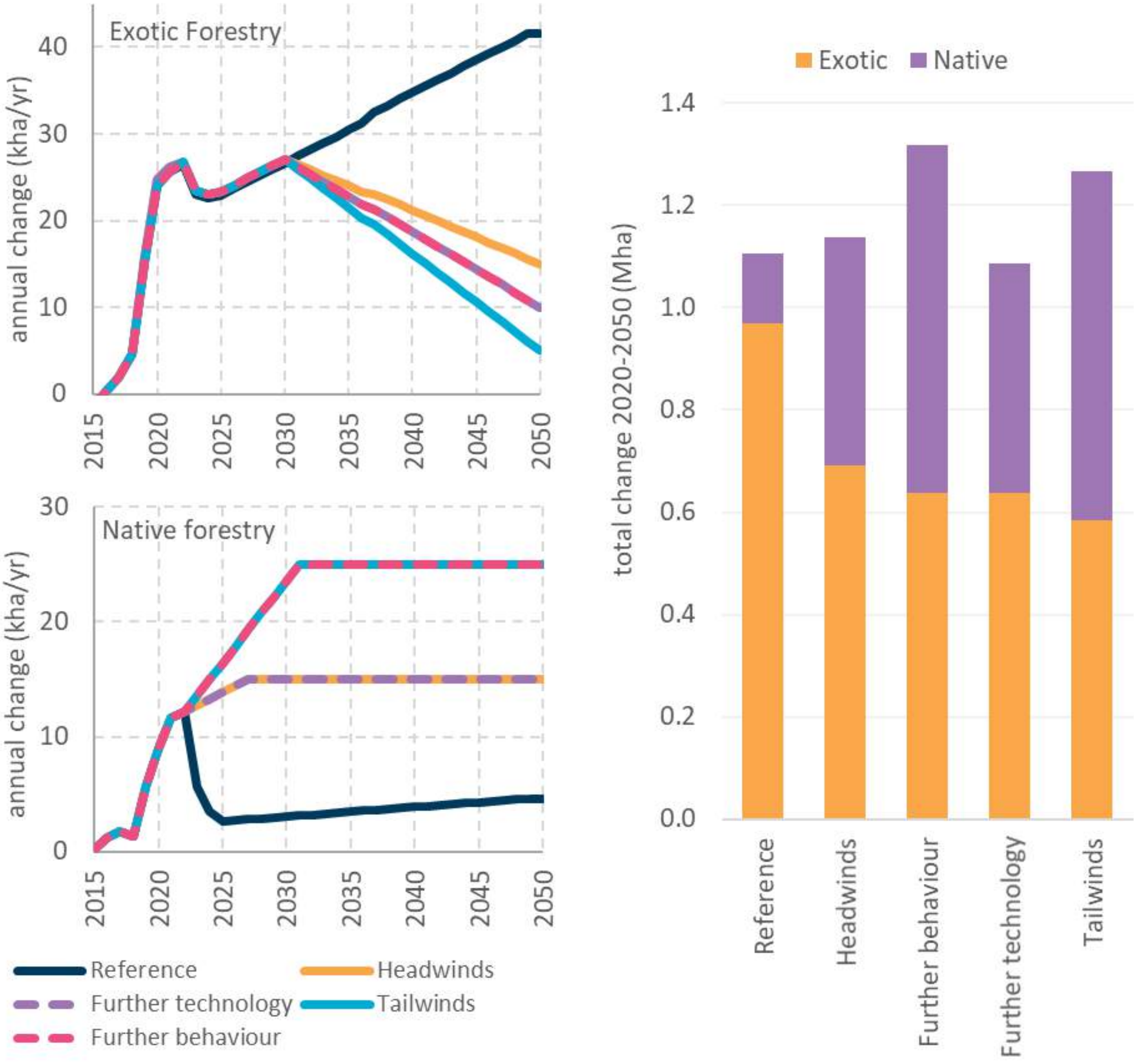

Figure 8.32: Annual change (left) and cumulative change (right) in exotic and native forest area by scenario

Source: Commission analysis.

Figure 8.33 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 the *Looking beyond 2050* section

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[8] (The Aotearoa Circle, 2020)

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

earlier in this chapter). In 2050, native forestry delivers annual net carbon dioxide removals of 2.7 $MtCO_2e$ in the Headwinds and Further Technology Change scenarios and 4.4 $MtCO_2e$ in the Further Behaviour Change and Tailwinds scenarios.

The annual rate of carbon dioxide removals in the scenarios peaks around 2040, about 10 years after the peak in exotic forest planting. Cumulative net carbon dioxide removals from 2021 to 2050 range from 392 to 413 $MtCO_2e$, slightly higher compared to 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.

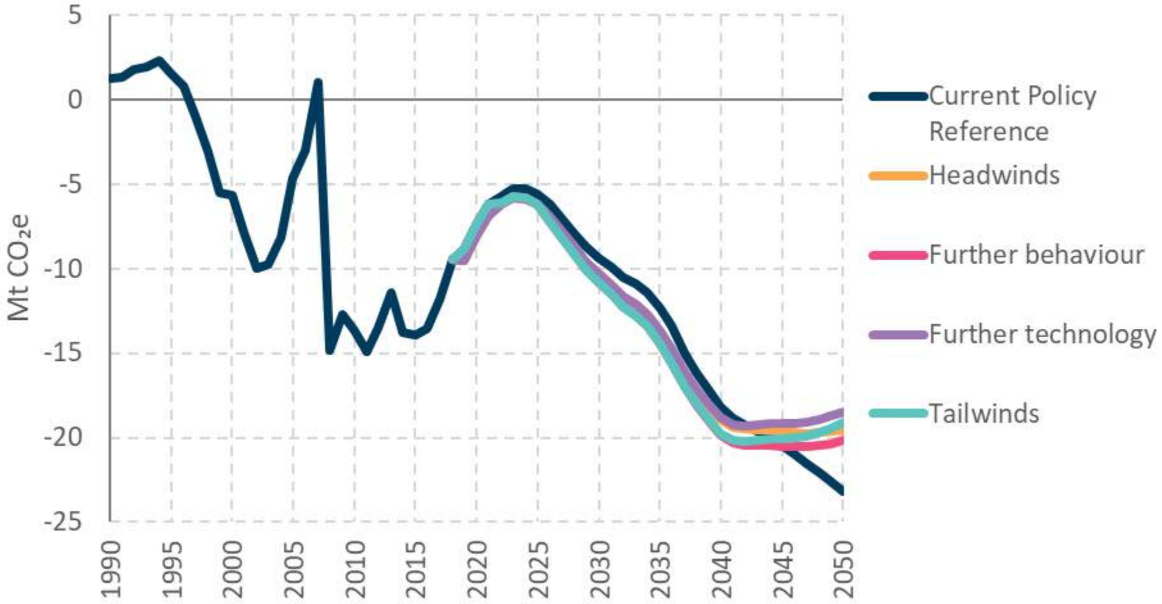

Figure 8.33: Net forestry emissions 1990-2050

Source: Commission analysis.

8.4.6 Agriculture

Land use

All scenarios see a reduction in the total area of land used for food production 2018 to 2050 (Figure 8.34). However, the reduction is smaller than in the Current Policy Reference case presented in *Chapter 7: 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 8.17 million hectares in 2018 to between 7.04 and 7.15 million hectares in 2050 (compared to 6.75 million hectares in the Current Policy Reference case). The largest reduction is seen in the Headwinds scenario.
- The same change in dairy land area in the Headwinds and Further Technology Change scenarios, reducing from 1.74 million hectares in 2018 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 other uses such as horticulture.

- Significantly greater native afforestation on unproductive land, as discussed above.[10]
- The same assumption on retirement of agricultural land into other uses.

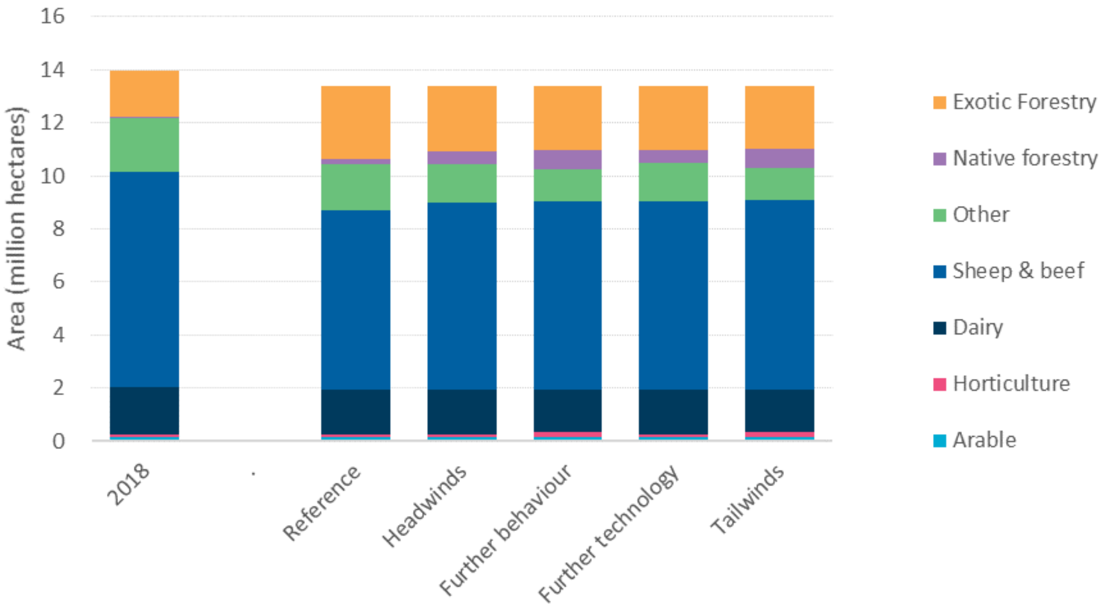

Figure 8.34: Agriculture and forestry land area in 2050 compared with 2018

Source: Commission analysis.

Changes to farm management practices

Chapter 4c: Reducing emissions – opportunities and challenges across sectors, Agriculture discusses a number of shifts in farm management practices which can reduce total feed inputs and emissions. Different approaches would better suit the diversity of farm situations, farmer preferences and objectives. Rather than making assumptions about adoption of individual practice changes, our scenarios consider the 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 8.7. 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 may then require an associated change in land use, such as putting some low-producing pasture into native forest or other uses.

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[10] In Figure 8.34 this is shown as taking land from the 'Other' category, which does not contribute to production. In reality, some native afforestation will likely occur on low producing sheep and beef or dairy pastureland. Some could also occur on land that is not classified as agricultural land, such as lifestyle blocks.

Table 8.7: Impacts of potential farm practice changes on livestock numbers, production and emissions

		Production per animal	**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 effect***	Reduce	Maintain	Reduce	Reduce
	Rebound effect	Reduce	Increase	Maintain or slightly reduce	Maintain or slightly reduce
Reducing breeding and replacement animals	***No rebound effect***	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 red meat production are shown below in Figure 8.35–Figure 8.37. 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.[11]

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 from current levels (by around 6% for dairy and 3% for sheep and beef in 2050). Relative to the Current Policy Reference case, production of sheep and beef meat is similar in 2050 due to less land being converted to exotic forestry. This scenario could represent a future in which some farmers choose to adopt practice changes that result in lower production, without necessarily reducing profitability. Alternatively, it could represent a future where farmers are less successful in improving animal performance, meaning there is limited potential for lowering stocking rates 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 particularly large reductions in the dairy herd due its explicit assumption that 5% of current dairy land is converted to other uses such as horticulture. Figure 8.37 shows that these production outcomes could be achieved if improvements in animal performance can continue at a similar rate to what has been achieved since 1990. Improvements in sheep and beef productivity occur at a declining rate out to 2050.

Figure 8.38 and Figure 8.39 below show the resulting methane emissions intensity for dairy and sheep and beef respectively. These results include the effects of technology adoption (discussed below), but the effect of changes in farm management practices can be seen in the difference between the Headwinds and Further Behaviour scenarios.

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[11] Small differences in livestock numbers and production arise due to the scenarios' different assumptions on the level of exotic afforestation.

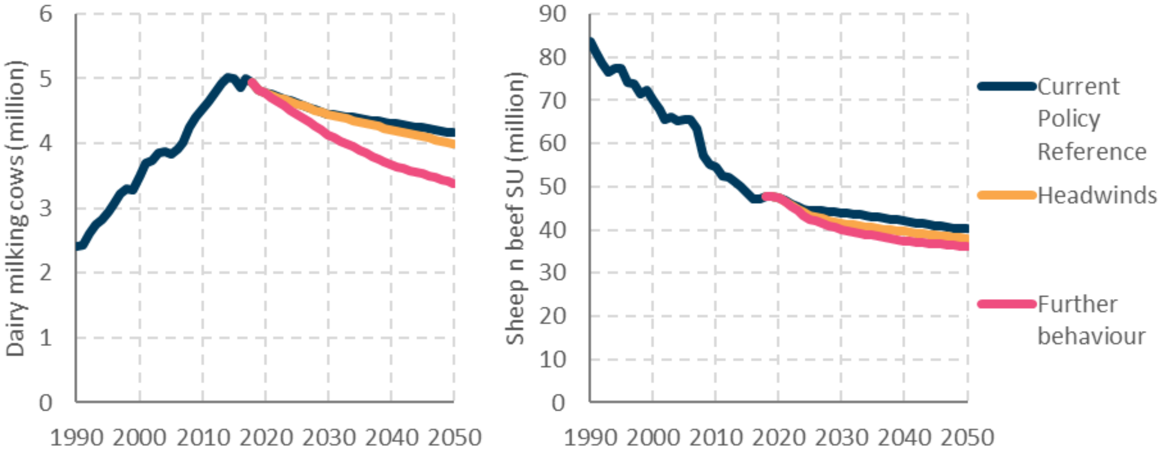

Figure 8.35: Number of milking cows (left) and sheep and beef stock units (right), 1990-2050

Source: Commission analysis.

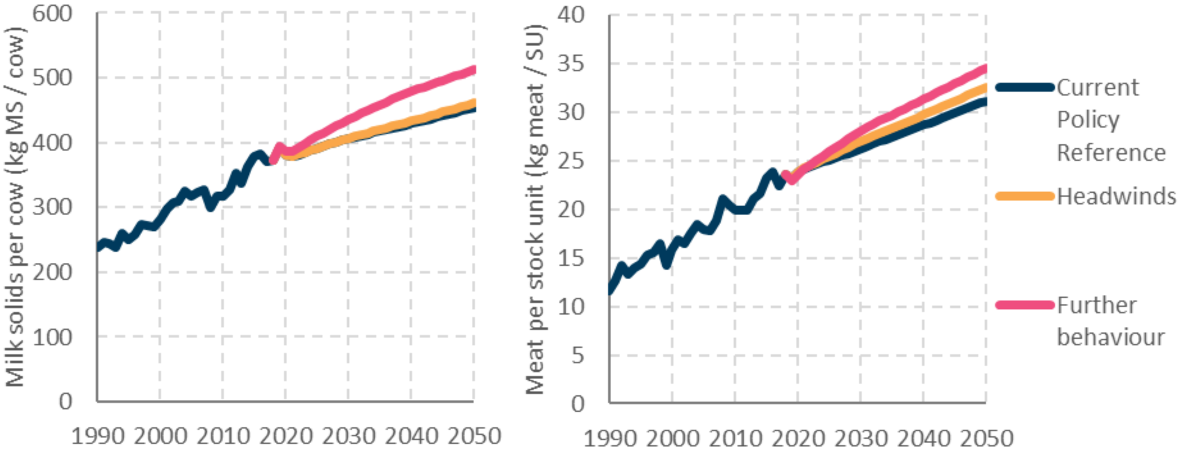

Figure 8.36: Production per milking cow in kilograms of milk solids (left) and sheep and beef stock unit (right), 1990-2050

Source: Commission analysis.

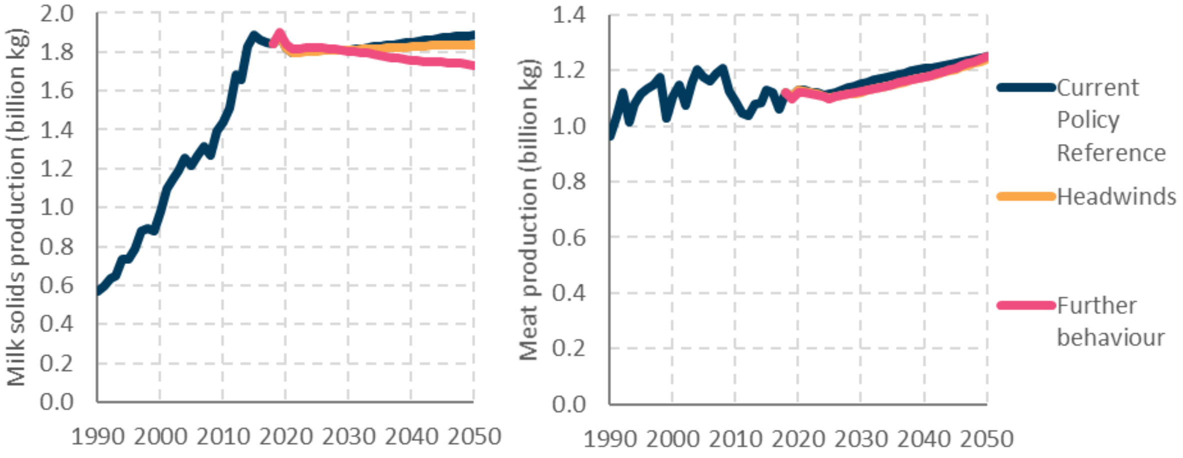

Figure 8.37: Total production of milk solids (left) and sheep and beef meat (right), 1990-2050

Source: Commission analysis.

Technological changes

The scenarios include assumptions on the adoption of several emerging technologies as described in the assumptions table in the appendix. 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. Figure 8.38 and Figure 8.39 show the impacts of these technology assumptions on methane emissions per unit of product.

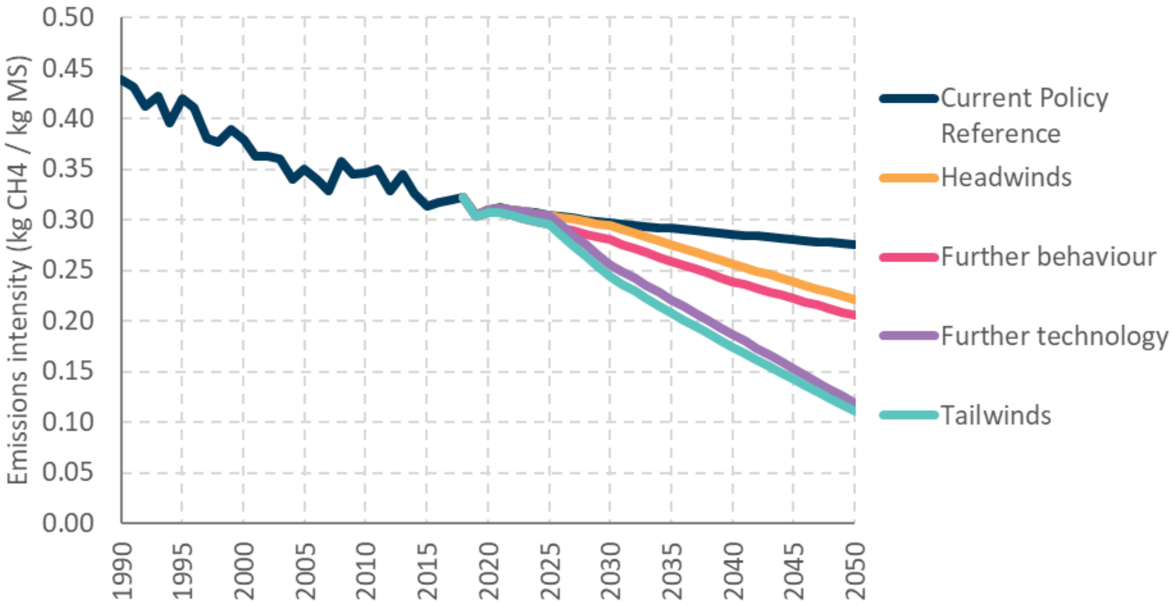

Figure 8.38: Dairy methane emissions intensity 1990-2050

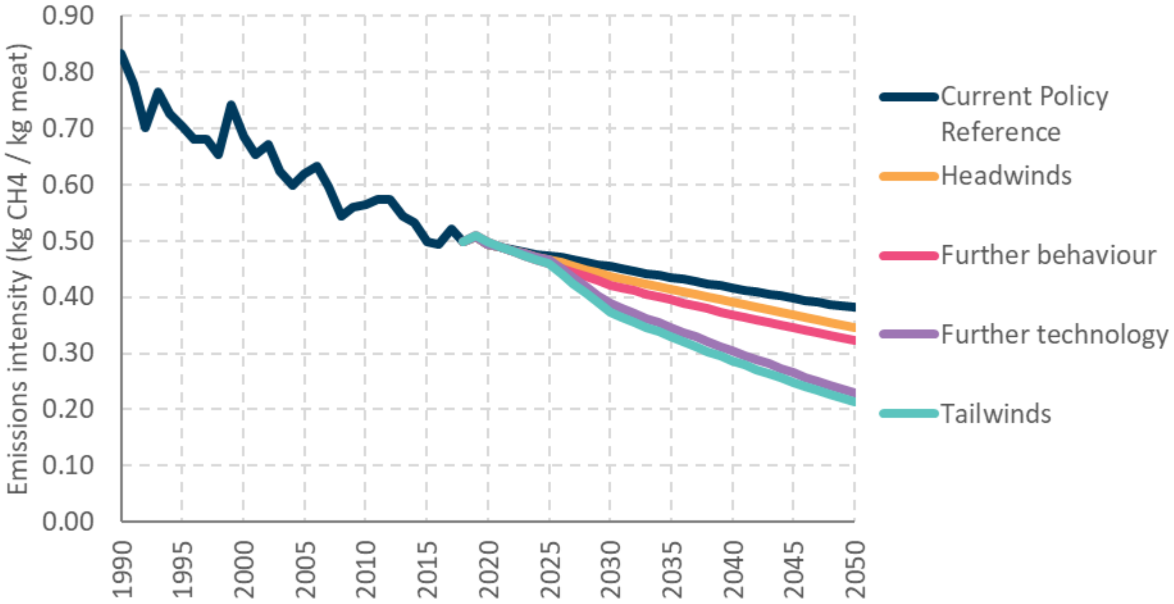

Figure 8.39: Sheep and beef methane emissions intensity 1990-2050

Source: Commission analysis.

Total methane and nitrous oxide emissions

Figure 8.40 shows the total biogenic methane emissions in 2050 across the scenarios compared with the Current Policy Reference case and with emissions in 2018. Relative to 2017 (the base year for the biogenic methane target), the scenarios see reductions of 27 to 59% by 2050. Figure 8.41 shows the emissions trajectory for all scenarios.

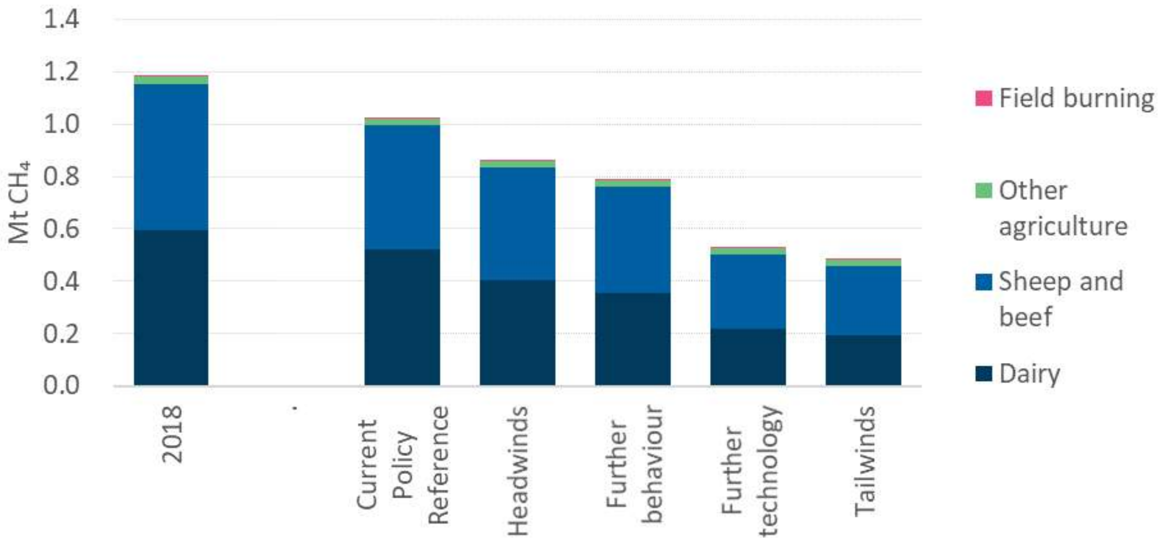

Figure 8.40: Agriculture methane emissions in 2050 compared with 2018

Source: Commission analysis.

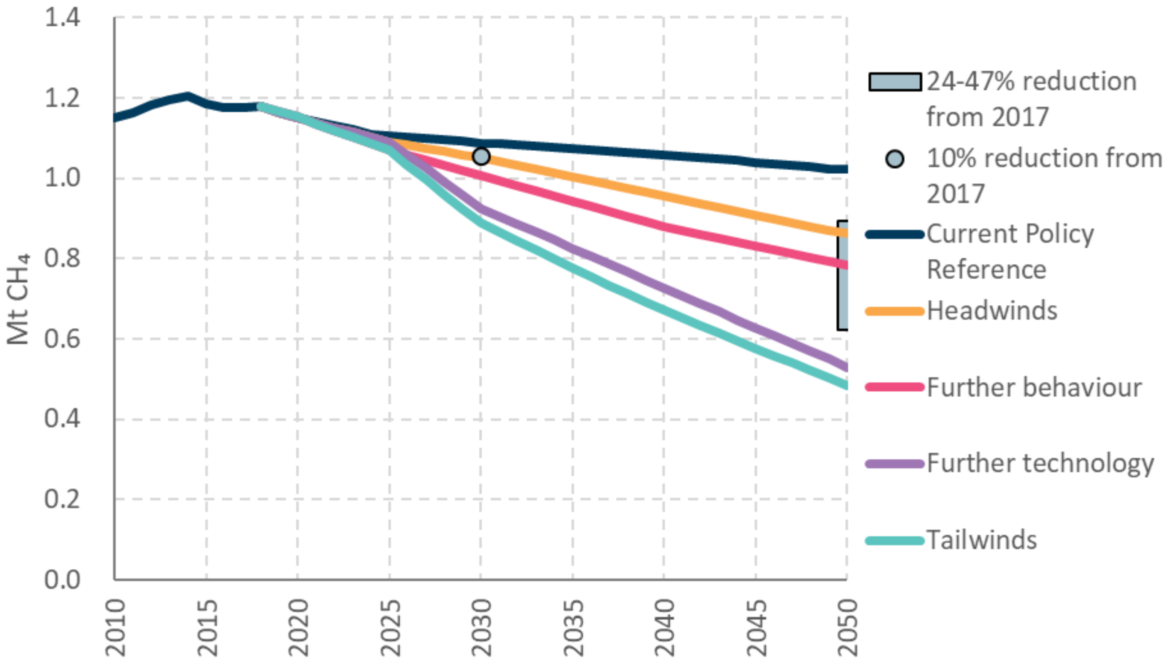

Figure 8.41: Agriculture methane emissions 2010-2050 across the scenarios

Source: Commission analysis.

Figure 8.42 and Figure 8.43 show the same information for nitrous oxide emissions.

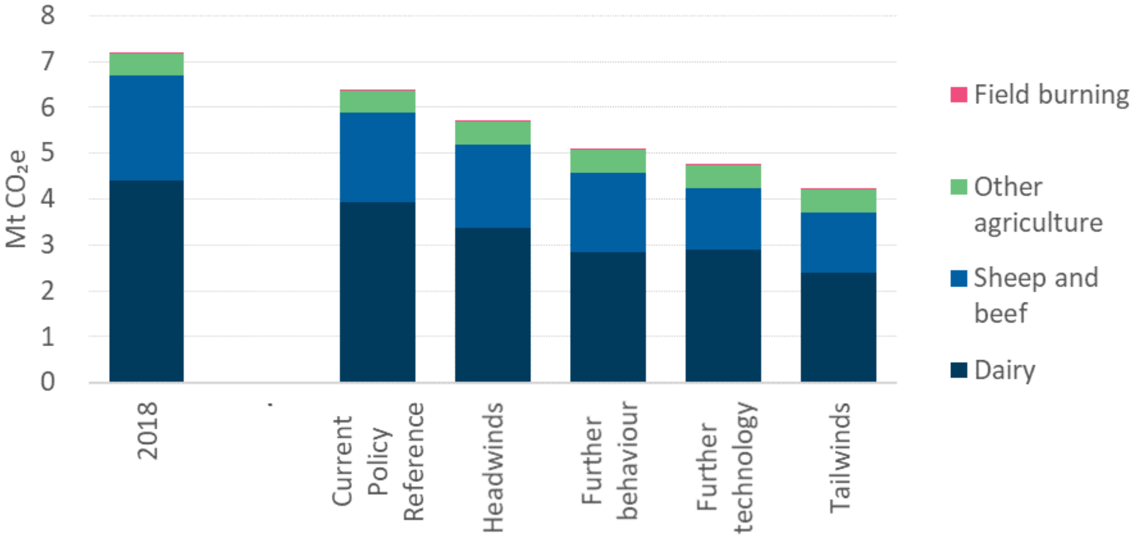

Figure 8.42: Agriculture nitrous oxide emissions in 2050 compared to 2018

Source: Commission analysis.

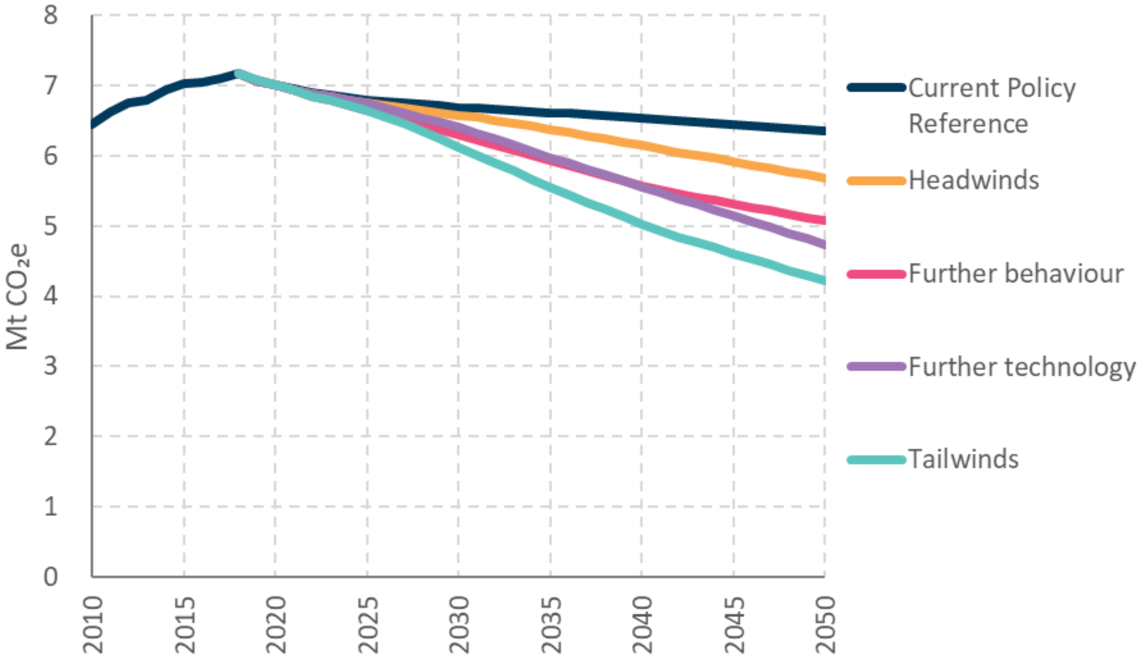

Figure 8.43: Agriculture nitrous oxide emissions 2010-2050 across the scenarios

Source: Commission analysis.

8.4.7 Waste

Future emissions from waste span a wide range across our four scenarios (Figure 8.44). In both the Headwinds and Further Behaviour scenarios, methane emissions reduce by less than 10% by 2030 compared to 2017, meaning the waste sector would be under-delivering relative to the 2030 biogenic methane target. The Further Behaviour scenario sees much larger reductions occurring over time, to 39% below 2017 levels by 2050. Despite large and fast cuts in the amount of organic waste sent to landfill in this scenario, emissions reductions occur more slowly as organic matter already in landfills continues to release methane for many years. This demonstrates the inertia associated with the waste decay process, as organic matter already in landfills continues to release methane for many years.

Improvements to landfill gas capture in the Further Technology and Tailwinds scenarios lead to sharper reductions of 18 and 23% by 2030, and 52% and 63% by 2050 respectively. This highlights the opportunity landfill gas capture provides to drive faster emissions cuts.

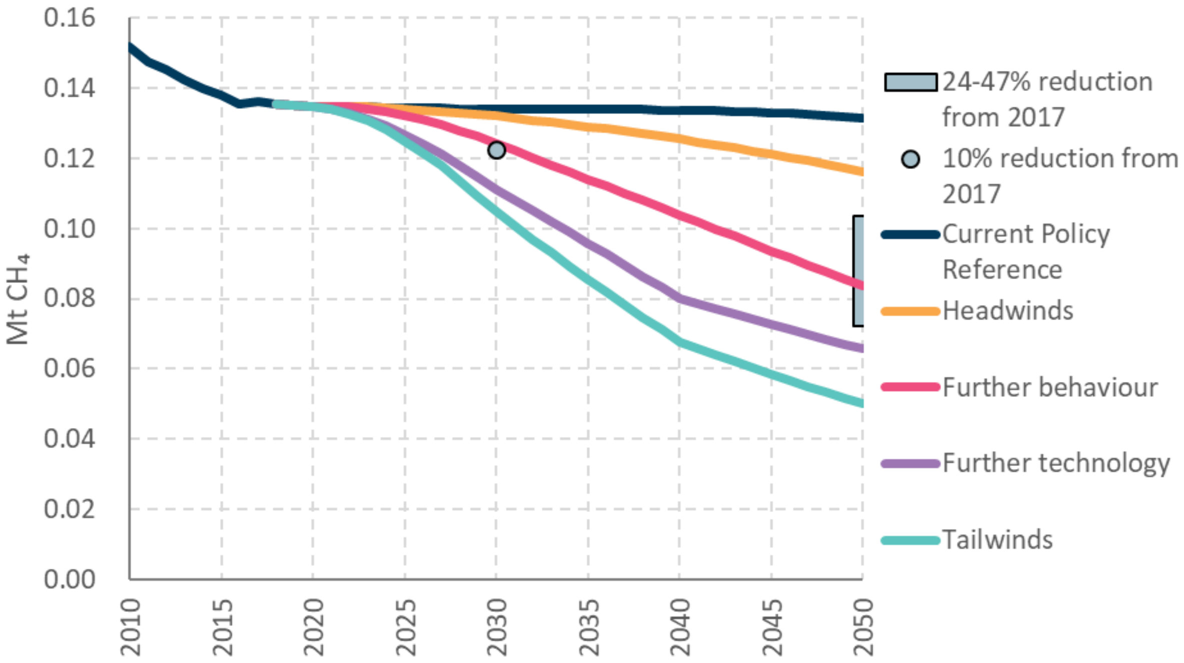

Figure 8.44: Methane emissions from waste by scenario

Source: Commission analysis.

Waste Generation

All scenarios see a reduction in waste generation from 2018 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:

- Headwinds and Further Technology Change: Municipal food and paper waste are 15% lower compared to the Current Policy Reference Case. All other waste types across all disposal sites have the same level of waste generation as baseline.
- Tailwinds and Further Behaviour Change: Paper waste is 35% lower, food waste is 30% lower, all other waste types are 15% lower for municipal landfills by 2050. Garden and wood

waste is 15% lower in 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 baseline, with the degree of increased recovery and the balance of recovery options varying by scenario.

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

- Headwinds and Further Technology Change: 50% of food waste, 28% of Garden waste, 33% of paper waste, 23% 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 is the most common recovery option for textile, paper and construction waste and use as boiler fuel is the most common recovery option for wood waste.
- Tailwinds and Further Behaviour Change: 90% of food waste, 84% of garden waste, 92% of paper waste, 60% of wood waste, 50% of textile waste and 48% 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 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 8.45 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.

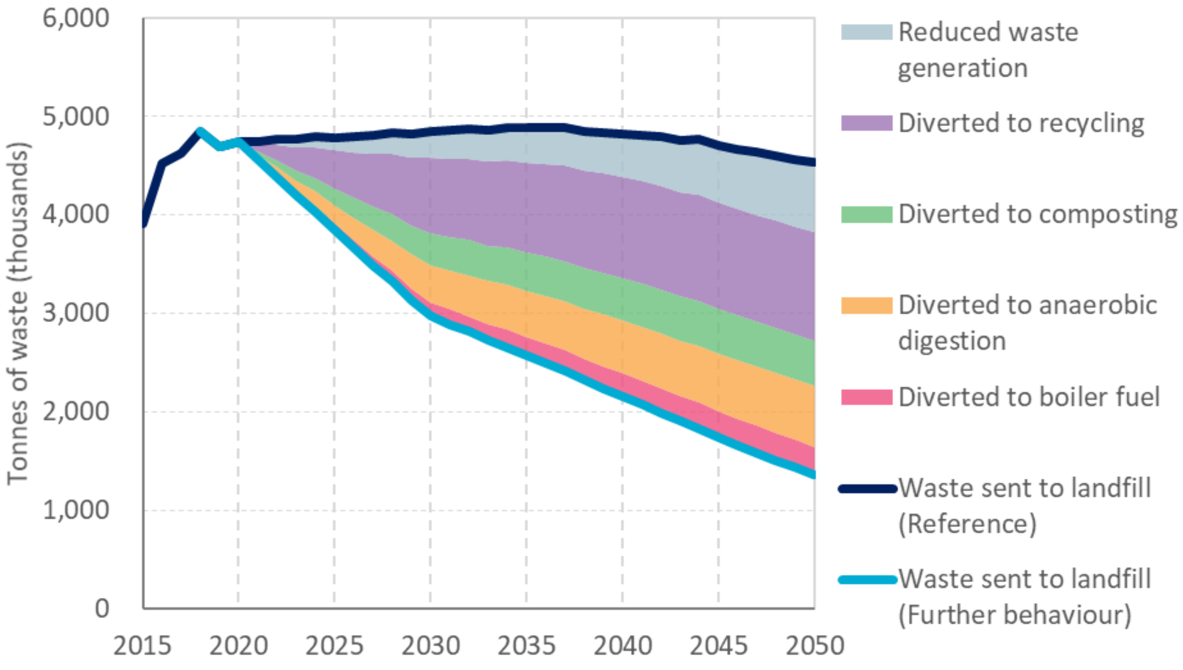

Figure 8.45: Total organic waste sent to landfill in the Further Behaviour scenario compared with the Current Policy Reference case, showing the effect of reduced waste generation and waste recovery

Source: Commission analysis.

Landfill gas capture

The two key variables in landfill gas capture are the efficiency of landfill gas capture and the portion of disposal sites with landfill gas capture. The efficiency of landfill gas capture refers to the portion of methane gas captured over the lifespan of the landfill and the portion of disposal sites with landfill gas capture refers to the percentage of sites with landfill gas capture in that particular category.

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:

- Headwinds and Further Behaviour Change: Landfill gas capture efficiency is the same as in baseline with 68% being the assumed constant through to 2050 and no change in the portion of sites with landfill gas capture.
- Tailwinds and Further Technology Change: Landfill gas capture efficiency for municipal landfills increases to 90% and 60% for other landfill sites by 2050. In addition, 100% of non-municipal sites would have landfill gas capture and 50% of municipal landfills with no landfill gas capture would have landfill gas capture by 2050.

8.4.8 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;

- The Headwinds and Further Technology scenarios make the same projection in emissions as the Current Policy Refence case. In these scenarios, emissions reduce only by 30% from current levels due to the continued usage of HFCs. In this future the Kigali phasedown on HFCs is largely ineffective due to a continued importation of recycled HFCs and HFCs in equipment and there are no improvements in industry practice around leak reduction or end of life disposal.

- The Further Behaviour and Tailwinds Scenario achieve substantial reductions in emissions relative to this due to replacement of refrigeration and air conditioning equipment with alternative systems charged with low-GWP refrigerants. In addition to this, industry practice improvements reduce emissions from equipment leakage and improper end of life disposal.

The emissions projections for these scenarios is shown in Figure 8.46 below. Over the period of 2020 to 2050 there is an 18 $MtCO_2e$ difference in cumulative emissions between these two projections.

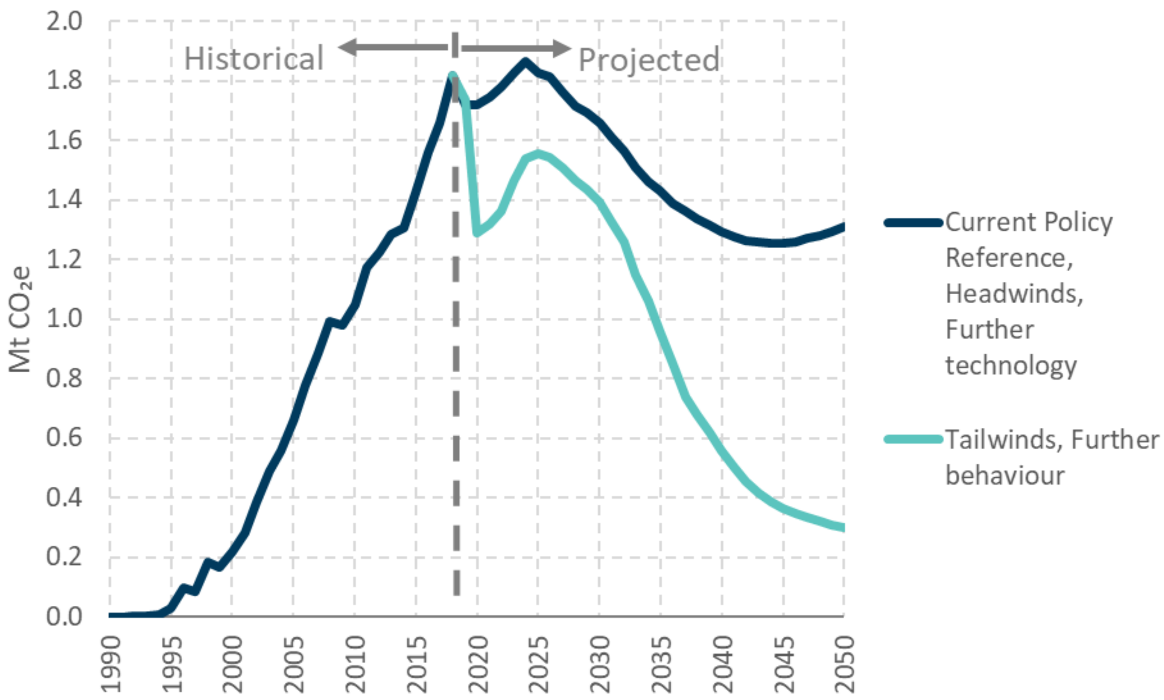

Figure 8.46: HFC emission projections across the scenarios

Source: Commission analysis.

These emissions projections are taken from a modelling exercise undertaken by the Verum Group on behalf of the Ministry for the Environment.[12] There is considerable uncertainty in the future emissions from HFCs.

8.6 Cross sector implications

8.6.1 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.

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[12] (Verum Group, 2020)

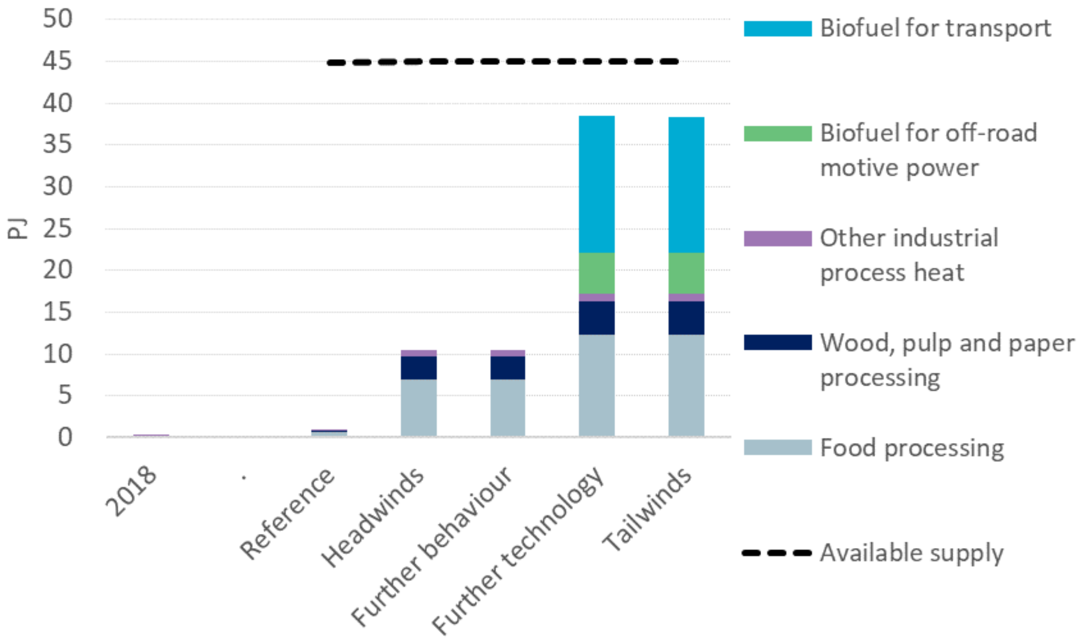

Figure 8.47: Additional biomass demand in 2035 across the scenarios and relative to 2018

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 - 16PJ and increasing to 18-25PJ by 2050, as shown in Figure 8.47. 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 270 million litres of fuel per year. 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 8.48 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.

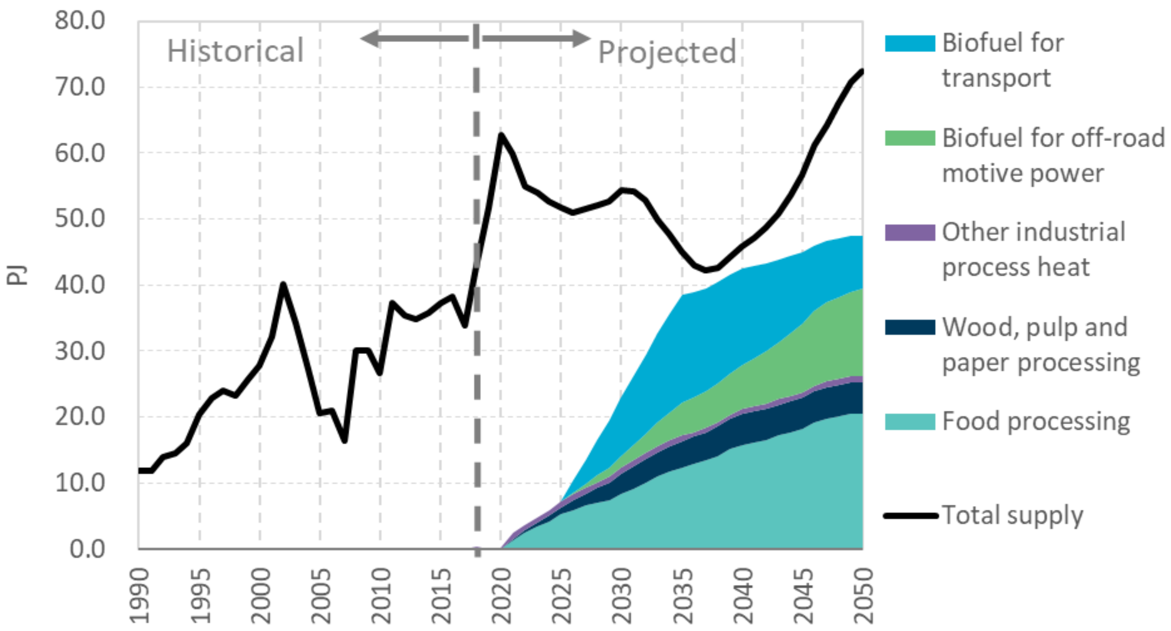

Figure 8.48: Biomass for energy demand for the Further Technology scenario. Note that this is additional bio energy to the amount already consumed.

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 5: 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.

Box 8.10: 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.

8.6.2 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[13] 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 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 depends on: [14]

- 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)

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[13] 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.

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

- 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.

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 natural 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.

8.6.3 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.

8.7 Comparison to 1.5 degree pathways and international pathways

In carrying out our analysis for the domestic emission reduction targets, we are required to set emissions budgets that are aligned with the goal of limiting warming to 1.5 degrees. These budgets must be “ambitious budgets that can realistically be met” and have a focus on domestic actions. The Climate Change Response Act requires that the emissions budgets that are set are indeed met.

We have compared the changes in use of fossil fuels for energy and emissions of methane and nitrous oxide from agriculture in our scenarios against the reductions in these fuels and gases modelled by the IPCC in their 1.5°C compatible pathways (see Figure 8.49 below).

The key features driving global reductions in emissions in 1.5 ° compatible scenarios are:

- deep cuts in coal use between 2020 and 2030 (by about ~75% from 2010 levels)
- reductions in gas use, except where it replaces coal use
- oil use peaking between 2020 and 2025 and declining steadily thereafter
- ongoing but more moderate reductions in agricultural methane emissions
- stabilisation or moderate reductions in nitrous oxide.

Figure 8.49 shows that our scenarios would achieve reductions in the use of coal, oil and gas that are broadly compatible with the reductions seen in the IPCC’s global pathways. However, the scenarios compare less favourably in terms of the total reductions in carbon dioxide emissions from energy and industrial processes, particularly the Headwinds scenario. In part, this reflects the country’s different energy profile compared with the world. Globally, coal power generation accounts for a much larger share of emissions and it is here the sharpest early reductions occur in the IPCC pathways. It also likely reflects significant deployment of carbon capture and storage occurring in the IPCC pathways.

The reductions in agricultural methane and nitrous oxide emissions in our scenarios are also seen to be broadly compatible with the IPCC pathways, spanning a similar range to the IPCC’s interquartile range.

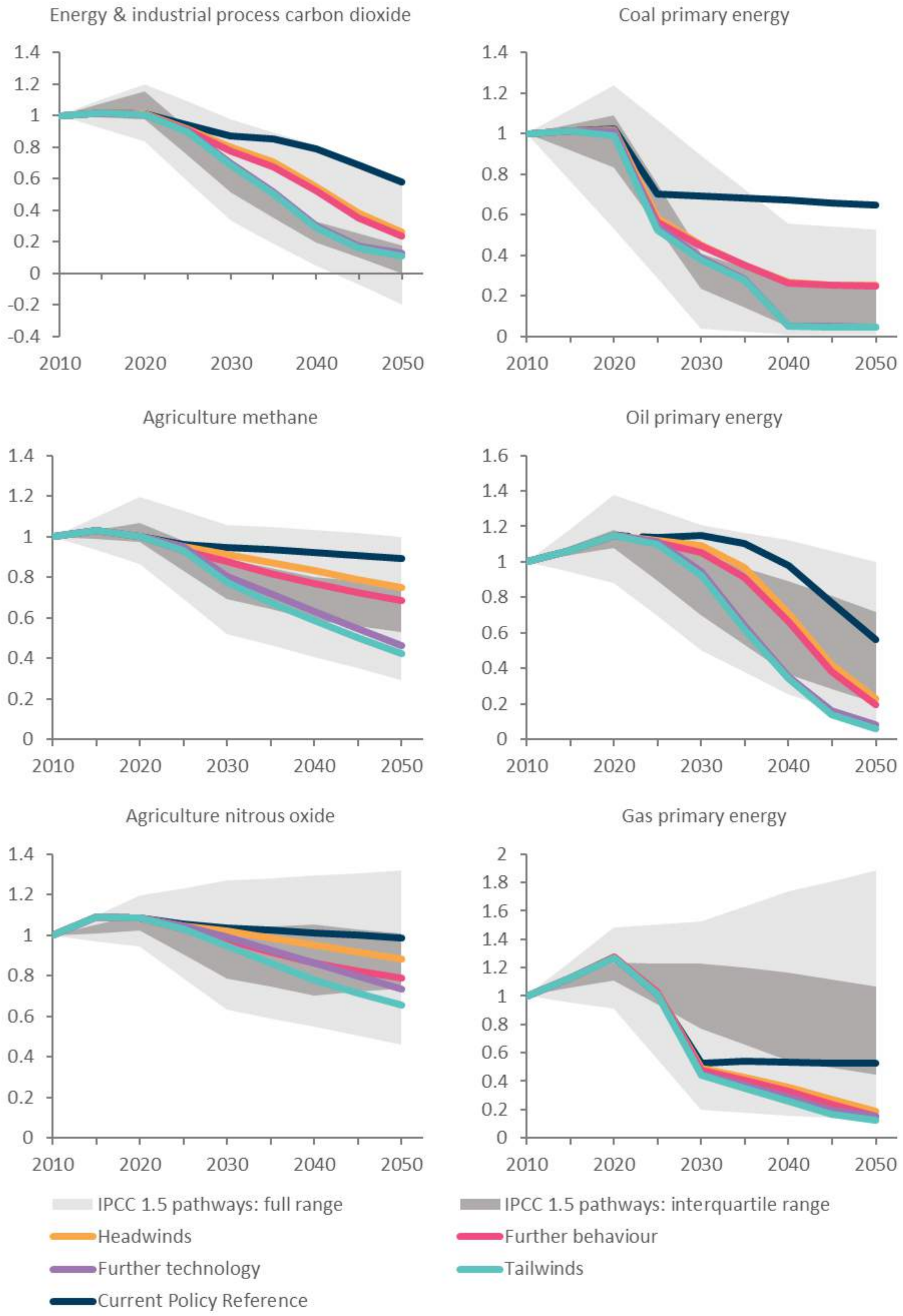

Figure 8.49: Changes in carbon dioxide emissions from energy and industry, agricultural methane and nitrous oxide emissions, and use of fossil fuels for energy in our scenarios compared with IPCC 1.5°C pathways.

8.8 References

IPCC (2018) *IPCC Data Distribution Centre Glossary*. Available at: http://phobos.badc.rl.ac.uk/guidelines/pages/glossary/glossary_s.html (Accessed: 17 November 2020).

Methanex (2018) *Methanex Reaches Long-Term Agreement for Natural Gas Supply to Its New Zealand Operations*. Available at: https://www.methanex.com/news/methanex-reaches-long-term-agreement-natural-gas-supply-its-new-zealand-operations (Accessed: 17 November 2020).

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Appendix: Detailed scenario assumptions

Assumptions held constant across all scenarios are not listed in the table below. This includes all macro drivers such as population and GDP. For other assumptions used in the Current Policy Reference case, see the appendix in *Chapter 7: Where are we currently headed?*

The Tailwinds scenario is not shown for brevity. In general, Tailwinds combines the further behaviour change and further technology change assumptions.

Table legend	*Same as Current Policy Reference*	*Low change from Current Policy Reference*	*High change from Current Policy Reference*	*Other*

		Current Policy Reference	**Headwinds**	**Further Behaviour Change**	**Further Technology Change**
Transport	Total household passenger-kilometres	68.7 billion in 2050 (56.0 in 2018)	62.5 billion in 2050	56.5 billion in 2050	Same as Headwinds
	Public transport share by distance	6.3% in 2050	10.9% in 2050	15.4% in 2050	Same as Headwinds
	Walking and cycling share by distance	Walking 1.4% / cycling 0.6% in 2050	Walking 1.9% / cycling 1.6% in 2050	Walking 2.3% / cycling 3.9% in 2050	Same as Headwinds
	Rail and coastal shipping freight share by tonne-kilometres	Rail 13% / coastal shipping 12% in 2050	Rail 15% / coastal shipping 14%	Rail 21% / coastal shipping 20%	Same as Headwinds
	Cost of batteries (USD/kWh)	US$60/kWh in 2030 US$37/kWh in 2050			US$38/kWh in 2030 US$19/kWh in 2050
	Capital cost penalties on light passenger electric vehicles	25% in 2019, phase out by 2050	25% in 2019, phase out by 2040		25% in 2019, phase out by 2040

<table>
<tr><th></th><th></th><th>Current Policy Reference</th><th>Headwinds</th><th>Further Behaviour Change</th><th>Further Technology Change</th></tr>
<tr><td rowspan="4">Transport (cont.)</td><td>Phaseout date for internal combustion engine vehicle imports (backstop)[1]</td><td>NA</td><td colspan="2">Light vehicles: new 2040 / used 2042
Medium trucks: 2045
Heavy trucks: NA</td><td>Light vehicles: new 2030 / used 2032
Medium trucks: 2035
Heavy trucks 2045</td></tr>
<tr><td>Electrification of rail and coastal shipping</td><td colspan="3">Rail: 12% in 2018, then follows heavy truck electrification once this exceeds 12%
Coastal shipping: follows heavy truck electrification</td><td>Rail increases to 23% in 2031, then follows heavy truck electrification</td></tr>
<tr><td>Electrification of air travel</td><td colspan="3">None</td><td>None to 2030; 50% by 2050</td></tr>
<tr><td>Low carbon liquid fuel utilisation[2]</td><td colspan="3">None</td><td>Increases to 270 million litres of biofuel by 2035, then constant</td></tr>
<tr><td rowspan="4">Buildings</td><td>Household energy intensity reduction[3]</td><td>4% by 2035, 6% by 2050</td><td colspan="2">6% by 2035, 10% by 2050</td><td>9% by 2035, 14% by 2050</td></tr>
<tr><td>Commercial and public building energy intensity reduction[3]</td><td>4% by 2035, 7% by 2050</td><td>11% by 2035, 20% by 2050</td><td>13% by 2035, 22% by 2050</td><td>16% by 2035, 26% by 2050</td></tr>
<tr><td>Phaseout date for fossil fuel heating in new buildings[4]</td><td>NA</td><td>2040 for commercial and public buildings, 2035 for residential buildings</td><td>2025 for all buildings</td><td>Same as Headwinds</td></tr>
<tr><td>Phaseout schedule for fossil fuel heating in all buildings</td><td>NA</td><td>Beginning 2040 and complete by 2060</td><td>Beginning 2030 and complete by 2050</td><td>Same as Headwinds</td></tr>
</table>

		Current Policy Reference	Headwinds	Further Behaviour Change	Further Technology Change
Heat Industry and Power	Food processing energy efficiency improvement	0.7% per year	0.9% per year	Additional 0.2% per year from reducing uptake barriers	Additional 0.2% per year from technology improvements
	Biomass availability for food processing	25% of regional forestry residue and export pulp logs			50% of regional forestry residue and export pulp logs
	Kinleith pulp mill conversion date to high efficiency recovery boiler	NA	2035		2025
	Zero-emissions steel production date	NA			2040
	Low carbon liquid fuel utilisation[2]	None			Increases to 270 million litres of biofuel by 2035, then constant
	Renewable electricity generation capital cost reductions	Wind: 0.5% per year Utility solar: 2.0% per year			Wind: 0.8% per year Utility solar: 3.0% per year
	Geothermal carbon capture and storage	NA			35% emission capture for all fields
Land use change	Exotic afforestation[5]	1.0 million hectares from 2020-2050	0.70 million hectares	0.64 million hectares	0.64 million hectares
	Native afforestation[6]	0.14 million hectares from 2020-2050	0.44 million hectares	0.68 million hectares	Same as Headwinds
	Exotic deforestation[7]	P89: 620 hectares per year until 2036 P90: 73 hectares per year	P89: 310 hectares per year until 2036 P90: none from 2022		

		Current Policy Reference	Headwinds	Further Behaviour Change	Further Technology Change
Land use change (cont.)	Native deforestation	664 hectares per year	498 hectares per year	Zero from 2026	Same as Headwinds
	Horticulture	Area increases from 112,000 hectares in 2018 to 131,000 hectares in 2050		Additional 87,000 hectares of dairy land (5%) converted by 2050	Same as Current Policy Reference and Headwinds
Agriculture	Livestock numbers[8]	Dairy milking cows: 4.16 million in 2050 (4.95 million in 2018) Sheep-beef stock units: 40.2 million in 2050 (47.6 million in 2018)	Dairy milking cows: 3.98 million in 2050 Sheep-beef stock units: 38.0 million in 2050	Dairy milking cows: 3.38 million in 2050 Sheep-beef stock units: 36.2 million in 2050	Dairy milking cows: 3.98 million in 2050 Sheep-beef stock units: 38.3 million in 2050
	Animal productivity improvements	Dairy: 22% increase from 2018 to 2050 Sheep and beef: 32% increase	Dairy: 24% increase Sheep and beef: 37% increase	Dairy: 38% increase Sheep and beef: 47% increase	Same as Headwinds
	Low methane breeding	None	Dairy: Available from 2030, methane emissions reductions increase linearly to 7.5% in 2050 (15% effectiveness x 50% adoption). Sheep and beef: Available from 2025, methane emissions reductions increase linearly to 4.5% in 2050 (15% effectiveness x 30% adoption).		Dairy: Emissions reductions increase to 13.5% in 2050 (15% effectiveness x 90% adoption). Sheep and beef: Emissions reductions increase to 7.5% in 2050 (15% effectiveness x 50% adoption).

		Current Policy Reference	Headwinds	Further Behaviour Change	Further Technology Change
Agriculture (cont.)	Methane inhibitor	None	Dairy: Methane emissions reductions of 1% by 2030 (10% effectiveness x 10% adoption) and 12% by 2050 (30% effectiveness x 40% adoption). Sheep and beef: None.		Dairy: Methane emissions reductions of 12% by 2030 (30% effectiveness x 40% adoption) and 37.5% by 2050 (50% effectiveness x 75% adoption). Sheep and beef: methane reductions of 1.5% by 2030 and 20% by 2050 (50% effectiveness x 40% adoption).
	Methane vaccine[9]	None			Dairy: Additional methane reductions 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: Additional methane reductions 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.

		Current Policy Reference	Headwinds	Further Behaviour Change	Further Technology Change
Agriculture (cont.)	Nitrification inhibitor	None	Dairy: Available from 2030, nitrous oxide emissions reductions increase to 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). Sheep and beef: none		Dairy: Emissions reductions increase to 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). Sheep and beef: none
Waste	Waste generation	Baseline in 2050: Food 555.7 kt; Garden 695.3 kt; Paper 362.3 kt; Wood 785.3 kt, Textiles 186.3 kt; Construction & demolition 1322 kt	Reduction from baseline in 2050: Food 15%; Paper 15%	Reduction from baseline in 2050: Food 30%; Garden 14%; Paper 34%; Wood 14%; Textiles 15%; Construction & demolition 10%	Same as Headwinds
	Waste recovery/diversion: percentage recovered by 2050	NA (Baseline)	Food 50%; Garden 28%; Paper 33%; Wood 23%; Textiles 15%; Construction & Demolition: 18%	Food 90%; Garden 84%; Paper 92%; Wood 60%; Textiles 50%; Construction & demolition 48%	Same as Headwinds
	Sites with LFG capture	Status quo: Municipal landfills required to capture			LFG capture installed at 100% of non-municipal landfills by 2050 and 50% of municipal landfills currently without LFG capture
	LFG recovery rate (average)	68% constant through to 2050			90% for municipal landfills, 60% efficiency for other sites by 2050

		Current Policy Reference	Headwinds	Further Behaviour Change	Further Technology Change
F-Gases	HFCs	21% emissions reduction from 2018 by 2035, 28% reduction by 2050		47% reduction by 2035, 83% by 2050	Same as Current Policy Reference and Headwinds

Assumption notes:

1) There is a 5-year transitional period for the phaseout.
2) Low carbon liquid fuel total is shared between transportation and off-road vehicles and machinery uses.
3) Given percentages are relative to 2018. Figure is for total energy use which includes heating, cooling and appliances.
4) There is a 3-year transitional period for the phaseout.
5) Exotic afforestation is assumed to occur on productive sheep and beef land. In Tailwinds the total area from 2020-2050 is 0.59 million hectares.
6) Native afforestation is assumed to have no net effect on agricultural production.
7) P89 = post-1989 forest land, P90 = pre-1990 forest land. P90 deforestation area is the net area after offsetting with carbon equivalent forest.
8) Sheep-beef stock numbers are slightly higher in Further Technology Change due to less land converted to exotic forestry.
9) Methane inhibitor and vaccine 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.