Energy Strategy Deep Dive using TIMES-NZ

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Contents

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TIMES-NZ is a project developed through joint effort from across government and industry with the core TIMES-NZ project team comprised of members of BEC, EECA, and PSI.

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Reference Group

In consultation with a small group of BEC-member experts, we distilled several sensitivities to test and understand the way the scenarios respond in terms of emission outcomes and cost of optimally responding to these changes. BEC would like to thank and acknowledge the group members here:

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Foreword

Future thinking is critical to ensure New Zealand's energy system remains resilient, sustainable, and affordable in the face of evolving economic, social, and environmental conditions.

Energy system thinking and scenario analysis are great tools for navigating the complex and rapidly changing energy landscape. Scenarios can help us identify potential challenges and opportunities, and inform whether decisions are needed now, or later, about energy investment, regulations, and policies.

Furthermore, scenario analysis can help to uncover potential risks and uncertainties. By understanding these risks, decision-makers can develop strategies to mitigate their impact and prepare for future challenges.

The following deep dive into the TIMES-NZ model aims to shed light on why a strategic approach to emissions reduction needs to embrace the real risk of the future turning out differently from that anticipated.

Optionality is a key factor for a successful energy sector transition. The TIMES-NZ model uses various combinations to find the lowest-cost options to reduce emissions across all energy relevant sectors including transport, industry, electricity, commercial and residential and agriculture.

New Zealand's energy system can best reflect the findings of this deep dive by ensuring we have options for all types of fuels. The more options we have, the more resilience, the lower emissions, and lower costs we are likely to have.

Tina Schirr
Executive Director
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Executive Summary

In an environment where there are so many uncertainties, there is significant value in understanding the interplay of these uncertainties with decision-making. Decision-makers and policymakers must commit ahead of time in the face of uncertainty, respond to major events the best way they can, adapt through time, and work with the consequence of their decisions after the fact.

Scenario modelling is a tool for examining possible outcomes rather than forecasting what will or will not happen. The outcomes from scenario modelling put decision-makers and policymakers in the position of better understanding the consequences of choosing different pathways in the chosen scenarios.

The TIMES-NZ model is one of New Zealand's most comprehensive energy system models and includes two different but internally consistent scenarios: Kea and Tūī. These scenarios are differentiated primarily on the degree to which governments prioritise emission reductions. In Kea, it is a priority earlier, while in Tūī it is deferred, and emission reductions are caught up later.

These scenarios show that if individual decision-makers behave rationally – a core premise of the TIMES-NZ model – the government's emissions budgets to 2035 would be met in Kea but not in the second or third budget period for Tūī.

While scenario analysis helps us understand the consequences of different pathways, sensitivity analysis can help us understand how resilient the decisions and their outcomes are to changes in the underlying assumptions.

This paper presents results from a sensitivity analysis on the "base case" Kea and Tūī scenarios, in which particular scenario parameters are systematically varied. This includes applying a constraint on emissions as per the budgets to 2035, which had not been developed when the TIMES-NZ model was first released.

The first sensitivity tests we undertook were to require the Tūī scenario to meet the governments emission reduction budgets (ERP budgets) and compare this with the original ("base case") Tūī emissions and cost outcomes. Since Kea meets the ERP budgets in its base case, there is no need to apply the same constraint. A range of other sensitivities are outlined in the following table, were applied. In each case, we tested Tūī outcomes with and without the ERP constraint. The results in the "Tūī_ERP" scenario, for each sensitivity, therefore, reflect both the impact of the sensitivity, as well as the impact of the ERP constraint.

What we have learned from the sensitivity deep dive is that when the system resets itself on a least-cost basis, most fuel options are adjusted whether they are low carbon or fossil fuels. If, hypothetically, fossil fuel options were removed, there would be fewer options, so when reality bites the cost would be higher than would otherwise be the case.

Label	Description of sensitivity and outcome			
ERP	**Incorporating ERP budgets.** The Tūī base case does not meet New Zealand's emission budget for 2026 - 2030 and 2030 - 2035. This sensitivity forces Tūī to meet each budget via a constraint in the model but does not prescribe how – it asks the model to find the least-cost solution.	Tūī_ERP	-2%	+0.1%
		Tūī_ERP	-2.4%	+0.3%
		Kea	n/c	+0.3%
BEV	**An increase in BEV costs of $10,000,** compared to the base case, increases total cost for all scenarios. In Tui, emissions increase as a result of lower BEV usage. In Tui_ERP, emissions decrease, but only due to the presence of the ERP constraint. Emissions in Kea do not change, as BEV uptake is unchanged.	Tūī	+0.5%	+0.2%
		Tūī_ERP	-2.4%	+0.3%
		Kea	n/c	+0.3%
VKT	**Lower ride sharing & higher private vehicle use is tested in the Kea scenario only[1].** This is the only sensitivity where an energy service demand is in-creased, hence a marked increase in Kea's costs and emissions is observed.	Tūī	+0.5%	+0.2%
		Kea	n/c	+0.3%
		Tūī_ERP	-2.4%	+0.3%
BIO	**A doubling of domestically produced woody bio-mass costs,** from around $10/GJ to $20/GJ, increases emissions for all scenarios as decision makers switch to fuels with higher emissions. Emissions rise in all scenar-ios. Costs increase in Tui, but Kea manages to transi-tion to other fuels with no impact on total cost.	Tūī	+1.6%	+0.1%
		Tūī_ERP	+0.5%[2]	+0.2%
		Kea	+1.5%	n/c
GAS	**The departure of a major gas consumer causes a significant disruption in gas markets, driving gas costs to $35/GJ.**[3] The remaining demand for gas shrinks further, substantially reducing emissions and increasing costs across all scenarios.	Tūī	-4.2%	+0.5%
		Tūī_ERP	-7.1%	+0.6%
		Kea	-9.0%	+0.5%
COA	**A ban on coal use** is introduced after 2037 (except for iron feedstock and unknown coal use). This reduces emissions for both scenarios, though has no impact on cost, suggesting any fuel switching required can hap-pen at a similar total cost.	Tūī	-0.4%	n/c
		Tūī_ERP	-2.8%	+0.2%
		Kea	-0.4%	n/c
GASCOA	As described for GAS above, but with a constraint on coal usage per the COA sensitivity case.	Tūī	-4.7%	+0.75%
		Tūī_ERP	-17.2%	+0.6%
		Kea	-9.4%	+0.5%

Two key observations are evident from the modelling.

Firstly, when faced with a significant change to a single underlying parameter, in pursuit of lowest cost decision makers in the model adjust energy delivery and consumption across a wide array of fuels. Put another way, **there does not appear to be a single "magic fuel option" which provides the resilience against significant changes.**

Second, when considering the variety of changes that the energy system may experience over the coming decades, **removing fuel optionality from decision-makers will increase the cost[4] of meeting New Zealand's emissions budgets.** Hence, as a corollary to the first insight, improving resilience, meeting emissions budgets, and keeping downward pressure on costs in the face of a changing world would benefit from greater choices of, and confidence in the availability of, cost effective, low emissions fuel options.

1 It is not tested in Tui, as Tui already had low use of ride sharing and high private vehicle use. In effect, this sensitivity applies Tui's VKT assumptions in Kea

2 It may at first be surprising that this sensitivity allows Tūī's emissions to rise compared with the baseline, despite the imposition of the ERP emissions budget constraint. That is because, while Tūī's emissions over the period 2025-2035 do, in fact, decrease in order to meet the ERP budgets, the emissions increase over the period 2035-2060, more than offsets this, underscoring the caveat that we did not impose any constraints on emissions after the third budget.

3 To this we also added $4/GJ, reflecting the cost of gas storage, for any electricity sector use of natural gas.

4 Unless those fuels are rarely used. This is a well-known result of optimisation theory.

What does this mean for policymakers?

From an emissions and cost perspective, our advice to policy-makers is to focus on enabling energy system decision-makers to respond to unexpected changes in the energy system - based on their assessment of the situation as it arises and the options available to them. This can be achieved through:

- **Giving low emissions options the best chance of being selected by energy system decision-makers** under any circumstances that may arise. This could mean using policies that keep options of known technologies viable through the transition.
- **Giving decision-makers as much certainty as possible about policy development** in order to minimise its impact on the cost and complexity decision-makers face in respect of managing and responding to risk.
- **Reducing regulatory barriers to all low-carbon energy supply solutions** (get the sand out of the cogs). The scenario modelling indicates there is value in ensuring a wide scope of low-emissions energy options is possible to support the management of uncertainty.
- **Avoiding regulatory barriers** (including bans) that get in the way of least-cost, rational, secure energy supply - especially low-carbon solutions (i.e., don't put sand in the cogs).

Our modelling assumes decision-makers have perfect foresight: they know our sensitivities are coming and can adapt accordingly to the information at hand.[5] The modelling shows that some of this anticipation occurs decades before the event.

This is a key component of the model's ability to keep the costs of responding relatively low. However, the ability to perfectly anticipate changes is obviously a poor reflection of reality, where there is a spectrum of "surprises" – in their source, magnitude, and timing – that energy decision-makers face. It seems intuitively reasonable that this real-life uncertainty increases the cost of responding (the cost of risk). While uncertainty can never be eliminated, policy makers have it in their power to ensure policy development does not unintentionally add to it.

5 In future TIMES-NZ modelling, we hope to adapt the optimisation so that the model can be genuinely "surprised" by a shock. This will allow us to quantify the cost of uncertainty.

BEC scenarios – Kea and Tūī

The idea of describing and quantifying two significantly different scenarios to help policymakers understand the dynamics of the energy system was pioneered by Shell and picked up by the World Energy Council (WEC) in the 1970s. WEC observes, "scenarios provide an inclusive and strategic framework that enables big-picture thinking and decision-making under deep uncertainty. They are designed to be used as a set to explore and navigate what might happen, not what should happen or what we want to happen."

The implications of the two BEC2050 scenarios (Kayak and Waka) on the New Zealand energy system were quantified in 2016 using the WEC energy system model. When BEC introduced two updated scenarios in 2018 (BEC2060, Kea and Tūī) it also commissioned a purpose-built New Zealand energy system model to quantify the impacts. Since the launch of Tūī and Kea in 2019, this model has been substantially improved. The New Zealand version is now known as TIMES-NZ and is run as a joint project by BEC, EECA, PSI and over 60 participants from the private and public sectors.

The Kea and Tūī scenarios are based on several critical uncertainties identified through industry stakeholder workshops. At the time BEC 2060 was modelled, it was understood that the principal uncertainty for the energy sector would be the stance taken by government (supported by New Zealand voters) in its response to climate change.

The two scenarios are described as follows:

Kea

New Zealand adopts the position that the economy cannot remain internationally competitive with its current emissions intensity. It takes a leadership stance in lowering emissions, choosing to undergo an assertive and urgent economic transformation. This leadership stance is strongly supported by business and the wider community. Policy settings strongly encourage the reduction of emissions. The early adoption of low emissions technology is supported.

Tūī

New Zealand society does not support the view that strong action on climate change is the most important issue of the day. New Zealand focuses on delivering economic prosperity by continuing to leverage off its traditional comparative advantages. Governments do what they can to meet international emissions reduction commitments. Otherwise, New Zealand is a slow follower on climate change responses, protecting some businesses from the full force of the carbon price and instead mirroring how other countries develop their climate policies. Adoption of low emissions technology is a purely commercial and competitive response.

TIMES-NZ – An energy system model

TIMES is an internationally reputable energy system modelling framework originally developed by the IEA in the 1970s. Given its open-source nature, it is regularly updated and improved by a global community of TIMES modellers. There are many variants and offshoots of TIMES.

TIMES is a "linear program" optimisation model that minimises the total system cost of energy and carbon and assumes perfect foresight.[6] Specifically, cost minimisation is achieved by choosing between technologies and fuels to meet expected energy demand. The model effectively invests in the various available technologies based on a combination of cost, efficiency, and fuel availability. More information about the New Zealand version of TIMES and the underlying scenario assumptions is available in the **TIMES-NZ User Guide.** Here we focus on what these model characteristics mean for interpreting the output:

- It is an **energy system** model. This sets it apart from models that focus their attention exclusively on e.g., transport, or electricity, or hydrogen, without considering the wider dynamic energy system impact of their conclusions. The reality is that decisions in one part of the energy system will have some impact – big or small – on the rest of the system. TIMES-NZ allows us to capture that and is capable of modelling individual system components and technology in substantial detail.

- The main advantage of an optimisation model based in linear programming is that it **guarantees the lowest cost solution for the entire system** is always found.[7] Linear programming also produces a vast array of information about the nature of the optimal solution that is not available with most other modelling frameworks, such as implied economic prices, the sensitivity of the solution, etc.

- However, linear programming requires that **all model calculations are linear.** There is some capacity in the model to represent the "stepped" nature of some costs (e.g., the costs of extracting different oil and gas reserves) but these models cannot properly represent the "non-linearity" in many aspects of the energy system (e.g., risk aversion, non-linear demand curves, learning rates of technologies dynamically linked to deployment etc). TIMES-NZ modellers attempt to approximate these factors as best they can, but their efforts are never perfect.

- The **model is rational** in that it will change a $100b system solution to save $1. **It will always find the lowest cost solution** based on the information that has been provided. There is substantial real-world evidence that decision makers do not see the world through the eyes of TIMES-NZ's relentless pursuit of minimum cost. However, the unwavering reliability of TIMES-NZ to always find the lowest cost solution means the quantification of sensitivity runs in TIMES-NZ is reliable, explainable, repeatable, and presents a well-understood "bar" to which we can compare real-world decision making.

- The model assumes all decision-makers know the future from day one and makes decisions accordingly. While this unrealistic assumption is somewhat offset by having multiple scenarios and sensitivities, it still is a frame through which TIMES-NZs' output must be understood. BEC intends to **explore a range of future variants** of TIMES-NZ which systematically allows for uncertainty in interesting and exciting ways.

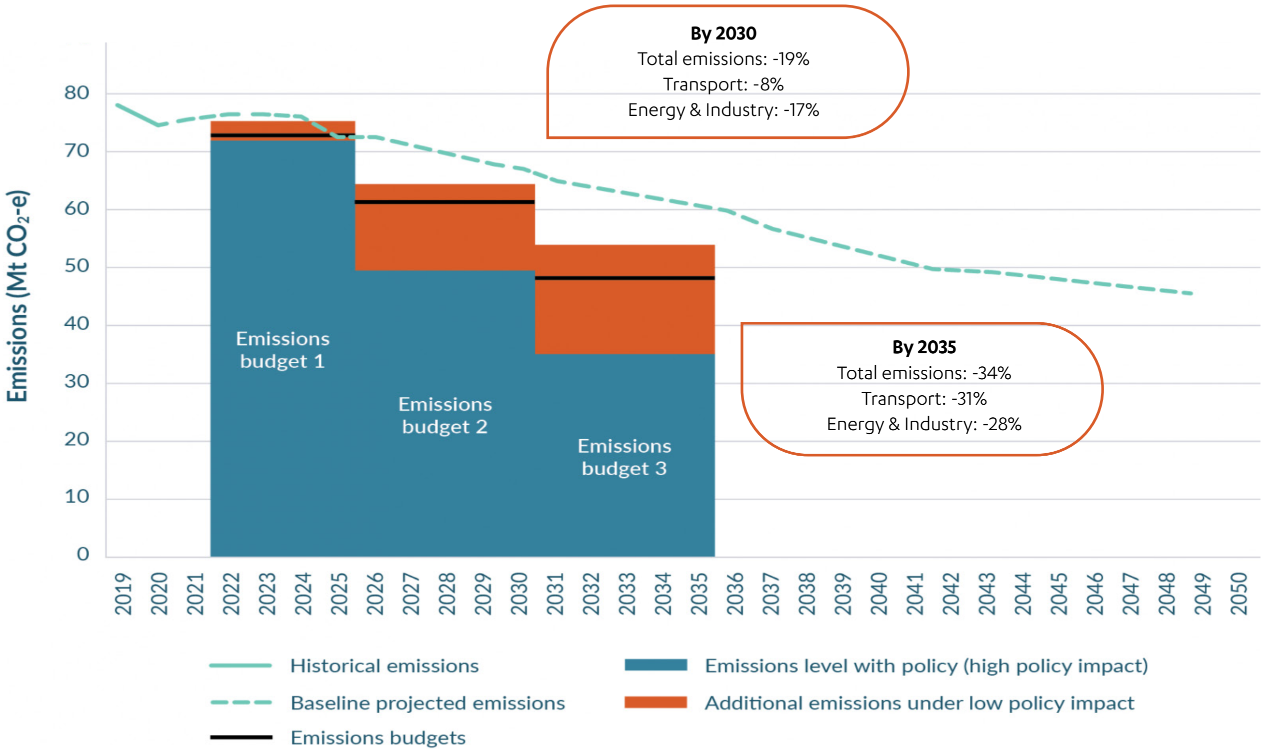
6 There are well established variants of linear programming – e.g., stochastic linear programming - which allow for uncertainty.

7 This is important – many other bespoke models that attempt to model the full energy system cannot guarantee that the underlying engine will always find the best solution.

New Zealand's first emissions reduction plan

The New Zealand Government published its first emissions reduction plan (ERP) in 2022, based on advice from the Climate Change Commission. The ERP sets out three sequential economy-wide emissions reductions targets, or carbon budgets, that will take us to 2035. It also includes actions that need to be taken to meet those carbon budgets. The actions cover every part of government and every sector of the economy from transport, energy, building and construction, waste, and agriculture, to forestry.

Figure 1 - The three New Zealand emissions budgets to 2035 (taken from ERP)



We note that the view of the future implicit in the ERP is aligned to neither Kea or Tūī – it is essentially an additional scenario which has its own inbuilt assumptions about economic and population growth, carbon prices, technology costs and availability etc. Within that narrative there are variations – e.g., "high policy impact" and "low policy impact" as illustrated in Figure 1 above. While some of these assumptions individually may align more closely with either Kea or Tūī, it is the collective effect of the assumptions that drives the modelled outcomes of the ERP.

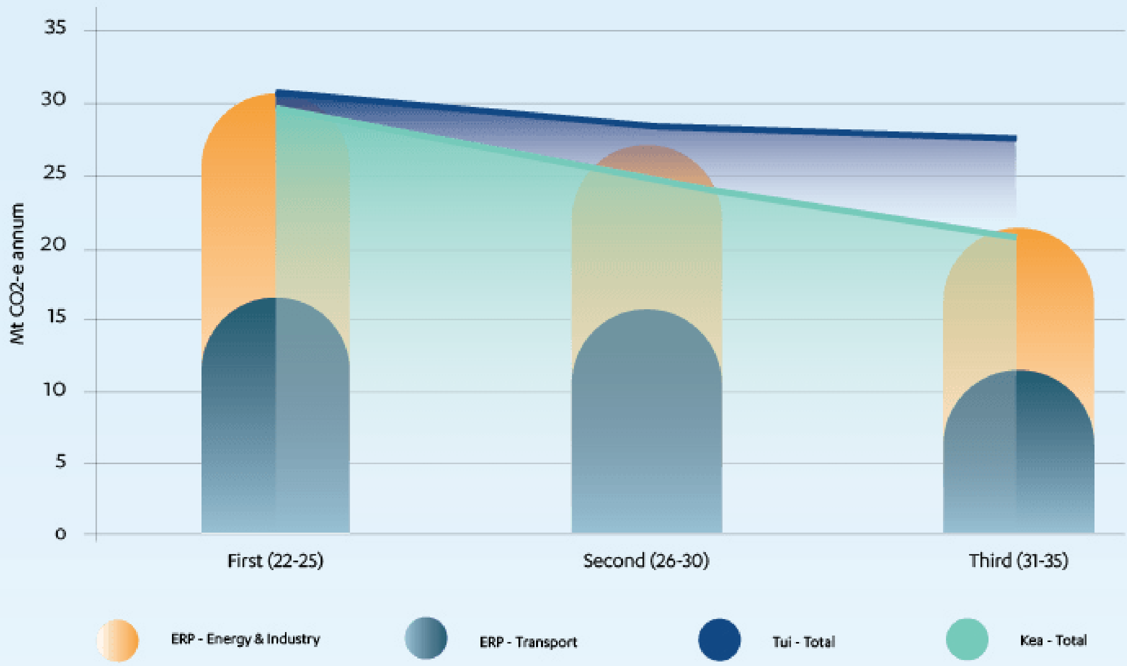
BEC does not have sufficient information regarding the ERP's underlying assumptions to be able to definitively show where Kea and Tūī deviate from the ERP. However, that is perhaps not the point. No organisation has a monopoly on how the future will turn out.

An important question is – if the world turned out according to Tūī and Kea (rather than the ERP view), would New Zealand still meet its emissions budgets?

Below we compare the Government's emissions budget outlined in the ERP with the TIMES-NZ scenarios. Figure 2 plots the emissions profiles for the transport and energy components of the three ERP budgets. We have used average annual emissions for each period because the first period is four years while the other two are five years. The equivalent TIMES-NZ modelled Kea and Tūī scenario emissions are overlaid on the budgets.

The Kea scenario emissions to 2035 would achieve the ERP budgets. Emissions under the Tūī scenario would not meet the second and third ERP budgets (1Mtpa and 8Mt pa).

Figure 2 Kea and Tūī transport, energy, industry emissions reductions compared to ERP budgets



Any failure to meet ERP emission budgets is likely to be a combination of the collective effect of the actions taken by all individual decision-makers in the economy, the effect of adopted policies in the scenario, and any failure of the scenario's policy settings.

We have not analysed the degree to which the initiatives in the ERP will be sufficient to achieve the emissions budgets.

Sensitivity tests

Our quantification of the Kea and Tūī scenarios relies on two sets of assumptions about a vast range of factors in the energy system. Of course, we expect the real world will result in variations from almost all those underlying assumptions.

In some cases, plausible deviations of reality from our assumptions will be immaterial to the outcome, but there are many parameters which could experience significant changes or even shocks, and these changes will have a significant impact on decisions made.

This is where sensitivity analysis can be very useful in understanding how the energy system – as modelled in TIMES-NZ – reacts to such changes. If we subject both Kea and Tūī to the same changes, we get the added benefit of seeing the model's decisions within the overall framing of two materially different storylines.

In consultation with a small group of BEC's member experts, we distilled several sensitivities we wished to test, to understand the way the scenarios would respond in terms of emissions outcomes and the cost of optimally responding to those changes. We also examined the impact of applying the ERP budgets to the base case scenarios, and each of the sensitivities.

We developed and undertook seven sensitivity cases and compared these with the base case results from Kea and Tūī. In all cases, we found that the Kea scenarios (base and sensitivity) met the ERP emissions budgets, and so the results with and without the ERP constraint are identical.

Label	Description of sensitivity and outcome		CO_2	$↑↓
ERP	**Incorporating ERP budgets.** The Tūī base case does not meet New Zealand's emission budget for 2026 - 2030 and 2030 - 2035. This sensitivity forces Tūī to meet each budget via a constraint in the model but does not prescribe how – it asks the model to find the least-cost solution.	**Tūī_ERP** **Tūī_ERP** **Kea**	-2% -2.4% n/c	+0.1% +0.3% +0.3%
BEV	**An increase in BEV costs of $10,000,** compared to the base case, increases total cost for all scenarios. In Tui, emissions increase as a result of lower BEV usage. In Tui_ERP, emissions decrease, but only due to the presence of the ERP constraint. Emissions in Kea do not change, as BEV uptake is unchanged.	**Tūī** **Tūī_ERP** **Kea**	+0.5% -2.4% n/c	+0.2% +0.3% +0.3%
VKT	**Lower ride sharing & higher private vehicle use is tested in the Kea scenario only[8].** This is the only sensitivity where an energy service demand is in-creased, hence a marked increase in Kea's costs and emissions is observed.	**Tūī** **Kea** **Tūī_ERP**	+0.5% n/c -2.4%	+0.2% +0.3% +0.3%
BIO	**A doubling of domestically produced woody bio-mass costs,** from around $10/GJ to $20/GJ, increases emissions for all scenarios as decision makers switch to fuels with higher emissions. Emissions rise in all scenar-ios. Costs increase in Tui, but Kea manages to transi-tion to other fuels with no impact on total cost.	**Tūī** **Tūī_ERP** **Kea**	+1.6% +0.5%[9] +1.5%	+0.1% +0.2% n/c
GAS	**The departure of a major gas consumer causes a significant disruption in gas markets, driving gas costs to $35/GJ[10].** The remaining demand for gas shrinks further, substantially reducing emissions and increasing costs across all scenarios.	**Tūī** **Tūī_ERP** **Kea**	-4.2% -7.1% -9.0%	+0.5% +0.6% +0.5%
COA	**A ban on coal use** is introduced after 2037 (except for iron feedstock and unknown coal use). This reduces emissions for both scenarios, though has no impact on cost, suggesting any fuel switching required can hap-pen at a similar total cost.	**Tūī** **Tūī_ERP** **Kea**	-0.4% -2.8% -0.4%	n/c +0.2% n/c
GASCOA	As described for GAS above, but with a constraint on coal usage per the COA sensitivity case.	**Tūī** **Tūī_ERP** **Kea**	-4.7% -17.2% -9.4%	+0.75% +0.6% +0.5%

8 It is not tested in Tūī, as Tūī already has low use of ride-sharing and high private vehicle use. In effect, this sensitivity applies to Tūī's VKT assumptions in Kea

9 It may at first be surprising that this sensitivity allows Tūī's emissions to rise compared with the baseline, despite the imposition of the ERP emissions budget constraint. That is because, while Tūī's emissions over the period 2025-2035 do, in fact, decrease to meet the ERP budgets, the emissions increase over the period 2035-2060 more-than offsets this, underscoring the caveat that we did not impose any constraints on emissions after the third budget.

10 To this we also added $4/GJ, reflecting the cost of gas storage, for any electricity sector use of natural gas.

Case study: detailed results for the "GAS" sensitivity

The following sets out the results of the "GAS" sensitivity to illustrate the types of information that TIMES-NZ produces about each sensitivity.

The GAS sensitivity models the impact of a situation where, following the exit of Methanex in each scenario, the gas price rises to $35/GJ, plus a $4/GJ cost-of-storage if flexible gas is required by the electricity industry for gas peaking and dry year support.

Note that the BEC2060 scenarios are not forecasting Methanex will leave. Rather, the scenarios have Methanex leaving in 2032 in Kea and 2047 in Tūī because these would be major events for the New Zealand energy sector. We simply need to understand the impact on the energy system should a major gas user leave. In other words, a stressed market that has just lost its biggest customer.

Figure 3 and Figure 4 show the changes in emissions by sector in the GAS sensitivity for Kea, Tūī and where Tūī is required to meet the ERP emission budgets.

Raising the gas price leads to:

- ↓ A reduction in use of natural gas for industrial, commercial, and agricultural consumption.
- ↑ Increase in usage of wood (mostly) in industrial consumption, plus some small increases in electricity, coal, and diesel.
- ↓↓ Significant reduction in use of gas for electricity generation. Also, due to the increase in wood use for direct heat in industry, use of wood for electricity generation also significantly decreases. Commensurately, there are significant increases in all renewable forms of generation (mostly wind and solar) in both scenarios.
- ↑ An increase in electricity and hydrogen for agricultural, and in Tūī, diesel for commercial consumption, while Kea utilises more wood pellets[11].
- ↑ Small increases in coal use in both scenarios, primarily in industry.

These effects are seen more dramatically across the model horizon for Kea than Tūī. This is due to the Methanex departure occurring earlier in Kea.

11 Arguably, there is an inconsistency with assuming a higher price for wood residues but not some flow-on effect for wood pellets.

Figure 3 Changes in emissions by sector in the GAS sensitivity for Kea (kT CO2-e)

KEY Emissions increase Emissions decrease

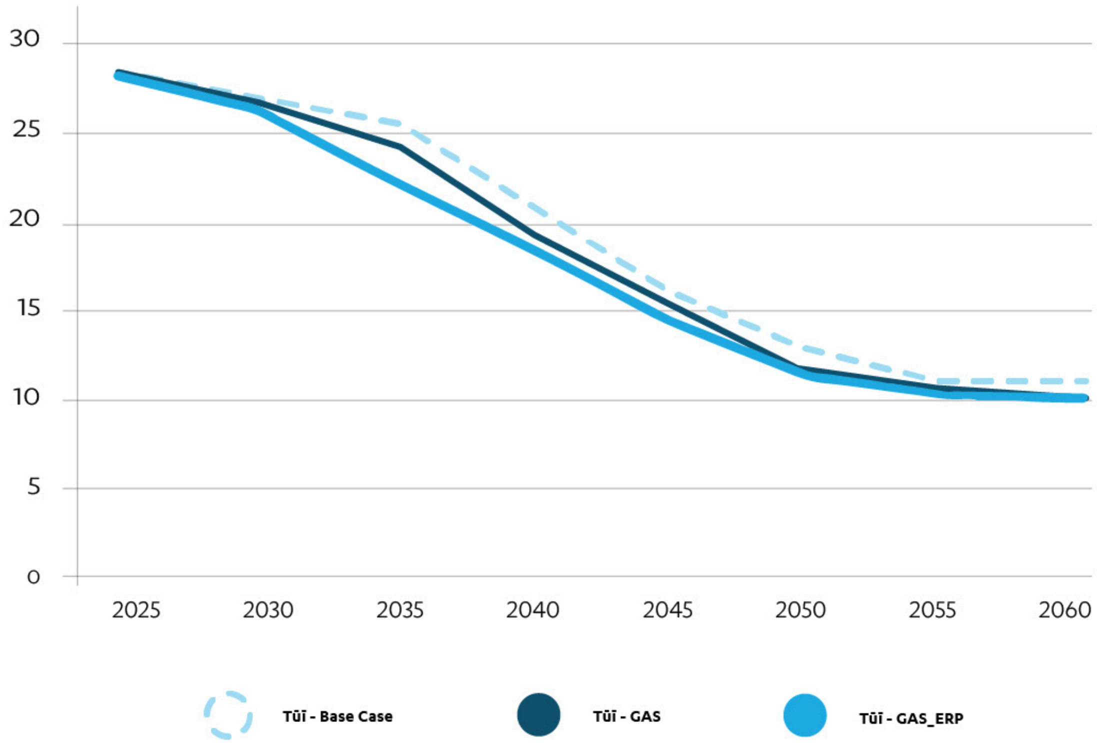
		2025	2030	2035	2040	2045	2050	2055	2060
Kea-GAS	Agriculture	30	-1	-3	0	0	0	0	0
Kea-GAS	Commercial	0	-1	0	-4	-4	-13	-15	-17
Kea-GAS	Electricity	-63	-204	-419	-503	-702	-866	-1191	-1628
Kea-GAS	Gas Flaring etc	-9	-51	-129	-217	-252	-293	-345	-410
Kea-GAS	Industrial	-10	-125	-563	-602	-493	-413	-455	-487
Kea-GAS	Refining	0	0	0	0	0	0	0	0
Kea-GAS	Residential	0	0	0	0	0	0	0	0
Kea-GAS	Transport	0	0	0	0	0	0	0	0
	Total	-53	-382	-1115	-1326	-1452	-1585	-2006	-2541

Figure 4 Changes in emissions by sector in the GAS sensitivity for Tūī (Tūī-GAS) and in the GAS sensitivity with Tūī required to meet the ERP budgets (Tūī-GAS_ERP).

		2025	2030	2035	2040	2045	2050	2055	2060
Tui-GAS	Agriculture	-29	-81	-66	-52	-9	0	0	0
Tui-GAS	Commercial	0	0	0	0	-1	-8	-8	-8
Tui-GAS	Electricity	-6	-195	-279	-197	-67	-232	-468	-715
Tui-GAS	Gas Flaring etc	-23	-86	-540	-532	28	-329	414	265
Tui-GAS	Industrial	53	-206	-420	-592	-581	-453	-452	-553
Tui-GAS	Refining	0	0	0	0	0	0	0	0
Tui-GAS	Residential	0	0	0	0	0	0	0	0
Tui-GAS	Transport	0	0	0	0	0	0	0	0
	Total	-206	-848	-3249	-2171	-1536	-1309	-515	-743
Tui-GAS_ERP	Agriculture	-38	-81	-212	-132	-90	0	0	0
Tui-GAS_ERP	Commercial	-8	-2	-26	-1	-4	2	0	2
Tui-GAS_ERP	Electricity	-6	-312	-542	-454	-254	-480	-474	-546
Tui-GAS_ERP	Gas Flaring etc	-18	-105	-675	-601	-440	-352	419	348
Tui-GAS_ERP	Industrial	-91	-299	-1718	-913	-722	-453	-448	-547
Tui-GAS_ERP	Refining	0	0	0	0	0	0	0	0
Tui-GAS_ERP	Residential	0	0	0	0	0	0	0	0
Tui-GAS_ERP	Transport	-46	-49	-76	-69	-26	-27	-12	0
	Total	-21	-533	-1341	-1757	-1042	-1200	-398	-811

Figure 5 plots Tūī emissions to 2060 in the original modelling, the emissions in the GAS sensitivity and the emissions in the GAS sensitivity with the additional constraint of the scenario having to meet the ERP emission budgets to 2035.

Figure 5 Tūī emissions in the GAS sensitivity, Gas cost raise to $35/GJ



It is notable that the model anticipates the change in gas price well before it occurs in 2047. Of course, this is a result of the model's perfect foresight. However, it is surprising that the model begins adapting to an event nearly 20 years in advance. Decision-makers do not have this foresight; the departure of a very large industrial consumer may be foreseen, at best, 5 years ahead. It is reasonable to assume that the cost of reacting much later than TIMES-NZ would result in higher costs being experienced.[12]

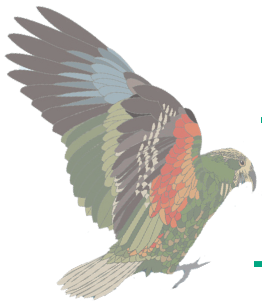
12 If not, TIMES-NZ's 20-year adaptation would not have been the lowest-cost solution.

Summary of all sensitivity analysis results

Impact of sensitivities on emissions

Figure 6 and Figure 7 summarise the whole-of-system change in emissions to 2060 from the base case in each of the sensitivities. We discourage any interpretation of the relative magnitude of the changes in emissions across the sensitivities.

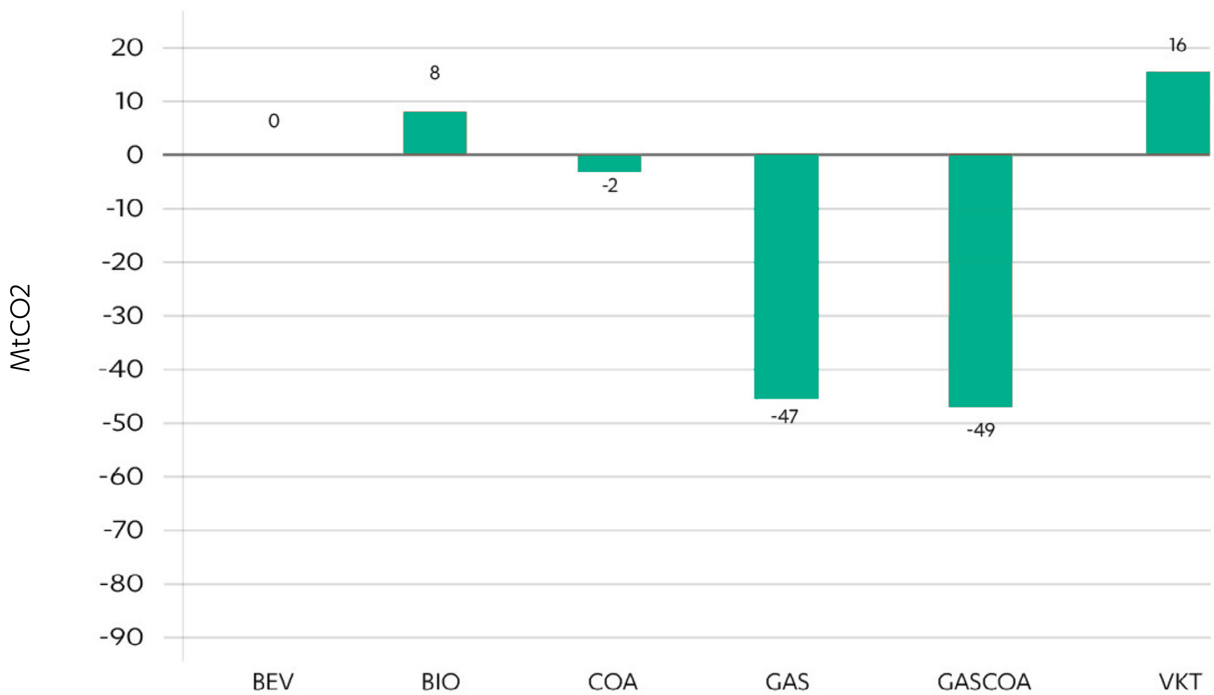
The magnitude of emissions changes is only a function of each sensitivity's assumptions. In choosing the sensitivity values, our objective was to test significant but still plausible changes. It was not our objective to achieve "equivalence" between the size of the impact; in practice that would be almost impossible to achieve, given the spectrum of sensitivities.



KEA

- ➔ The BEV scenario has no impact on Kea. This somewhat reflects the "whole of life cost" perspective of the model, and the dominance of the reduction in fuel cost (especially at Kea's increasing carbon prices) that a BEV delivers.
- ↑ Emissions rise in Kea sensitivities VKT and BIO over the period to 2060 but the emission budgets to 2035 are still met due to the small headroom that Kea has over this early part of the horizon.
- ➔ The coal ban in COA has a very small impact on emissions in Kea.
- ↓ The GAS sensitivity reduces emissions by the equivalent of ~2 years of current total energy sector emissions in NZ. This equates to a 12% reduction in emissions over the period to 2060.

Figure 6 Changes in total emissions under each of the sensitivities, compared to Kea baseline, 2025-2060



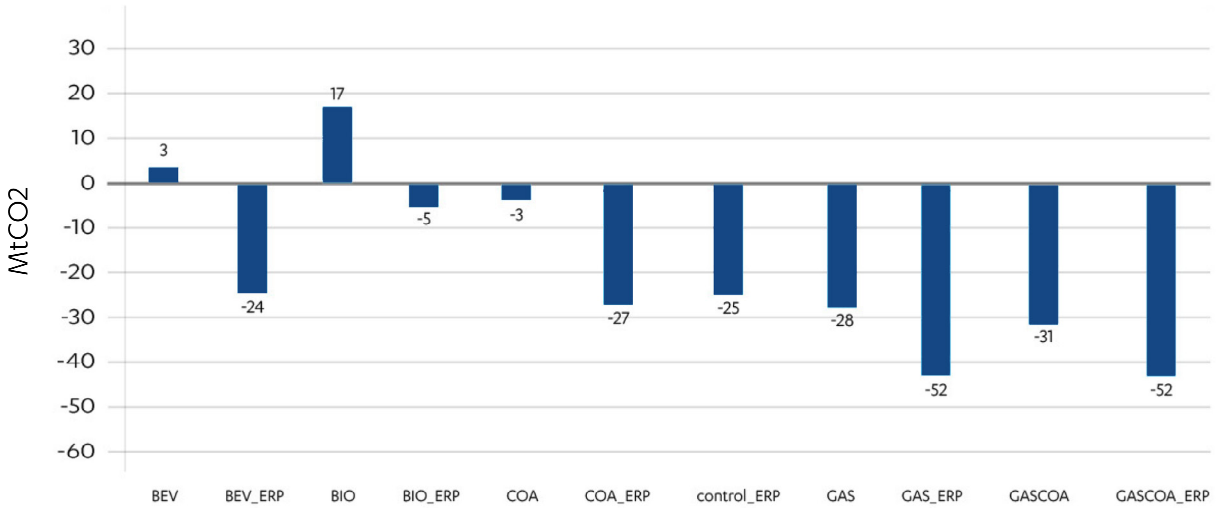
TUI

- In Tūī, emissions rise in the BEV, BIO, and BIO ERP sensitivities. We note that, despite being constrained to meet the emissions budgets over the period 2025-2035, which results in an emissions reduction, the increase in the cost of biomass results in increases in emissions over the remainder of the horizon.

  This underscores the fact that we have not modelled emissions budgets past 2035.

- Again, the GAS sensitivities have by far the most significant impact on the Tūī scenarios – reducing lifetime emissions by between 8%-11%.[13]

Figure 7 Changes in emissions under each of the sensitivities, compared to Tūī baseline, 2025-2060 (with and without a requirement for Tūī to meet the ERP budgets to 2035 in each case).



Impact of sensitivities on fuels used

Figure 8 and Figure 9 indicate change in the quantity of fuel consumed for each sensitivity compared with the control scenario model outputs. **Green** is an increase in the specific fuel use for each sensitivity, **red** shows a decline in fuel use for each sensitivity.[14]

Two observations emerge:

1. In each sensitivity (except the coal ban) the "shock" results in changes to several fuels, as the model makes rational choices to "rebalance" the whole energy system. In each case the first-order effects are obvious (e.g., in GAS, consumption of natural gas decreases) while the second-order effects are more diverse (e.g., a resulting increase in the use of electricity impacts several underlying resources at once – hydro, wind, solar and geothermal).

2. The rebalancing in Tūī, in response to the sensitivities, is more complex and diverse than in Kea. This greater complexity is mostly concentrated in the sensitivities where Tūī is being asked to meet the ERP emissions budgets – reflecting the combined impact of the "shock", as well as the need to reduce emissions over the 2022-2035 period to meet the budgets.

It is also notable that Kea – despite its narrative – still increases its consumption of natural gas, coal, and petrol in some sensitivities, and remains within the ERP emissions budgets. The implication of this is that Kea's aggressive pursuit of emissions reductions in these early years leaves a degree of headroom which improves its resilience to shocks, without leading to emissions levels inconsistent with NZ's commitments to emissions reduction.

13 Depending on whether the ERP emissions budget constraint is included or not.
14 We have excluded any changes in fuel use less than 1%. Often these very small changes are a distraction, as they can occur as a result of the model calibrating the last fraction of optimality.

Figure 8 Change in fuels consumed, by sensitivity – Kea

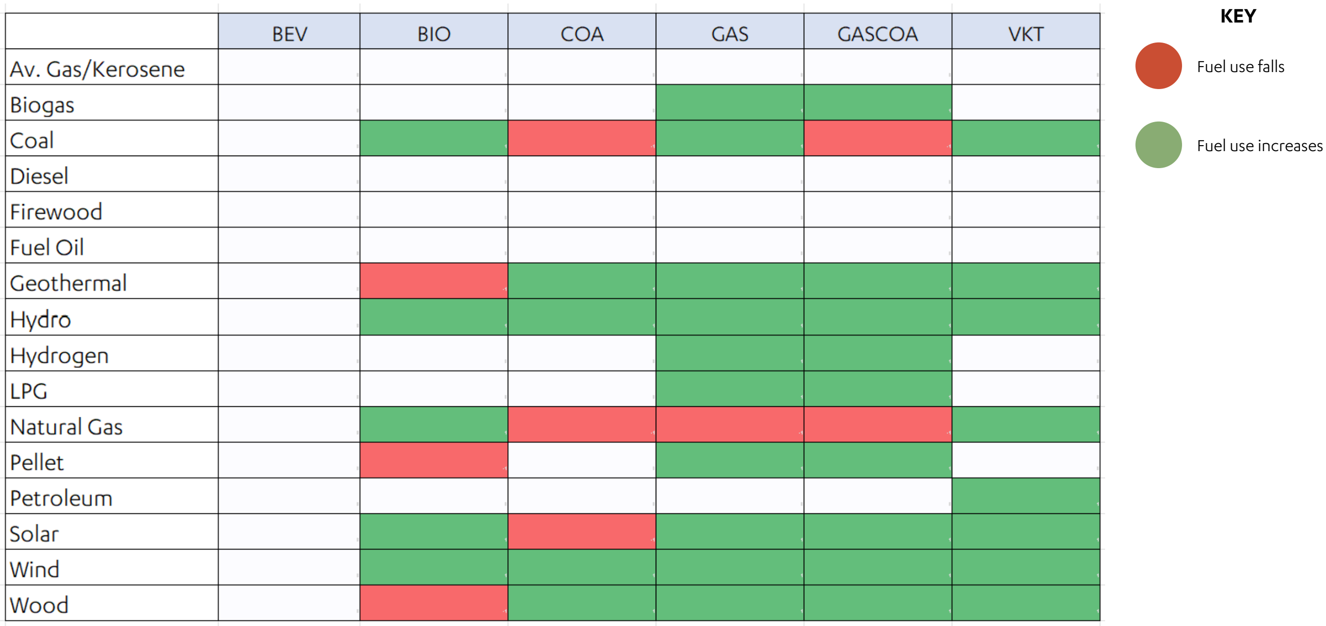


Figure 9 Change in fuels consumed, by sensitivity – Tūī

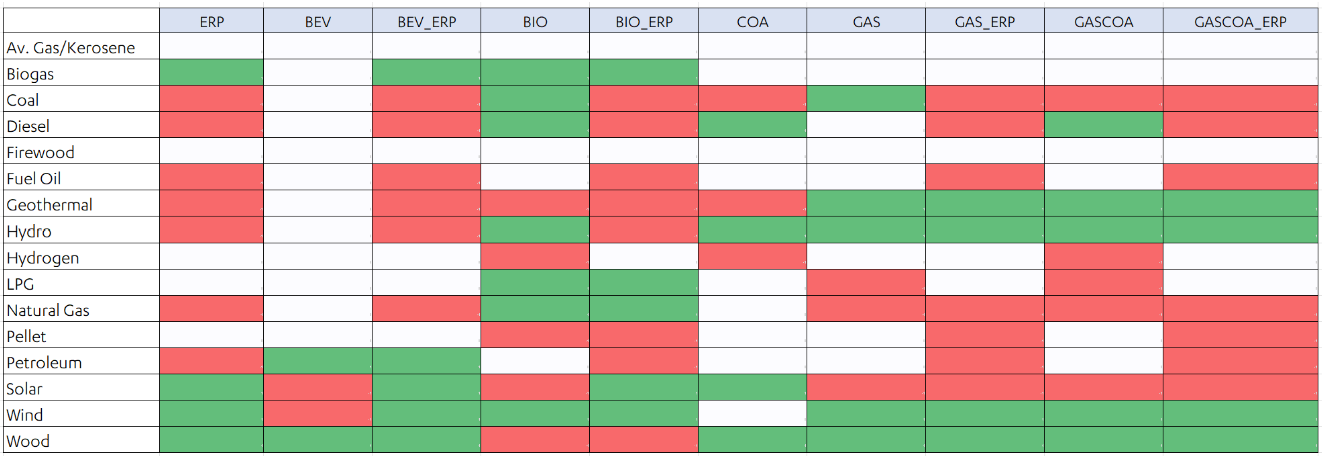


Figure 9 highlights the range of fuels involved in responding to the shocks in Tūī, especially when it has to meet the ERP emissions budgets. Even then, Tūī's response to the BIO shocks, with and without the ERP emissions budgets constraints, sees an increase in the use of natural gas to provide industrial heat. Tūī can respond to the BIO shock, and simultaneously meet the ERP emissions budgets, by reducing coal consumption, and significantly increasing the use of solar and wind, balanced by an increased use of gas for electricity peaking.

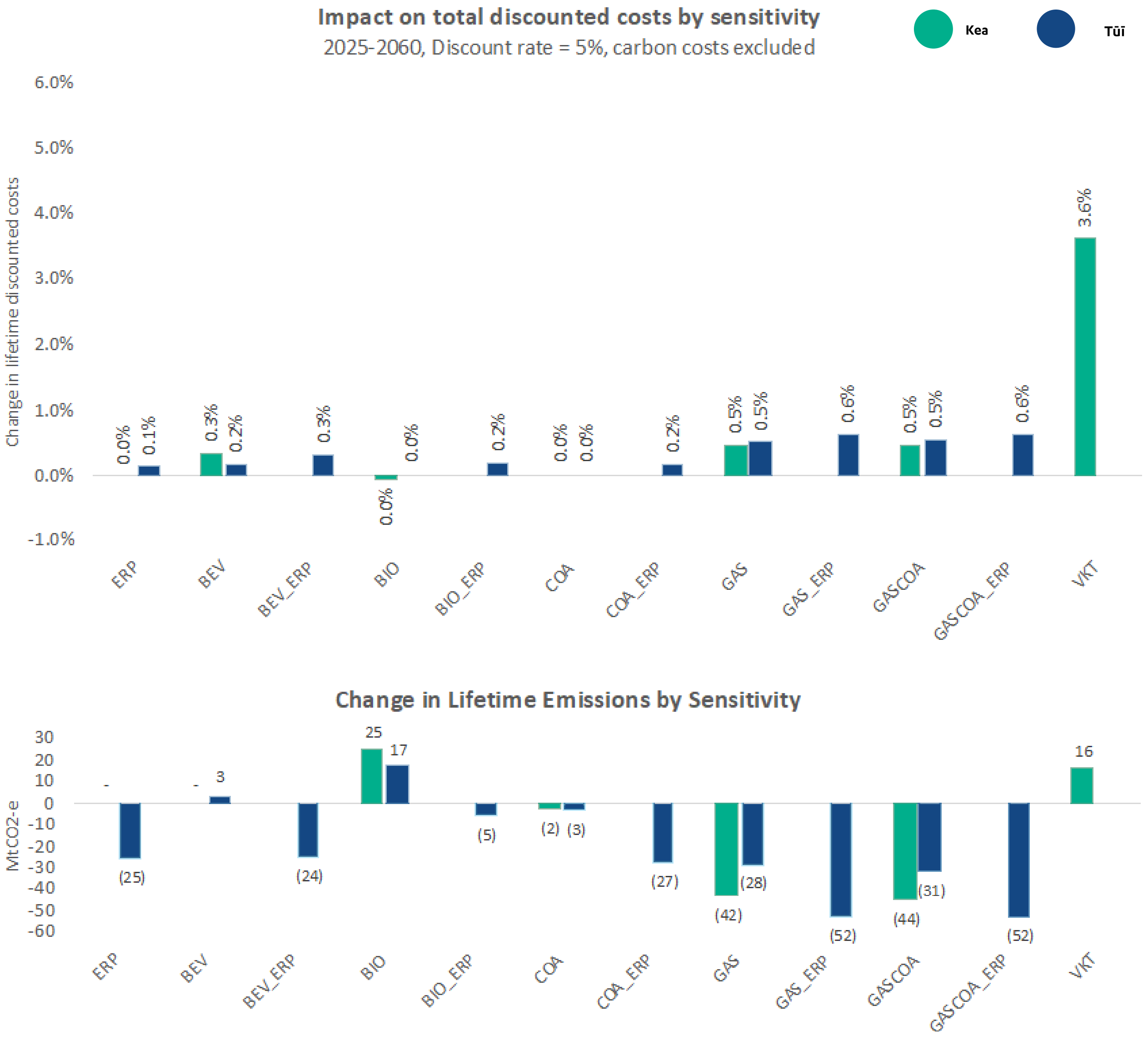
Impact of sensitivities on costs

The model provides the total energy system cost in each sensitivity. This can be used to assess the impact of responding to the sensitivities on costs. These costs include the costs of fuels, and the technologies and equipment purchased to either transform the fuels into useful energy (e.g., converting geothermal into electricity), or to consume each form of energy (e.g., vehicles).[15]

The changes in total costs over the 2025-2060 period for each sensitivity are presented in Figure 10. Costs have been discounted to a present value using a discount rate of 5%. We have also repeated the impact on emissions in each sensitivity (i.e., a combination of Figure 6 and Figure 7), in order to provide a comparative metric to cost.

Noticeably, the significant increase in distances driven in vehicles in Kea's VKT sensitivity has the biggest impact on cost. This is largely because it represents an overall increase in energy demand by consumers; the other sensitivities maintain the same final energy demand, but rearrange the fuels needed to meet that demand. Hence this sensitivity increased cost and increased emissions, yet still satisfied the 2022-2035 emissions budgets.

Figure 10 Change in costs (%)



15 Carbon costs excluded.

Other than the VKT scenario, all sensitivities increased lifetime costs by less than 0.7%.

- **Doubling bioenergy costs in Kea reduces total cost.** However, while the total technology/fuel cost decreases, payments by consumers in carbon charges increased by more offsetting this decrease. We exclude carbon charges in all cost figures above.

- **The BIO sensitivity was the only sensitivity other than VKT to lead to an increase in total emissions in both scenarios.** While the cost of adaptation was relatively minor, the emissions increase stood out amongst all sensitivities conducted, suggesting that there were no competitively priced low emissions alternatives.[16]

- **Constraining Tūī to meet the ERP budgets only increased lifetime costs by 0.1%** (around $2.2b spread over the 35-year period), and reduced Tūī's emissions by 24 Mt (2.6%).

- Given Kea's heavier use of electric vehicles (compared with Tūī), the $10,000 sticker increase in the **BEV sensitivity had a higher cost impact than in Tūī.** That said, Tūī's emissions increased in the BEV sensitivity.

- **The ban on coal had very little impact on costs or emissions.** We expect this is due to competitively-priced alternative fuels leading to little impact on total costs.

- Kea appeared to much more "easily" adapt to the GAS and GASCOA shocks, in that the **costs of adaptation were lower and the emissions reductions higher than Tūī.** This is despite the shock occurring much earlier in Kea (2032) than in Tūī (2047).[17]

As discussed above, a clear insight across sensitivities is that a variety of fuels were used by the model in responding to the sensitivities. Comparing one sensitivity to another, however, is more challenging. The relative magnitude of the changes in costs and emissions between sensitivities is somewhat related to our chosen input parameters. Our intent was to choose sensitivity values that were significant but plausible; our choice was not driven by a desire to achieve some notion of relative equivalence between these values. Obviously, a 25% increase in the cost of an electric vehicle is in no way "equivalent" to a quadrupling of the cost of gas.

Notwithstanding this, it is tempting to ask whether particular sensitivities were more or less "expensive" than others – in that the energy system found some sensitivities more or less difficult to adapt to than others. While we do not think this is a definitive analysis, Figure 11 normalises the cost of adaptation by the change in emissions, illustrating each sensitivity by the total change in cost divided by the total change in emissions.[18] Note that two sensitivities have positive average adaptation costs, as they experienced an increase in emissions (Kea-BEV and Tūī-BIO).

16 However, when Tūī was asked to meet the ERP budgets in the BIO sensitivity, the cost impact was about double that of Tūī meeting the ERP emission budgets without the increase in bioenergy costs.

17 Noting that, as outlined above, Tūī's adaptation (through perfect foresight) began very early in the modelling horizon.

18 For ease of viewing, we excluded the VKT sensitivity, as it had very high costs of adaptation

Figure 11 Average Adaptation Costs (AACs) in t/CO2-e, 2025-2060, carbon cost excluded

Key observations on Figure 11:

- There is no obvious dominance of one scenario over the other.[19]
- Other than Tūī's response to the GAS and GASCOA sensitivities, the average cost of adaptation sits in a band between $0/t and $500/t.[20] While these costs aren't directly comparable to a carbon price, it shows the cost of adapting to a "shock" isn't wildly different to the expected cost of carbon abatement; and
- The cost of reducing emissions in a Tūī world, such that it meets the ERP emissions budgets, is around $200/t. This can be interpreted as showing that, in a properly functioning Emissions Trading Scheme (ETS) constrained by the ERP emissions budgets, expected (discounted) carbon prices in a Tūī world would have to rise to around $200/t. This is not the case in the "base case" Tūī world, where carbon prices (undiscounted) climb from $50/t in 2022 to $130/t in 2060.

19 Note that the zero average cost ascribed to Kea in the BEV sensitivity is due to it having a zero impact on emissions; mathematically, for the response in per-t CO2-e terms, the average cost was positive infinity.

20 Some may find it surprising that the average cost of Tūī's adaptation to the GAS sensitivity (~$900/t) is substantially higher than its adaptation to both GAS and the ERP constraints (~$500/t). This shows that the average cost of the ERP budgets is significantly lower than the average cost of responding to a four-fold increase in the cost of gas; the combination of the two lowers the overall average cost of the emissions reduction achieved to around $500/t. It is also important to recognise that the two impacts are almost completely independent of one another. GAS responds to a significant gas cost increase that doesn't happen until after 2047; reductions in gas consumption over the period of the ERP budgets (2025-2035) provide no benefit whatsoever to the GAS sensitivity.

What the sensitivity analysis tells us

The TIMES-NZ model reaches for the rational approach to energy supply solutions based on the cost of known technologies. It tells us what we can expect if policy settings are allowed to act on the cost of energy with no interference, albeit under the assumption of perfect foresight.

In this modelled context, we used sensitivities to test how outcomes change if certain real-world events occur differently from the scenarios originally anticipated. The TIMES-NZ model responds to incentives (or the impact of an actual binding constraint). It does not model political rhetoric.

It is clear from the modelled outcomes that, when faced with a significant change to a single underlying parameter, decision-makers in the model adjust energy delivery and consumption across a wide array of fuels in pursuit of lowest cost. Put another way, **there does not appear to be a single "magic fuel" option which provides the resilience against all sensitivities modelled.** Having options clearly provides a benefit, as most of the options are at some point exercised, even in a model which has perfect foresight.

It is also clear that all but one sensitivity increased costs. The single direction of cost change is unsurprising, since all chosen sensitivities revolved around increasing the cost of a fuel or technology, a constraint on a particular fuel, or an increase in demand. However, when faced with a more restricted choice (economically or physically), the model unambiguously increased cost. The degree to which costs increase will, in large part, depend on the availability of a competitively-priced fuel or technology that does an equivalent or better job of achieving the ERP budgets. For many people this is not a startling conclusion. We believe it is important to reiterate the cost of constraining decision-makers.

In this context, when considering the variety of "shocks" that the energy system may experience over the coming decades, we can say:

- **Removing fuel options from decision-makers will almost certainly increase the cost of meeting New Zealand's emissions budgets, unless low emissions options are made available (and decision-makers are confident of their availability) at a similar cost.**[21] Hence, improving resilience, meeting emissions budgets, and keeping downward pressure on costs in the face of a changing world will benefit from greater choices of, and confidence in the availability of, cost-effective, low-emissions fuel options.

- Our modelling assumes decision-makers have perfect foresight: they know the "shock" is coming and can adapt accordingly to the information at hand.[22] This is a key component of the model's ability to keep the costs of responding low. In some sensitivities, the model began adapting 20 years in advance of a future change. However, this is obviously a poor reflection of reality, where there is a spectrum of "surprises" that our energy decision-makers face in uncertain times. It seems intuitively reasonable that this real-life uncertainty increases the cost of responding (the cost of risk). **While uncertainty can never be eliminated, we need to ensure policy does not unintentionally add to it.**

21 Unless those fuels are rarely used. This is a well-known result of optimisation theory

22 In future TIMES modelling, we hope to adapt the optimisation so that the model can be genuinely "surprised" by a shock. This will allow us to quantify the cost of uncertainty.

What this means for policy makers

The TIMES-NZ model results assume decision-makers do not face any uncertainty about the commercial implications of the options available to them when there is a shock. In the real world the decisions would not be so immediate or so clinical because there are more uncertainties to consider (e.g., the future carbon price).

Some approaches to policy development could create greater uncertainty or risk for decision-makers and this risk may not be able to be managed in a commercial manner.

Everyone understands the future is uncertain. Policymakers should take care to avoid upsetting the balance between accelerating the rate of emissions reduction, keeping costs as low as possible, and maintaining security. Policymakers should take into account the benefits that come with maintaining consistency, transparency, and foreseeability in policy development.

What we have learned from the sensitivity deep dive is that when the system resets itself on a least-cost basis, most fuel options are adjusted whether they are low-carbon or fossil fuels. If, hypothetically, fossil fuel options were removed, there would be fewer options, so when reality bites the cost would be higher than would otherwise be the case.

A better strategy for policymakers wanting to increase lower-carbon emissions outcomes would be to leave the fossil options in place – for the sake of resilience - and put effort into getting the low-carbon options to a lower cost than fossil fuel options. Under that strategy the system would resort to fossil fuel options less and less.

From an emissions and cost perspective, our advice to policymakers is therefore to focus on enabling energy system decision-makers to respond to unexpected changes in the energy system – based on their assessment of the situation as it arises and the options available to them. This can be achieved through:

- **Giving low-emissions options the best chance of being selected by energy system decision-makers**, under any circumstances that may arise. This could mean using policies that keep options of known technologies viable through the transition.
- **Giving decision-makers as much certainty as possible about policy development** to minimise its impact on the cost and complexity decision-makers face in respect to managing and responding to risk.
- **Reducing regulatory barriers to all low-carbon energy supply solutions** (get the sand out of the cogs). The scenario modelling indicates there is value in ensuring a wide scope of low-emissions energy options are possible to support the management of uncertainty.
- **Avoiding putting regulatory barriers (including bans)** that get in the way of least-cost, rational, secure energy supply - especially low-carbon solutions (don't put sand in the cogs).

About BEC

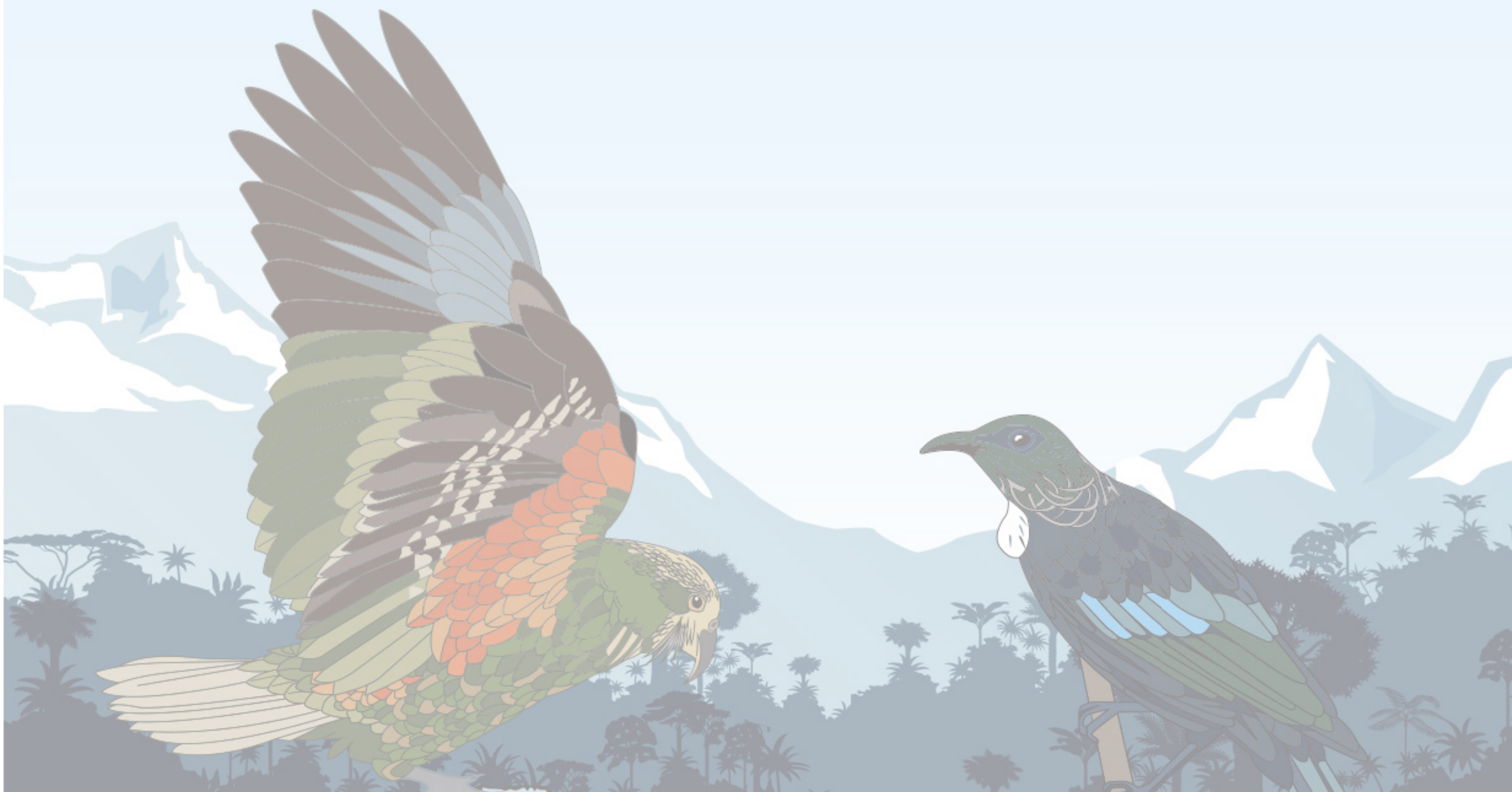
BEC represents the World Energy Council in New Zealand. BEC is a brand of BusinessNZ, New Zealand's largest business advocacy body. Together with its members, BEC is shaping the energy agenda for New Zealand and globally.

The BusinessNZ Energy Council (BEC) is a cross-section of leading energy-sector business, government and research organisations taking a leading role in creating a sustainable, equitable and secure energy future.

About Sapere

Sapere Research Group is one of the largest expert services firms in Australasia, providing independent expert testimony, strategic advisory services, data analytics and other advice to private sector corporate clients, major law firms, government agencies, and regulatory bodies internationally.

The Group has been working with the BusinessNZ Energy Council for more than ten years developing and continuously improving the TIMES-NZ model work to support and prepare New Zealand's sustainable, affordable and secure energy future.



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