New Zealand Energy Scenarios

TIMES-NZ 2.0

A guide to understanding the TIMES-NZ 2.0 model

EECA TE TARI TIAKI PŪNGAO ENERGY EFFICIENCY & CONSERVATION AUTHORITY

WORLD ENERGY COUNCIL | BusinessNZ Energy Council

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Foreword

I am very happy to see New Zealand build, develop and use the TIMES-NZ 2.0 model to explore future energy system scenarios to usefully inform policy decisions on energy and climate action. I congratulate the Energy Efficiency and Conservation Authority, BusinessNZ Energy Council and The Paul Scherrer Institut for their important collaborative efforts in bringing this to fruition.

The TIMES-NZ 2.0 model draws on, and contributes to, a long legacy of international collaboration over the past 45 years. The Energy Technology Systems Analysis Programme (ETSAP) is part of the Technology Collaboration Programme initiated under the auspices of the International Energy Agency. This programme supports the work of independent, international groups of experts, enabling governments and industries from around the world to lead programmes and projects on a wide range of energy technologies and related issues. ETSAP was one of the first of these collaborations and has been working on energy systems modelling tools since the mid 1970s, building and improving the TIMES modelling tools, providing training and supporting TIMES modelling teams around the world to develop future energy scenarios to underpin evidence based policy decisions.

ETSAP is delighted that New Zealand has joined our international collaboration and looks forward very much to a strong and deep partnership building on methodological developments and robust scenario analysis such as presented in this report.

Professor Brian Ó Gallachóir

Chair

International Energy Agency - Energy Technology Systems Analysis Program TCP

Climate change is one of the most urgent issues of our time. Almost 41% of New Zealand's total greenhouse gas emissions come from energy use and the challenge is to get this number down. The climate emergency means that decisions need to be made now across all sectors, if we are to have any chance of avoiding the worst effects of climate change. This is where a modelling tool such as TIMES-NZ can help explore carbon reduction scenarios across sectors.

EECA, in partnership with the BusinessNZ Energy Council and Paul Scherrer Institut (Switzerland), is delighted to have played a key role in developing phase two of the TIMES-NZ New Zealand Energy Scenarios. TIMES-NZ 2.0 is based on the International Energy Agency (IEA) Energy Transition Systems Analysis Program methodology which is one of the IEA's longest running technology collaboration programmes. Throughout this project it has been invaluable to draw on international best practice and blend it with local knowledge about New Zealand energy needs across sectors.

The original BEC2060 model was based on the IEA ETSAP Technology Collaboration Partnership TIMES model - this update includes further New Zealand specific detail about the renewable energy options, energy needs and associated emissions across the following sectors: - Transport; Heat, Industry, Power; Agriculture, Forestry and Fishing; Commercial and Residential. Modelling is based on input from experts across both government and industry.

Developing the TIMES-NZ 2.0 update aligns with EECA's strategy of mobilising New Zealanders to be world leaders in clean and clever energy use by reducing carbon emissions in business, transport, and housing. EECA focuses on enabling a low-carbon future by improving New Zealand's energy efficiency and increasing its use of renewable energy. TIMES-NZ 2.0 is a useful tool to understand cost effective ways of achieving emissions reduction across sectors, as it combines global best practice with local insights.

EECA is pleased to have delivered the TIMES-NZ 2.0 model updates and make the findings from the New Zealand Energy Scenarios TIMES-NZ 2.0 accessible as an online interactive R Shiny app www.eeca.govt.nz/times-nz with downloadable open datasets, to enable a continued focus on identifying ways for government, industry and communities to embrace a low carbon future.

Kate Kolich

Manager

Evidence, Insights and Innovation

EECA TE TARI TIAKI PŪNGAO
ENERGY EFFICIENCY & CONSERVATION AUTHORITY

How do you tell the story of the future? What if most Kiwis chose to see climate change as the most important problem to solve? What would happen if they invested now in new technologies and led the world in decarbonising the economy? How would New Zealand's energy sector evolve? What are the choices and trade-offs?

In a year like no other, we have witnessed first-hand challenges and opportunities in the energy sector. Our energy scenarios have become more important than ever, equipping energy leaders with a powerful tool in preparing for the unpredictable and supporting decision-making in a time of uncertainty.

While most modelling arrives at a destination by indicating what needs to change to get there, our scenarios explore the 'what-if stories' rather than the 'what-musts'. Our internationally renowned, New Zealand-specific modelling paints a rich picture of both potential and plausible energy system futures. Using an explorative, scenario-based analysis, we can provide a more open-ended view of what New Zealand's future energy mix might look like.

This time round, we are proud to be working with EECA, an organisation that has brought a wealth of knowledge and insight to the table. Together, BEC and EECA will be the preeminent source of up-to-date hard data on our energy future. Once again, we have used Kea and Tūī, both iconic New Zealand birds, matching our scenarios to their characteristics.

It is clear New Zealand, like the rest of the world, faces rapidly changing patterns of energy use, emerging disruptive technologies and the challenge of living affordably and sustainably.

Our modelling presents two contrasting stories New Zealand could follow, depending on how fast the country moves toward decarbonising the economy.

The Kea story represents a future where climate change is the most pressing issue. Kiwis want to get ahead of the rest of the world and the government transforms the economy quickly to match. The carbon price is higher than the global price; governments make it easier for consumers to take up new energy technologies; business aggressively trials and invests in more energy-efficient solutions, and buses, light rail and other forms of public transport are preferred.

By contrast, under Tūī, economic growth is not constrained by efforts to decarbonise and Kiwis are willing to follow other countries in using market mechanisms. Carbon prices are lower than the global price; the government's light hand means new energy technologies are adopted when they become price competitive; business favours the lowest-cost energy sources and private car ownership dominates the passenger fleet.

We trust our scenario refresh will help you plan for an uncertain future.

Tina Schirr

Executive Director

WORLD ENERGY COUNCIL | BusinessNZ Energy Council

With the enhanced energy system model for New Zealand, as performed in this second model development phase of TIMES-NZ, the future challenges for the transformation of the energy sector can be now analysed in greater detail.

This development builds on the fruitful collaboration of the experts of EECA, BEC and energy system modellers of the Energy Economics team of the Paul Scherrer Institut (PSI) in Switzerland.

It was a great pleasure and experience for the PSI team to work on this joint project with EECA. While the PSI team has many years of experience in TIMES-based energy systems modelling, it was the close interaction with the EECA team and other collaborators in New Zealand which allowed us to include a rich set of detailed technical and economic data in TIMES-NZ 2.0 and makes the model a unique analysis tool for New Zealand. This has been demonstrated with the current scenarios and will hopefully continue with versatile applications of the model in future.

Dr Tom Kober

Group Lead

Energy Economics Group of the Laboratory for Energy Systems Analysis

PAUL SCHERRER INSTITUT

PSI

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TIMES-NZ 2.0 has been a joint effort from across government and industry with the main TIMES-NZ project team comprised of members of EECA, BEC and PSI.

TIMES-NZ 2.0 Project Team Members

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TIMES-NZ 2.0 Assumptions Working Group

Throughout the project we have been grateful for the input from the following organisations and people who have provided feedback as part of the Assumptions Working Group reviewing the input assumptions for the model. The inclusion of the Assumptions Working Group in the project have enabled the integrity checks on data input assumptions.

Agcarm, ARUP, Beca, BP, BRANZ, Contact Energy, Dairy NZ, Environmental Science & Research, Farmlands, Federated Farmers NZ, Fletcher Building, Flux Federation, Fonterra, Genesis Energy, Hiringa Energy, Horticulture NZ, Infratec, Kiwi Property Group Limited, LIC, Lion, Massey University, Master Builders, Meat Industry Association of NZ, Mercury Energy, Meridian Energy, Methanex, Ministry of Business Innovation and Employment, Ministry for Primary Industries, Ministry of Transport, Motor Trade Association, Naylor Love, NERI, New Zealand Marine Industry Association, NZ Steel, Oceana Gold, OJI Fibre, OMV, Pan Pac Forest Products, Powerco, Ravensdown, Rio Tinto, Sanford, Scion Research, Stonewood, The A2 Milk Company, Todd Energy, Transpower, Trustpower, University of Auckland, Vector, Waka Kotahi New Zealand Transport Agency, Westland Milk Products, Whakatane Mill, Winstone Pulp Intl, WPMA, Z Energy, Zespri International Ltd.

Acronyms

AF	Availability Factor
BEC	BusinessNZ Energy Council
BEV	Battery Electric Vehicle
BNEF	Bloomberg New Energy Finance
CAGR	Compound Annual Growth Rate
CBA	Cost Benefit Analysis
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
EA	Electricity Authority
EDGS	Electricity Demand and Generation Scenarios (MBIE)
EECA	Energy Efficiency and Conservation Authority
EEPT	Energy Economic Potential Tool (EECA)
EEUD	Energy End Use Database (EECA)
EMI	Electricity Market Information (EA)
EPA	Environmental Protection Authority
ETSAP	Energy Technology Systems Analysis Program (IEA)
EV	Electric Vehicle
GDP	Gross Domestic Product
GEM	Generation Expansion Model (EA)
GHG	Greenhouse Gas
GJ	Gigajoule
GW	Gigawatt
HDD	Heating Degree Days
HEEP	Household Energy End-use Project (BRANZ)
HUD	Ministry of Housing and Urban Development
HV	High Voltage
IATA	International Air Transport Association
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IEA	International Energy Agency
IPPU	Industrial Processes and Product Use
kW	Kilowatt
kWh	Kilowatt-hour

LCV	Light Commercial Vehicle
LED	Light-Emitting Diode
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LPV	Light Passenger Vehicle
LV	Low Voltage
MBIE	Ministry of Business, Innovation, and Employment
MfE	Ministry for the Environment
MoT	Ministry of Transport
MPI	Ministry for Primary Industries
MV	Medium Voltage
MW	Megawatt
NG	Natural Gas
NI	North Island
NIWA	National Institute of Water and Atmospheric Research
NREL	National Renewable Energy Laboratory
NREL ATB	National Renewable Energy Laboratory's Annual Technology Baseline
NZD	New Zealand Dollar
NZIER	NZ Institute of Economic Research
OCGT	Open Cycle Gas Turbine
O&M	Operations & Maintenance
PEM	Polymer Electrolyte Membrane
PHINZ	Process Heat in New Zealand (MBIE and EECA)
PJ	Petajoule
PSI	Paul Scherrer Institut (Switzerland)
SI	South Island
SMR	Steam-Methane Reforming
TCP	Technology Collaboration Programme
TIMES	The Integrated MARKAL-EFOM System
TLA	Territorial Local Authority
WCM	Winter Capacity Margin
UoW	University of Waikato
VFEM	Vehicle Fleet Emissions Model (MoT)
VKT	Vehicle-Kilometres Travelled
VSD	Variable Speed Drive
WEM	Winter Energy Margin
Wp-AC	Watts Peak Alternating Current
WSR	Warehouses, Supermarkets, and Retail

CHAPTER 1

Introduction

1.1 Energy and the climate change challenge

The world is facing a huge climate change challenge as greenhouse gas emissions change our atmosphere. Globally, the majority of these emissions are from energy-related activities, while in New Zealand this proportion was around 40% in 2018 (Figure 1). How we supply and use energy in the future will have a big impact on how successfully we respond to the challenge and TIMES-NZ 2.0 seeks to provide more information and insight into the choices we face about energy use and emissions.

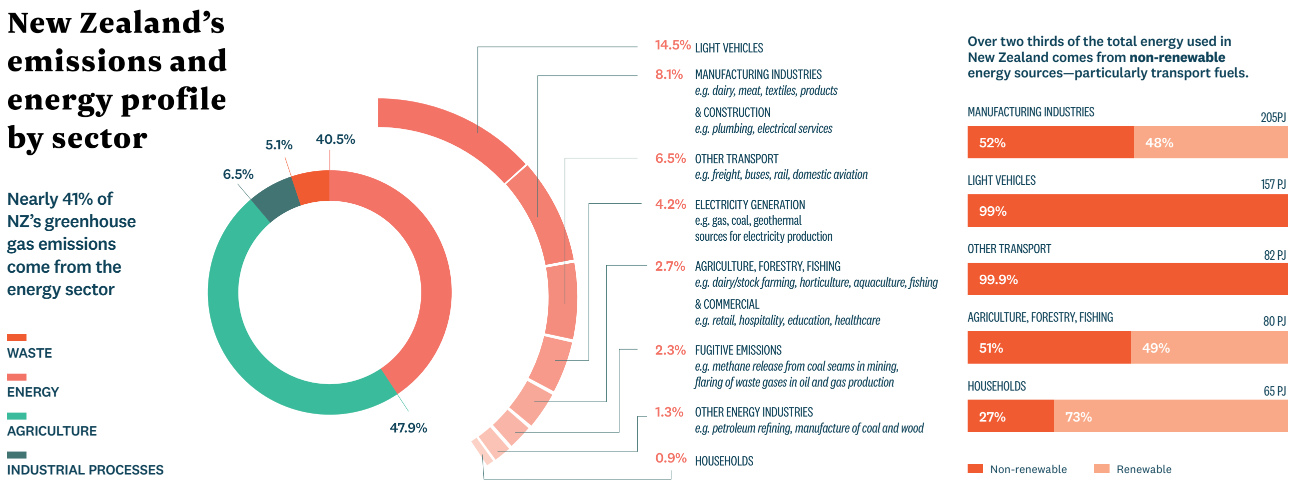


Figure 1: Breakdown of NZ's 2018 greenhouse gas emissions by source

1.2 TIMES-NZ 2.0 project background

The TIMES-NZ 2.0 project grew out of BEC2060[1], which was developed by BEC as an exploration of possible energy futures based on contrasted scenarios.

The TIMES-NZ model is based on the IEA ETSAP Technology Collaboration Program modelling methodology. TIMES is an internationally recognised modelling approach used in over 60 countries. TIMES-NZ is an instance of the international modelling standard which has been adapted to cater for New Zealand's energy system needs across sectors. EECA represents New Zealand as the contracting party for IEA ETSAP.

This latest iteration of TIMES-NZ 2.0 builds on the BEC2060 work, and has been developed in partnership between EECA, BEC and Paul Scherrer Institut adding more detail and sophistication to sectors, subsectors, technologies, and end uses.

Assumptions and data inputs are based on EECA's efforts to include the best available data and have been subjected to a validation process by external experts.

The 2020 update of EECA's Energy End Use Database (EEUD) provides a greatly improved input dataset for describing demand sectors.

The results presented in this document are from the model run from 28 April 2021.

1.3 Document overview

This document provides the reader with additional information to understand and interpret the results from the TIMES-NZ New Zealand Energy Scenarios.

Throughout this document the terms "TIMES-NZ" and "TIMES-NZ 2.0" are used interchangeably and refer to the current version of the model.

Chapter 2 provides a high-level introduction to the TIMES-NZ model, including the sophisticated TIMES model generator, a historical review of how the model was developed over time, and an overview of the current model structure, i.e. TIMES-NZ 2.0.

Chapter 3 contains a summary of key modelling results from the two contrasting scenarios Kea and Tūī. For these selected results, which we have termed key insights, we have provided charts enabling direct comparison of the two scenarios, like the annual emissions chart (Figure 2) below. For more detailed scenario outputs, see the TIMES-NZ R Shiny app www.eeca.govt.nz/times-nz which provides an interactive experience to understand the scenario outcomes.

Chapter 4 outlines the macro-economic assumptions underlying data inputs and demand projections to the model.

Chapters 5 to 9 describe the main data inputs and assumptions currently used in the model, with each chapter focusing on a particular sector of the energy system.

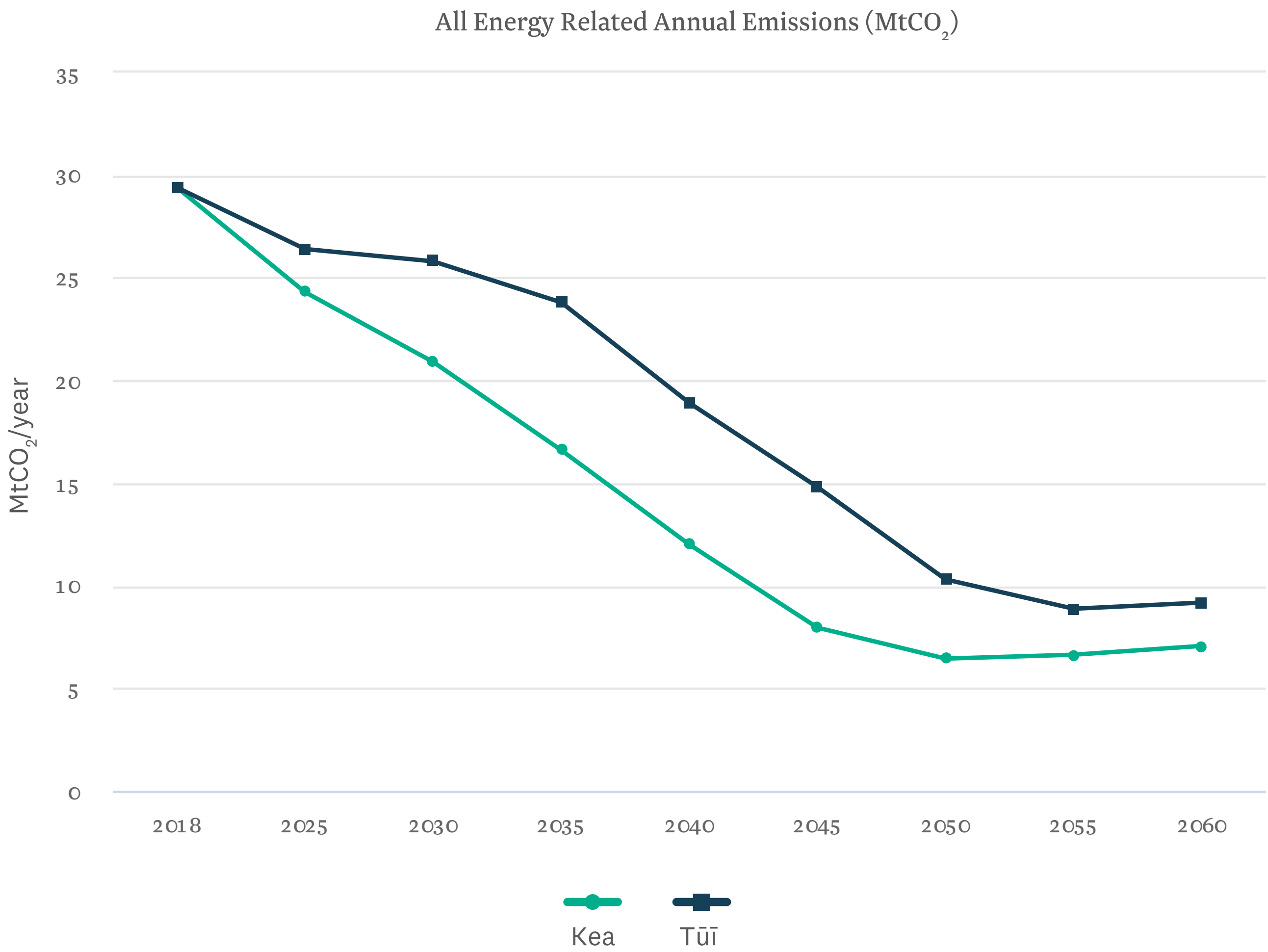


Figure 2: Total energy related annual emissions under Kea and Tūī

CHAPTER 2

TIMES-NZ 2.0 model overview

2. TIMES-NZ 2.0 model overview

TIMES-NZ is a technology-based optimisation model that represents the entire New Zealand energy system, encompassing energy carriers and processes from primary resources to final energy consumption.

TIMES-NZ is based on the IEA ETSAP TCP TIMES[2] energy model generator, it models scenarios[3] for the energy system, incorporating both technical, engineering and economic considerations. TIMES-NZ 2.0 Model is a bottom-up model which requires a detailed description of energy technologies, processes and costs, plus additional infrastructure such as transmission and distribution systems, fuel production and processing, and energy security considerations.

TIMES is an integrated energy system model, meaning that it simultaneously models all components of the energy system, ensuring that any interdependencies and trade-offs are reflected.

TIMES uses a linear-programming solver to minimise the total discounted energy system cost[4] over the entire modelled time horizon. The 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 the combinations of cost, efficiency and fuel availability. TIMES models are particularly suited to explore the evolution of possible least-cost configurations of the system.

If the model sees a technology as 'optimal' – even only fractionally more economic than another technology - it will try to maximise the use of that technology. TIMES has a high degree of sophistication in it, which ameliorates this to some extent (which is the natural tendency of any linear model), in some cases it utilises constraints to prevent unfeasible results.

A feature only available to linear programming optimization models, is that TIMES produces a rich array of economic information as part of its solution. Rather than simply tell us what the optimal quantities of different fuels and technologies are for each scenario, it also tells us what the implied commodity prices are, and how far away technologies are (economically) from becoming 'optimal'. TIMES tells us the optimal commodity prices associated with the solution at every point in time, as well as information about how far it was from finding a different solution.

It is important to note that the core version of TIMES is a partial equilibrium model, which does not account for economic interactions outside of the energy sector.

Different scenarios can be generated depending on model inputs, which can be classified as:

- Potential energy service demand over time
- Potential primary resource supply over time
- Policy settings
- Descriptions of the existing and future technologies available for each energy sector.

The preparation of high-quality data inputs to feed the model is essential for establishing the model structure and for providing confidence in the model's results. In this way, data inputs and even the model structure can change over time due to access to new or improved data sources.

2.1 TIMES-NZ 2.0 scenario definitions

BEC2060 provided two plausible and coherent scenarios about New Zealand's energy future: Kea and Tūī. These scenarios have been extended in this latest iteration to include more granular data.

Kea (cohesive)

Kea represents a scenario where climate change is prioritised as the most pressing issue and New Zealand deliberately pursues cohesive ways to achieve a low-emissions economy.

Tūī (individualistic)

Tūī represents a scenario where climate change is an important issue to be addressed as one of many priorities, with most decisions being left up to individuals and market mechanisms.

It is important to note that the TIMES-NZ Kea and Tūī scenarios are not predictions about the future or an attempt to pick winners – they show energy and emissions scenarios in five-year time steps based on data and assumption inputs. From a modelling perspective, these two scenarios differ in terms of the assumptions and data inputs to the model.

The key model input differences between Kea and Tūī are:

- GDP assumptions
- Carbon price input assumptions
- Technology cost curves
- Discount rates

2.2 TIMES-NZ 2.0 model structure

TIMES-NZ has a modular structure that encompasses resource supply, electricity generation, other fuel supply, fuel distribution, and demand sectors as illustrated in Figure 3. The five demand sectors are Residential, Commercial, Industrial, Agriculture Fishing and Forestry, and Transport, which are disaggregated further into subsectors as described in Table 1.

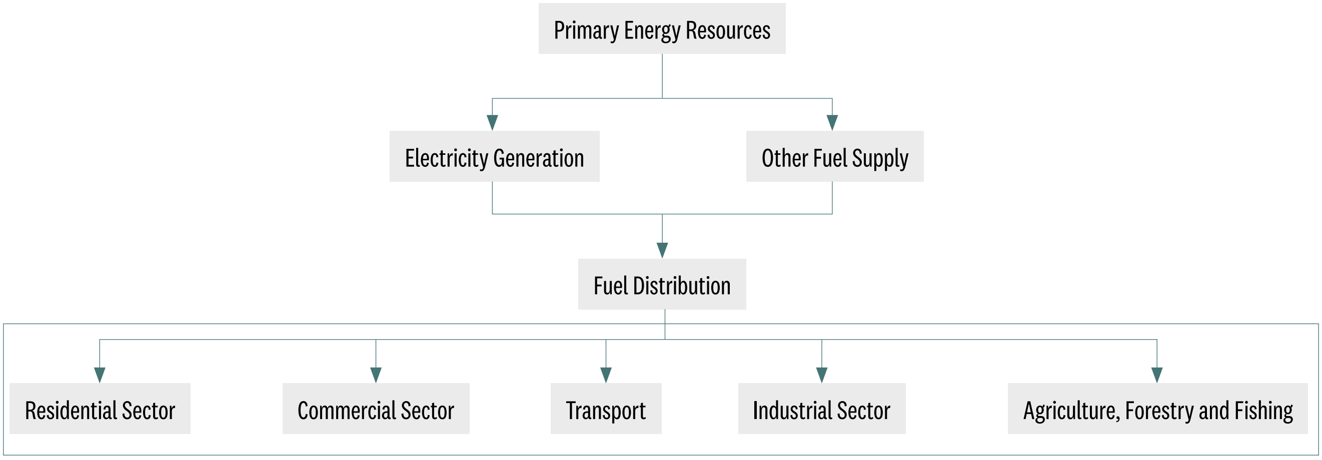


Figure 3: Illustration of the TIMES-NZ model structure

Table 1: Disaggregation of energy demand sectors in TIMES-NZ 2.0

Demand Sector	Subsectors
Residential	Detached Dwellings, Joined Dwellings
Commercial	Education, Healthcare, Office blocks, Warehouses Supermarkets and Retail (WSR), and Other (e.g. Recreation)
Transport	Road Transport (including Light Road and Heavy Road), Aviation, Shipping, Rail
Industrial	Aluminium, Petroleum/Chemicals, Construction, Dairy Product Manufacturing, Food Processing, Iron/Steel Manufacturing, Meat Processing, Metal Product Manufacturing, Methanol Production, Mineral Production, Mining, Wood Pulp and Paper Processing, Refining of Petroleum Products, Wood Product Manufacturing, Urea Production
Agriculture, Forestry and Fishing	Dairy Cattle Farming, Livestock Farming, Outdoor Horticulture, Indoor Cropping, Forestry, Fishing

All fuels included in the TIMES-NZ model are shown in Table 2. They have been grouped as “Fossil Fuels”, “Renewables (direct use)”, and “Electricity”. Green Hydrogen, which is produced from electrolysis, is included in the Electricity group. Blue Hydrogen, produced from Steam Methane Reforming (SMR) with Carbon Capture and Storage (CCS), is included in the Fossil Fuels group.

Table 2: Fuels included in the TIMES-NZ model

Fossil Fuels	Coal, Diesel, Fuel Oil, Jet Fuel, LPG, Natural Gas, Petrol, Waste Incineration, Blue Hydrogen
Renewables (direct use)	Biogas, Biodiesel, Drop-in Biofuels (Drop-in Diesel, Drop-in Jet), Geothermal, Hydro, Solar, Wind, Wood
Electricity	Electricity, Green Hydrogen

In the TIMES-NZ model New Zealand has two regions, North Island (NI) and South Island (SI).

The model has a time horizon of 2018-2060. The time horizon is split into 5-year periods in general:

- The first period is for a single year (2018) in order to facilitate the calibration of the model to national energy balances.
- The following period has a length of 4 years (represented by milestone year 2020).
- All following periods have a length of 5 years (represented by milestone years 2025, 2030, 2035... 2060). Time periods are described in Table 3.

Table 3: Model time periods and associated middle years (also known as milestone years)

Time Period	Milestone Year
2018	2018
2019-2022	2020
2023-2027	2025
2028-2032	2030
2033-2037	2035
2038-2042	2040
2043-2047	2045
2048-2052	2050
2053-2057	2055
2058-2062	2060

Additionally, each year is temporally split by season, time of week, and time of day as detailed in Table 4, resulting in 24 time slices per year. Such time slices are helpful in representing generation patterns of different technologies, which is particularly important in the case of renewable resources. The most important function of time slices in the TIMES-NZ model is representing variable electricity supply and demand and subsequent security of supply calculations.

GHG emission factors have been defined in accordance to MBIE estimates of greenhouse gas emissions from the energy sector in New Zealand[5].

Only domestic emissions are counted in TIMES-NZ, which is consistent with other government models. International aviation and shipping emissions are therefore excluded in the results, however, fuel consumption from international aviation and shipping was included to account for the availability of domestic supply of fuel.

Fugitive emissions from natural gas extraction and refinery emissions are accounted for in TIMES-NZ in order to capture the carbon tax for each fuel accurately. However, these are not included in the results for output emissions as they are not directly energy related.

Table 4: Sub annual time resolution

Category	Values
Season	Summer, Autumn, Winter, Spring
Weekday type	Weekday, Weekend
Time of day	Day Time, Peak Time, Night Time

CHAPTER 3

Key insights - New Zealand Energy Scenarios TIMES-NZ 2.0

3. Key Insights - New Zealand Energy Scenarios TIMES-NZ 2.0

The following is a short summary of some of the key insights from the TIMES-NZ 2.0 scenario run on the 28th April 2021. They highlight a number of cost-effective pathways for increasing renewable energy use and accelerating decarbonisation across sectors.

3.1 Energy emissions decline strongly in both scenarios

Both scenarios show strong reductions in energy emissions. In Tūī, energy emissions decline to 10 Mt CO_2/year in 2050 while in Kea they fall further to 6.5 Mt CO_2/year. Moreover, Kea's more rapid emissions decrease means that the model output indicates cumulative emissions through to 2050 as almost 25% lower in the Kea scenario than the Tūī scenario.

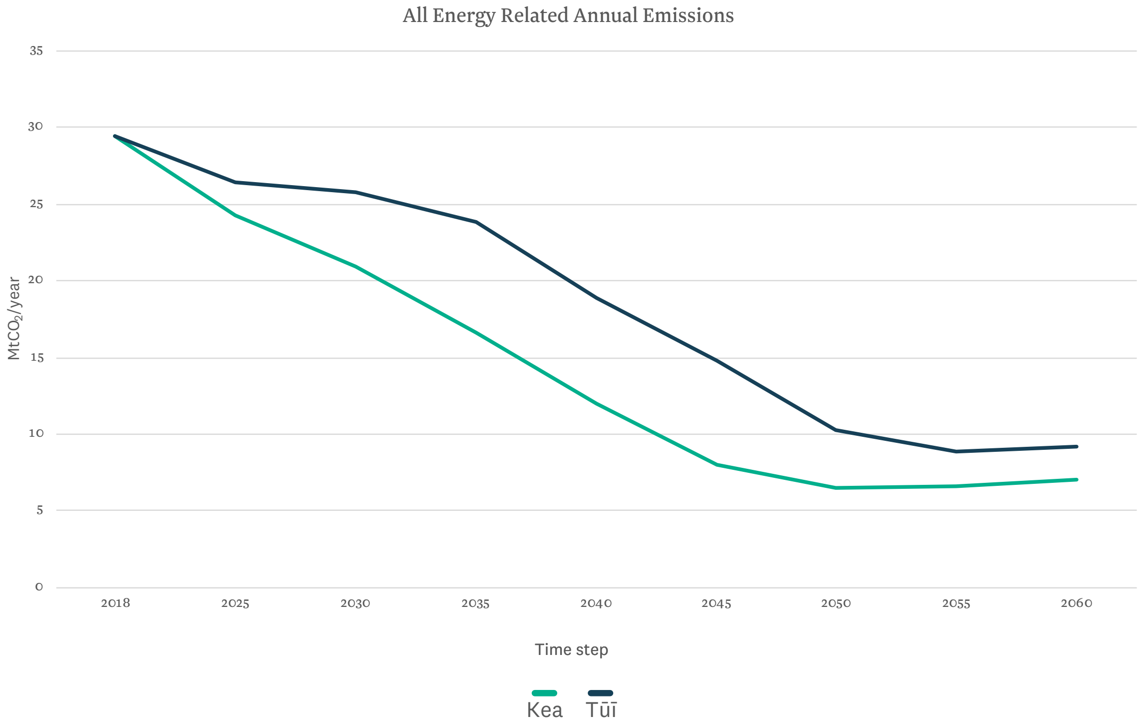


Figure 4: Total energy related annual emissions TIMES-NZ 2.0 Kea and Tūī scenarios

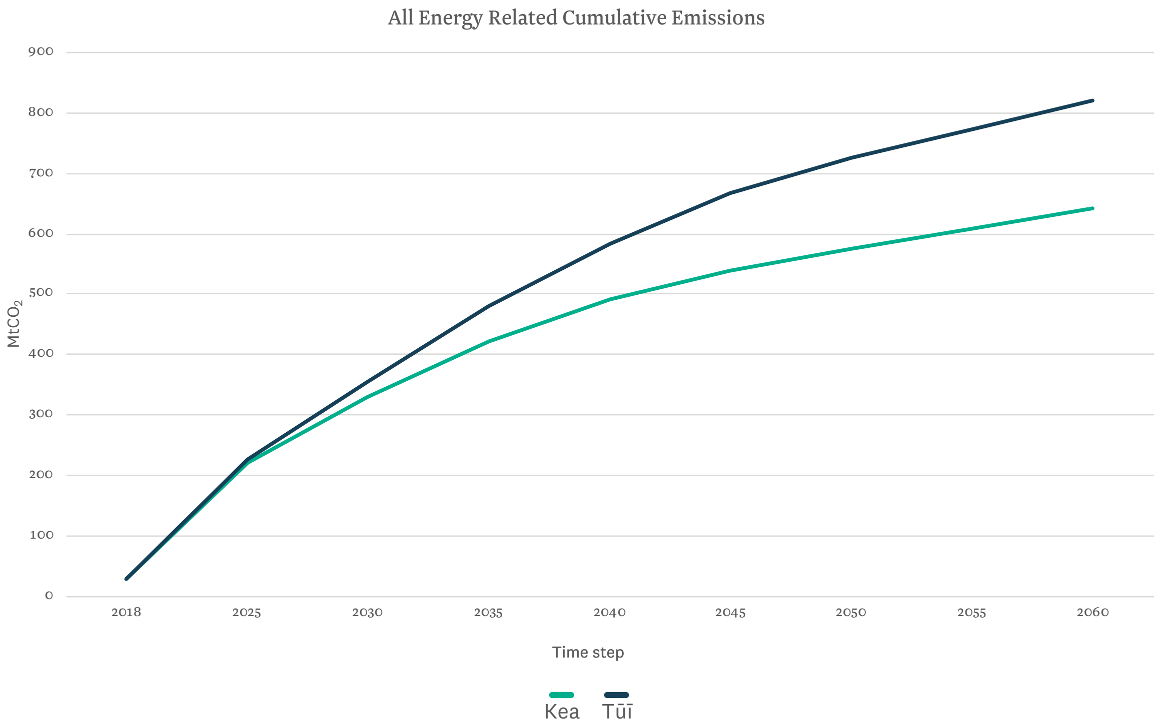


Figure 5: Total energy related cumulative emissions TIMES-NZ 2.0 Kea and Tūī scenarios

3.2 Demand for fossil fuels decreases significantly in both scenarios

Both scenarios indicate that between 2018 and 2050, energy demand (excluding feedstocks) met by fossil fuels goes from 63% to 22% under Kea and 33% under Tūī. In some sectors, particularly road transport, food processing, residential and commercial, fossil-fuel demand falls to a small fraction of current levels. Most remaining demand is in hard-to-abate sectors (such as aviation, shipping and fishing). This means renewables provide 78% of energy demand (excluding for feedstocks) under Kea and 67% under Tūī in 2050.

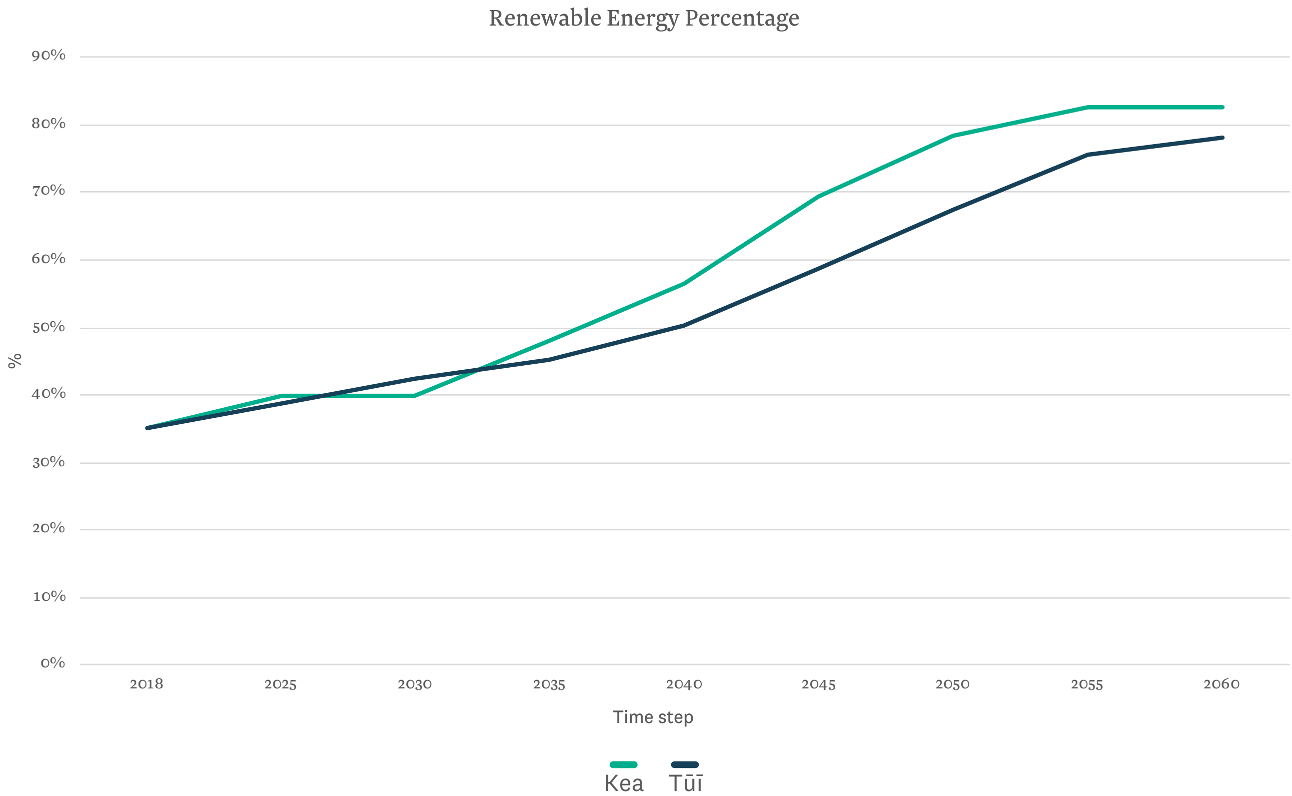


Figure 6: Total renewable energy percentage TIMES-NZ 2.0 Kea and Tūī scenarios

3.3 Road transport becomes almost entirely fossil-fuel free

Both scenarios see a transition of the light vehicle fleet from being almost completely fossil-fuelled to being almost completely electric by 2050 in Kea and by 2055 in Tūī. Kea sees markedly slower growth in the overall number of vehicles due to a lower distance travelled assumption in the model. Both scenarios also show conventional hybrid vehicles as transitional technologies as a result of modelled economic and supply limitations for battery electric vehicles.

There is a large reduction in the use of fossil-fuel across the heavy vehicle fleet in both scenarios as the model selects only electric heavy vehicles by 2050 for Kea and 2055 for Tūī (based on lowest cost to service demand). While there are many other options available for heavy fleet decarbonisation available, the cost of these options (such as biofuels and hydrogen technologies) resulted in them not emerging in the model results. As these are rapidly evolving technologies, the TIMES-NZ model will be frequently reviewed and updated as technology develops, and future model versions may explore further disaggregation of heavy duty vehicles to provide the model with more decarbonisation alternatives.

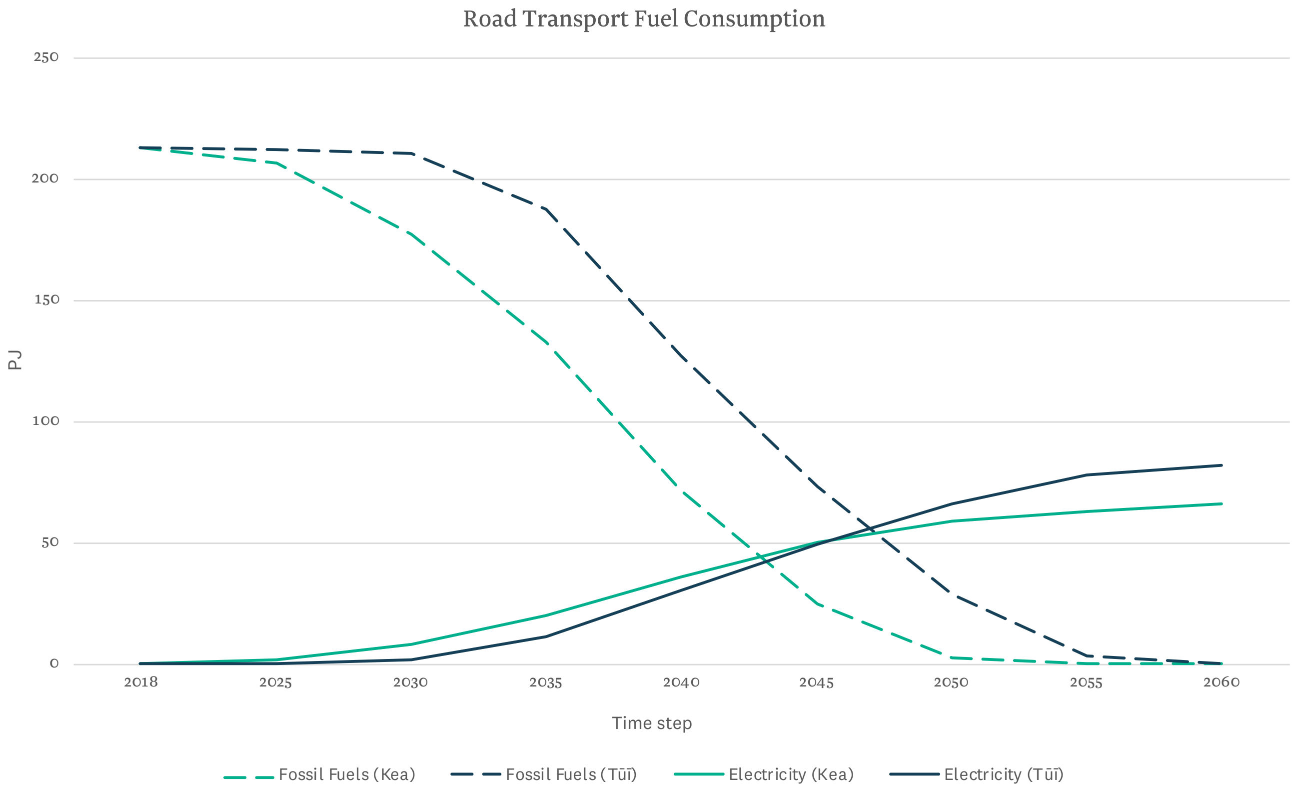


Figure 7: Road transport consumption of fossil fuels and electricity TIMES-NZ 2.0 Kea and Tūī scenarios

3.4 Transport emissions

Transport emissions fall dramatically in line with the fall in road transport fossil-fuel usage as light and heavy vehicle fleets electrify. In both scenarios the residual emissions are from marine and aviation transport. The steeper reduction in Kea's transport emissions is from the more rapid uptake of EVs and lower growth in vehicle numbers compared to Tūī.

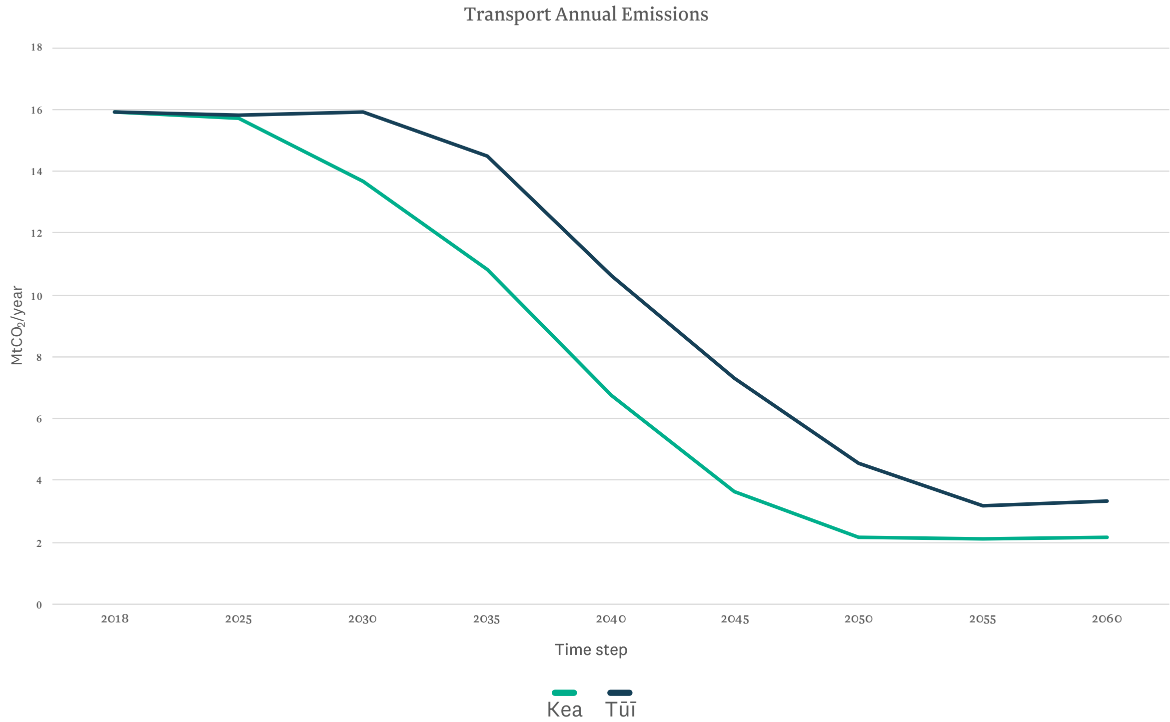


Figure 8: Transport annual emissions TIMES-NZ 2.0 Kea and Tūī scenarios

3.5 Industrial emissions

Industrial emissions see a sharp decline in Kea to 2.7 Mt CO_2/year in 2050 due to the uptake of direct use of renewables and electrification.

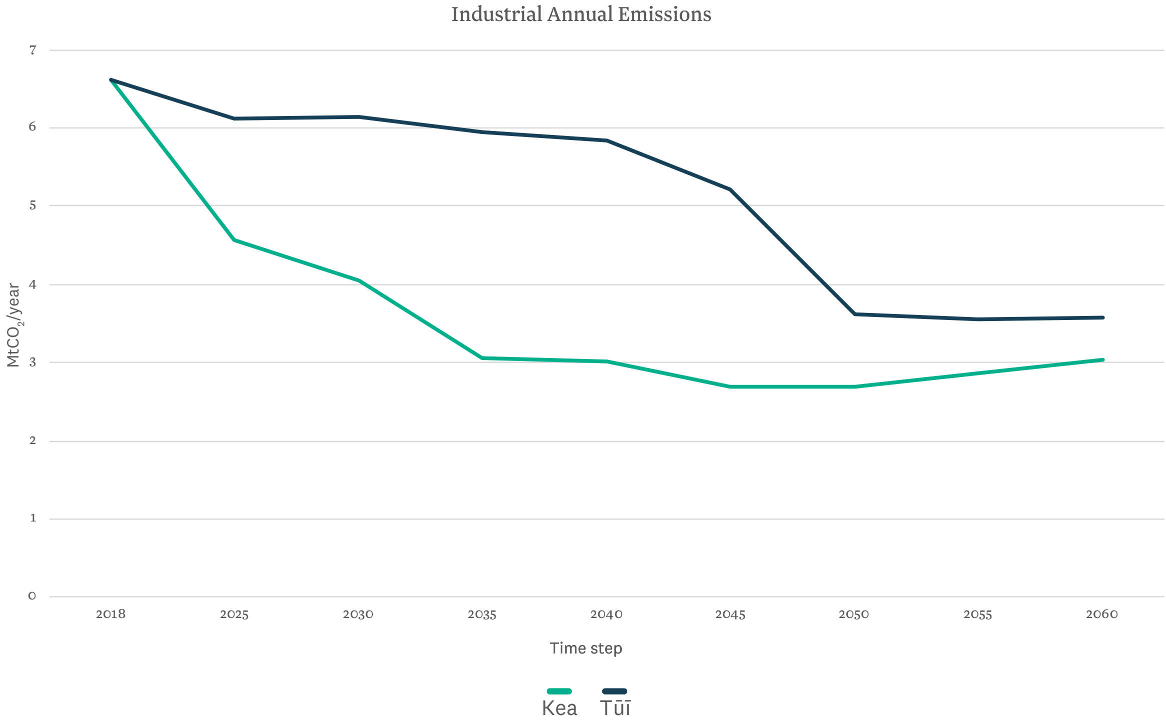


Figure 9: Industrial annual emissions TIMES-NZ 2.0 Kea and Tūī scenarios

3.6 Both scenarios reduce overall usage of gas

Overall gas demand remains below potential levels of domestic supply, avoiding any import of LNG or other substitutes. The model output sees gas demand cease entirely in the residential sector by 2040 in both Kea and Tūī scenarios, due to a combination of rising carbon prices and increasingly attractive alternative technologies, making switching away from gas economically optimal.

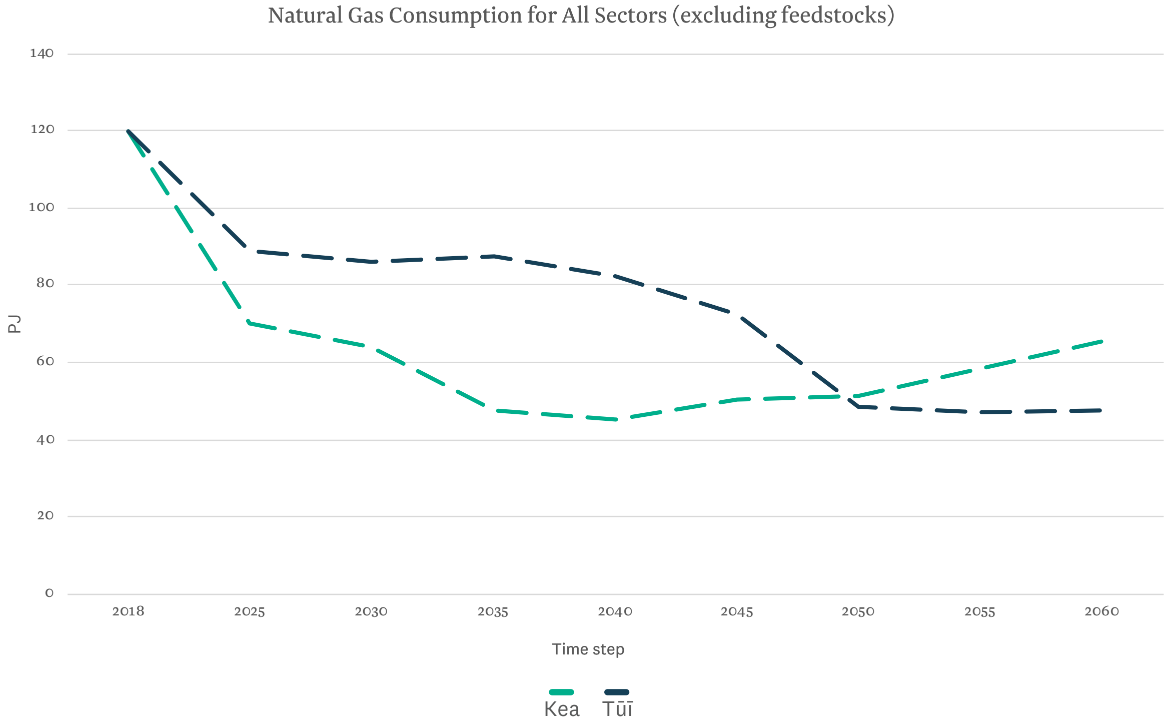


Figure 10: Total consumption of Natural Gas (excluding feedstocks) TIMES-NZ 2.0 Kea and Tūī scenarios

3.7 Energy efficiency plays a key role in decarbonisation

In both scenarios adoption of more efficient technologies increases energy efficiency and results in significantly decreased energy consumption. For example, road transport energy-use per distance travelled reduces by nearly 80% as a result of EV adoption because EVs are much more efficient than the fossil-fuelled ICE technologies they replace. Similarly, the electricity required for residential lighting falls by 70% as incandescent lights and fluorescent lights are phased out and replaced by more efficient LED options. The model finds a 35% increase in industrial energy efficiency – mainly due to electric boilers and conversion to biomass. Our scenarios also find a 70% increase in agricultural energy efficiency – mainly due to fuel switching off-road fuels and high temperature heat pumps in indoor cropping.

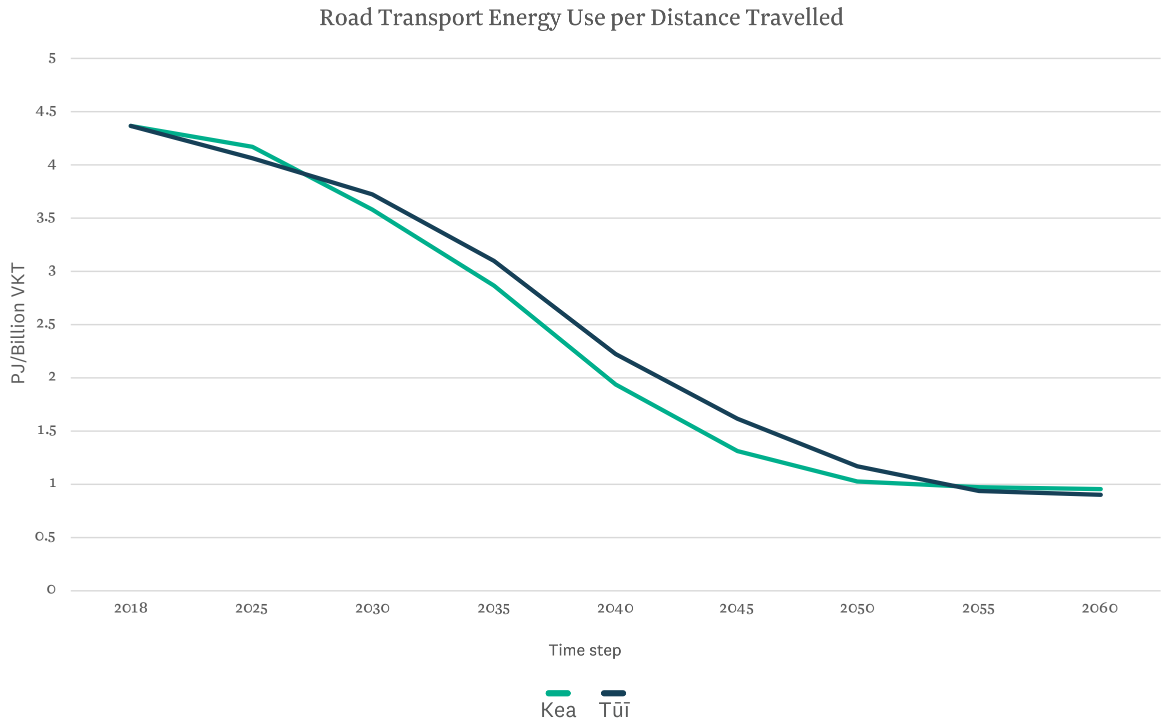


Figure 11: Road transport energy use per vehicle-kilometres travelled TIMES-NZ Kea and Tūī scenarios

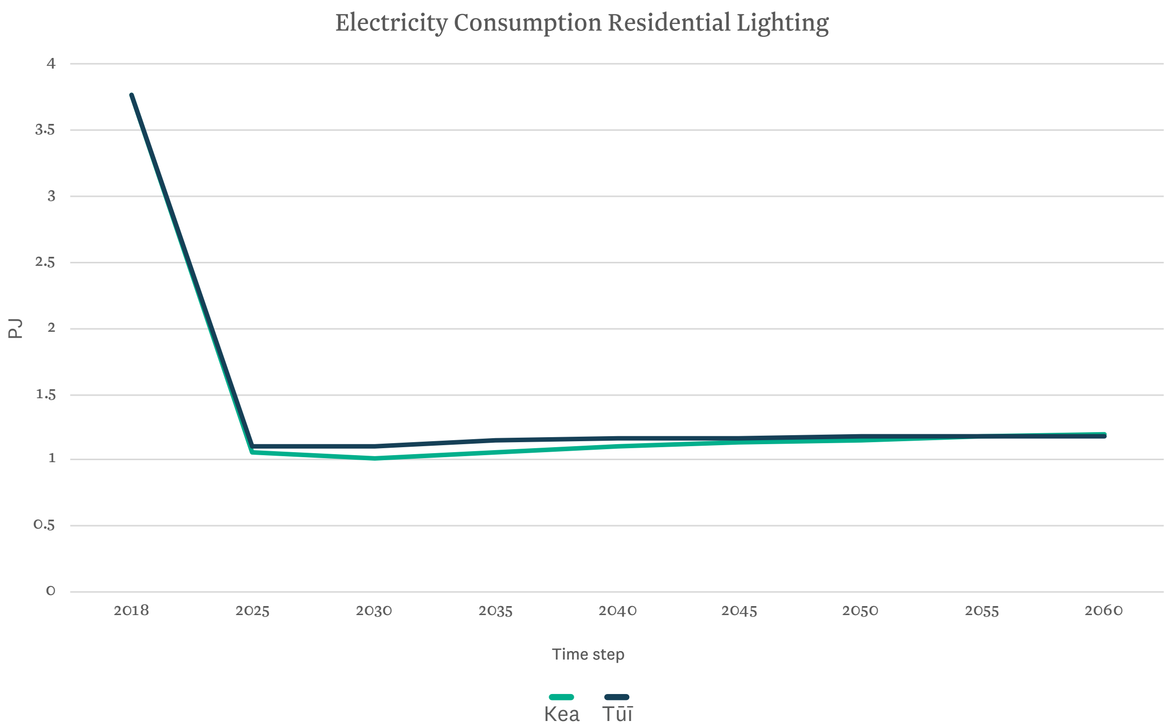


Figure 12: Electricity consumption residential lighting TIMES-NZ Kea and Tūī scenarios

3.8 Major increases in electricity demand and electrification

Electrification across all sectors results in electricity demand roughly doubling in both scenarios, from 144 PJ in 2018 to around 270 PJ in 2050. Electricity supplies up to 59% in Kea and 54% in Tūī of all energy demand by 2050. Under both scenarios, this increased demand is met by very large increases in wind generation accompanied by large increases to solar (primarily grid-scale) in later years by the model. Both scenarios converge on a very high renewable electricity percentage of around 95%. Under both scenarios, winter gas peaking is retained, and there is a gradual decline in geothermal generation. Under the Tūī scenario, hydro generation expands where possible, reducing dependence on gas peakers.

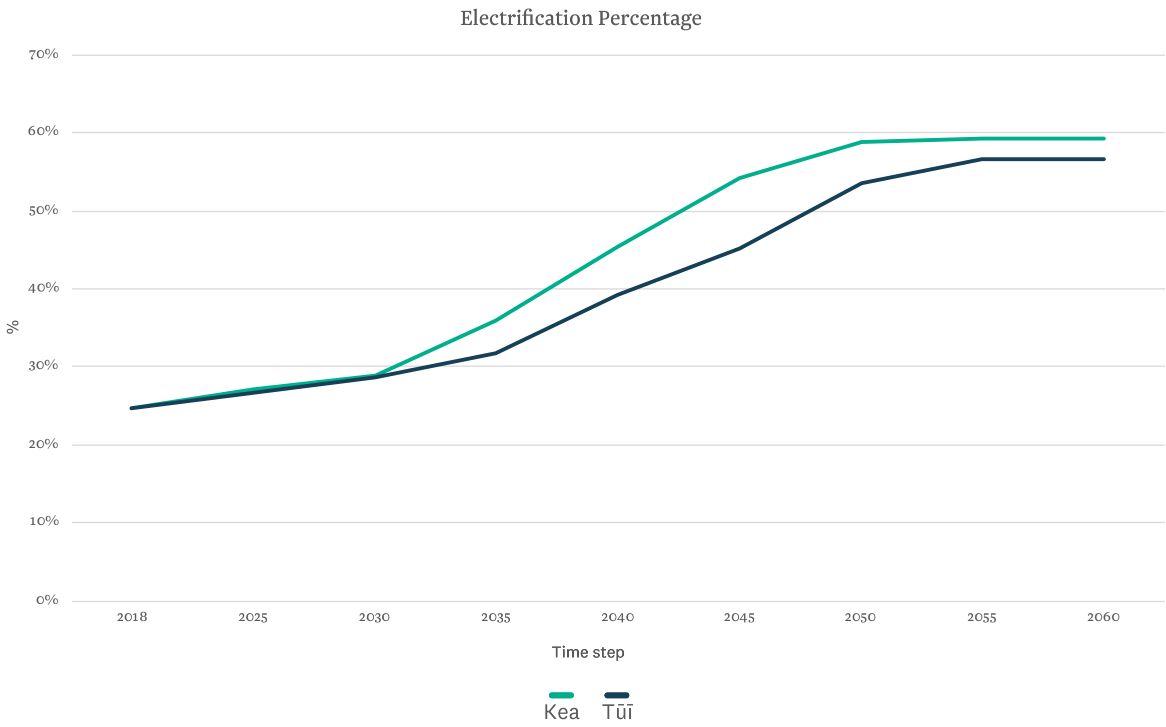


Figure 13: Electrification percentage TIMES-NZ 2.0 Kea and Tūī scenarios

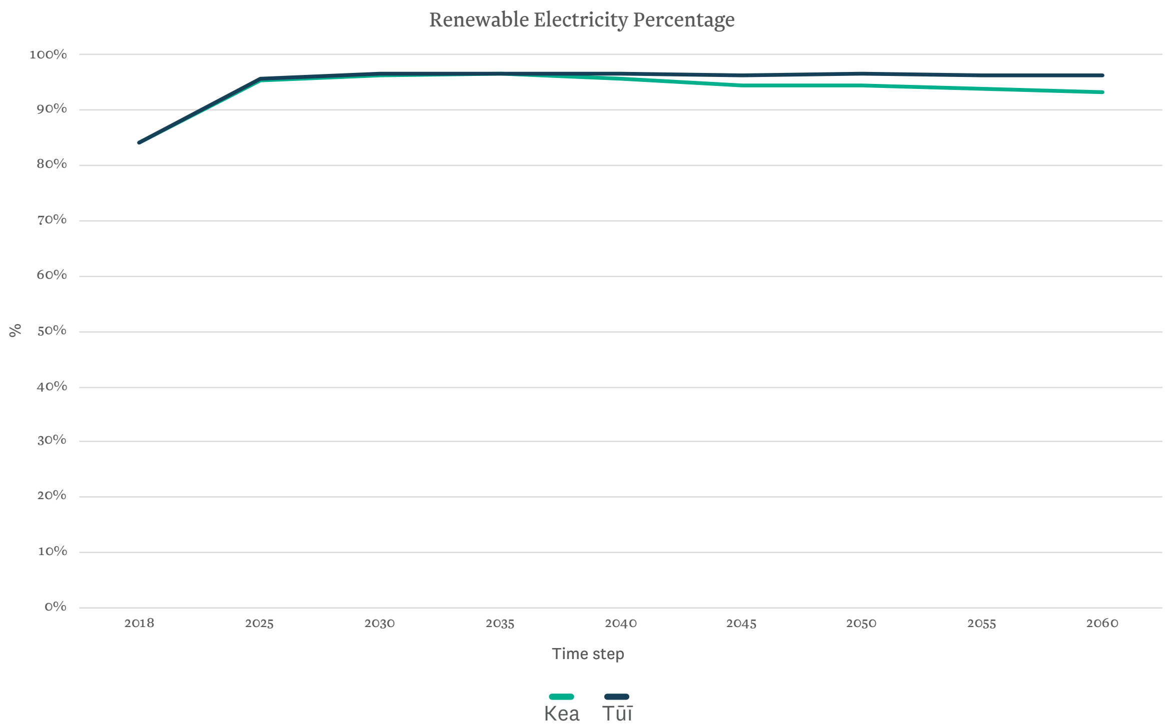


Figure 14: Renewable electricity percentage TIMES-NZ 2.0 Kea and Tūī scenarios

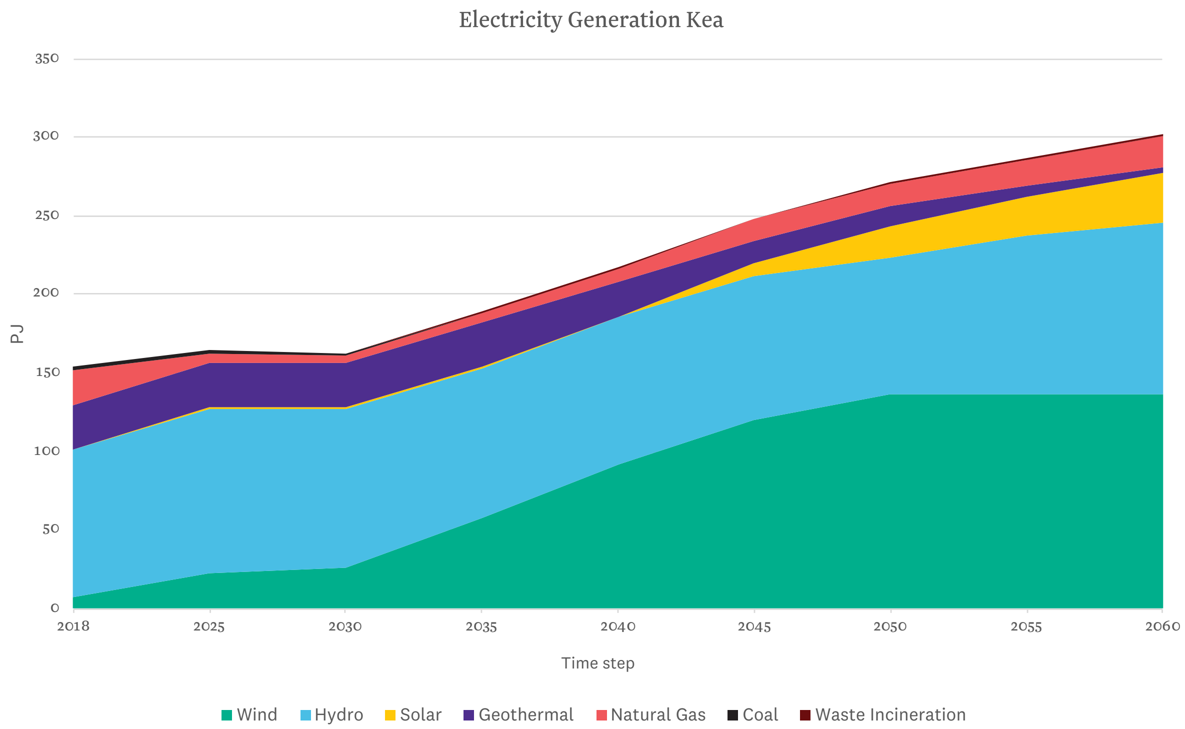


Figure 15: Electricity Generation by Fuel TIMES-NZ 2.0 Kea scenario

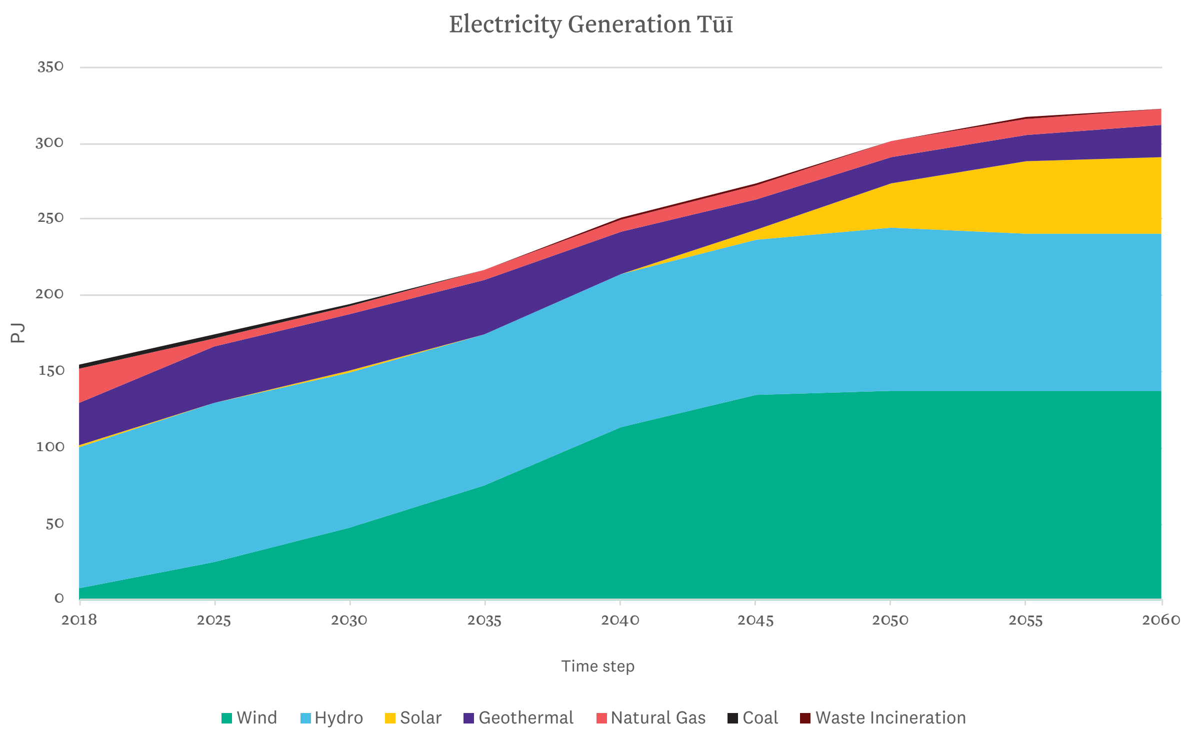


Figure 16: Electricity Generation by Fuel TIMES-NZ 2.0 Tūī Scenario

3.9 Demand for wood fuel doubles

The model indicates the amount of energy supplied. Wood fuel roughly doubles from 50 PJ to between 100 and 115 PJ in 2050. Most of the wood is is selected by the model to replace coal and gas for process heat.

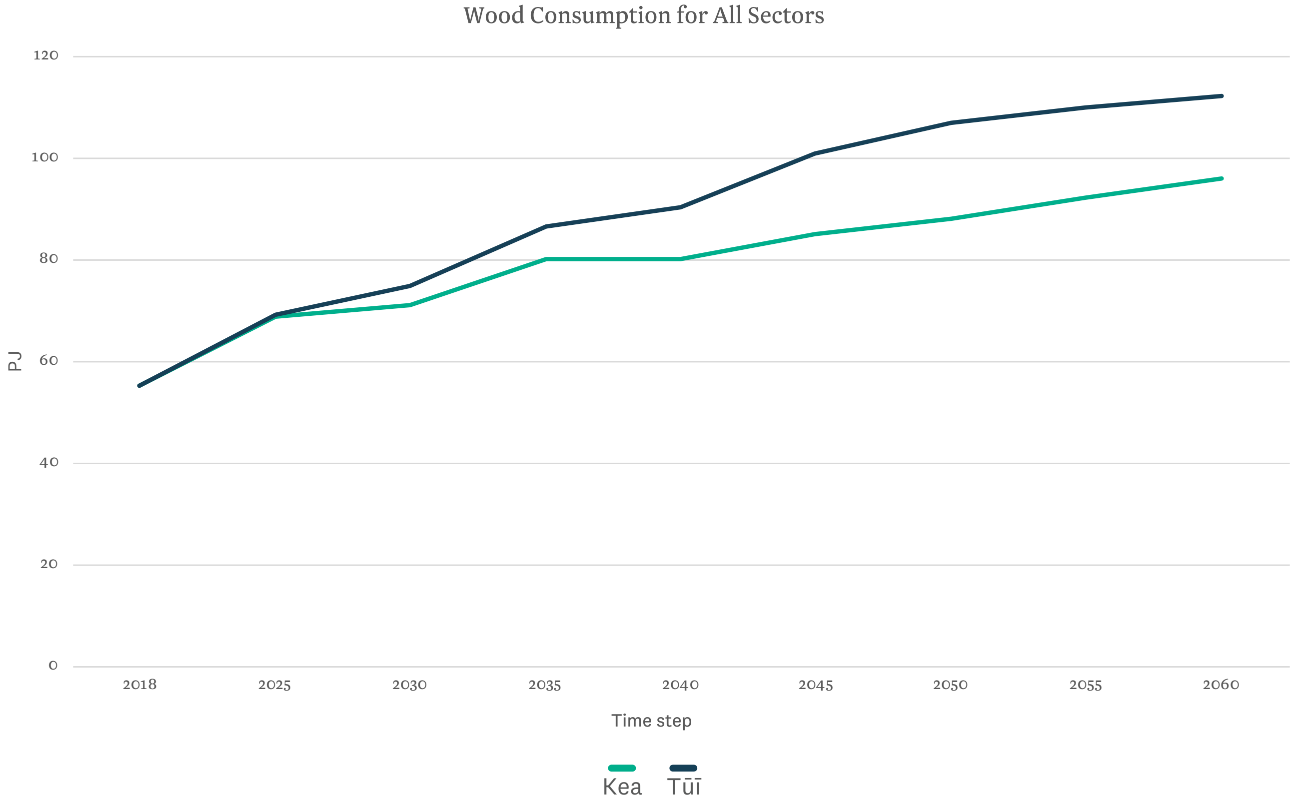


Figure 17: Wood consumption TIMES-NZ 2.0 Kea and Tūī scenarios

3.10 Storage plays a key role in the electricity system

Both TIMES-NZ scenarios use electricity storage to meet demand peaks, particularly from lithium-ion batteries, with capacity from storage technologies of 1.9 GW in Kea and 2.9 GW in Tūī by 2050. Both scenarios make limited use of large-scale pumped hydro from 2050 onwards, while Tūī makes greater use of battery storage. TIMES-NZ does not specifically model dry years, so the storage requirement findings represent average hydro years only.

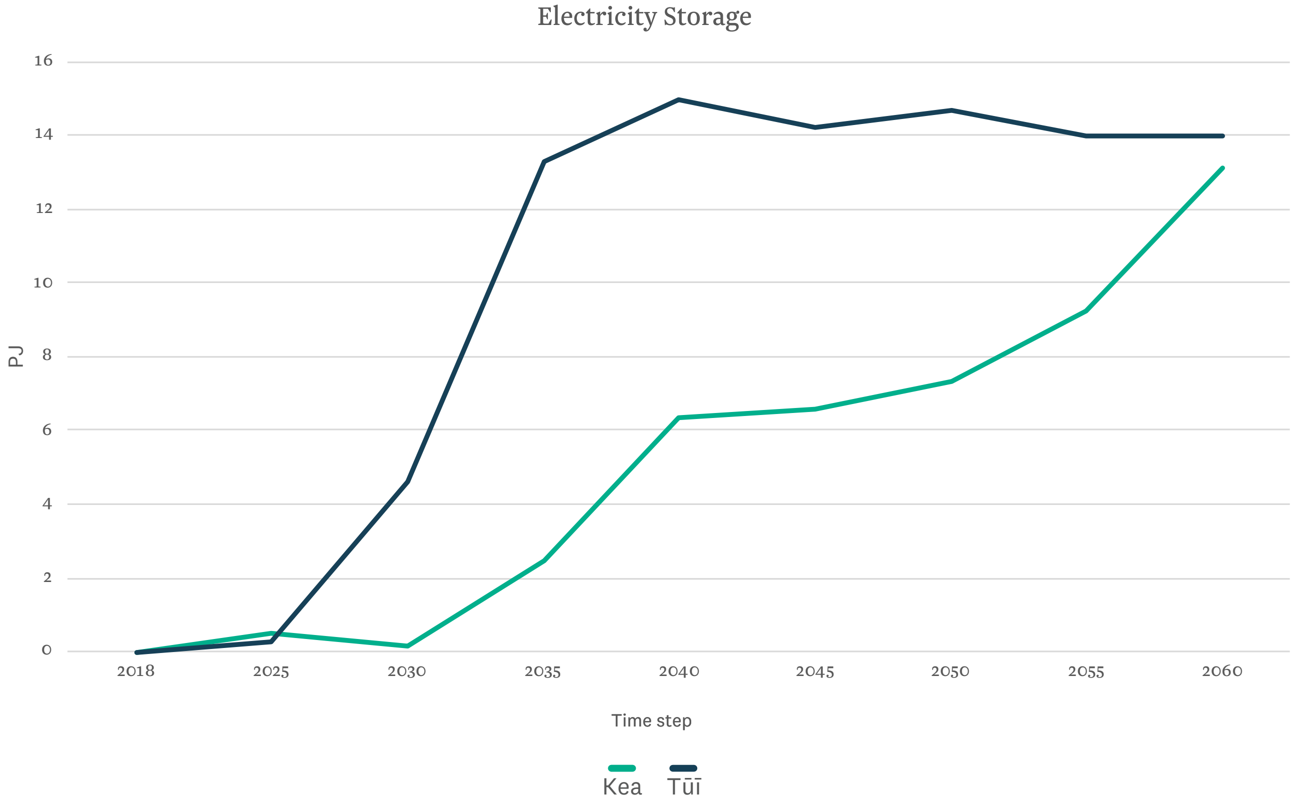


Figure 18: Electricity storage TIMES-NZ 2.0 Kea and Tūī scenarios

3.11 Hydrogen plays a role in agricultural niches under both scenarios

Hydrogen plays a limited role under both scenarios (due to the higher cost compared to other available technology types). This is based on current technology performance and cost curves for meeting energy demand. Hydrogen finds its niche in agricultural machinery, where the model determines it can decarbonise equipment working in remote areas, such as farms and forests. The model shows that it makes up around to 20% of agricultural fuel consumption in Kea and 16% in Tūī towards the end of the modelled period.

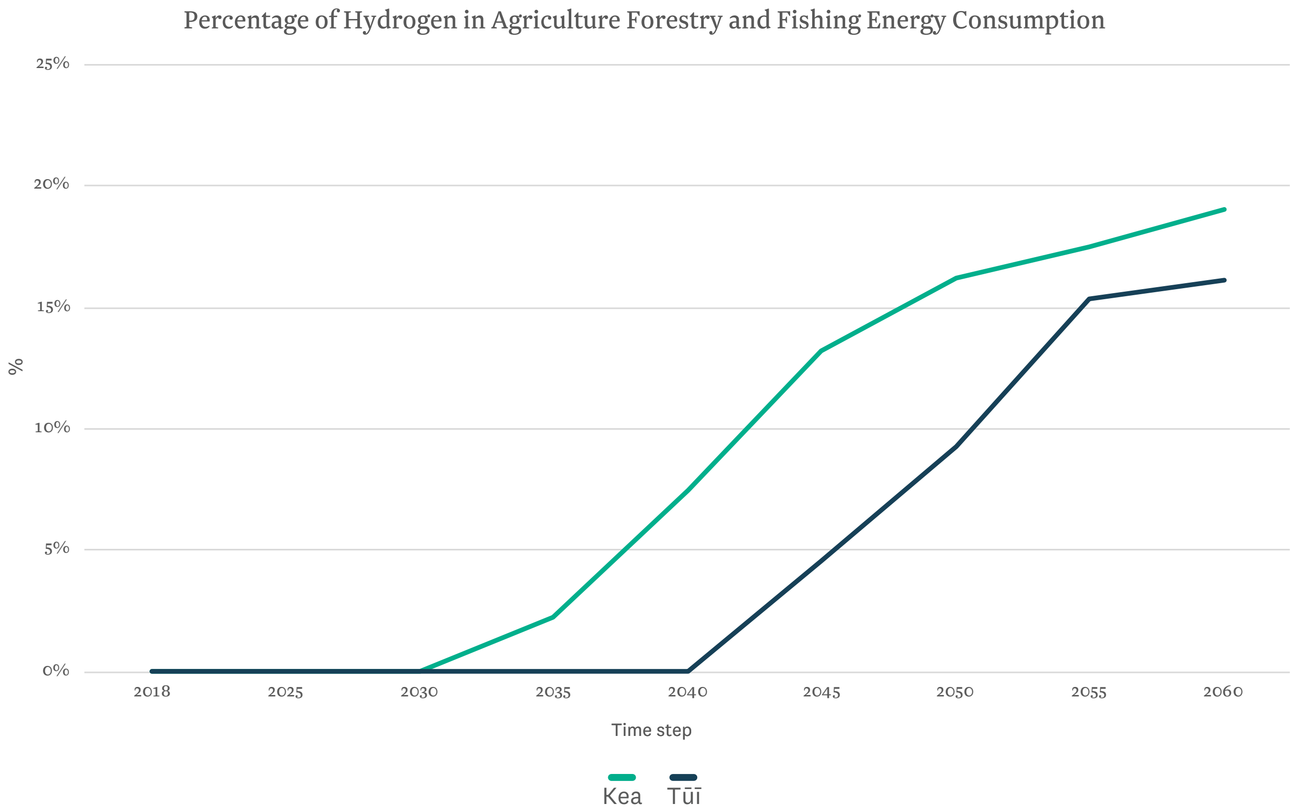


Figure 19: Percentage of hydrogen in Agriculture Forestry and Fishing energy consumption TIMES-NZ 2.0 Kea and Tūī scenarios

3.12 Wood and electricity displace coal

Under both scenarios, coal is replaced for all non-feedstock uses by wood and electricity by 2045. Under Kea, the dairy sector is nearly at zero emissions by 2035 (while it takes until nearly 2055 under Tūī). Similar results are found in the wider food sector although the model indicates natural gas is retained at reduced levels.

3.13 Biofuels play a relatively modest role

Biofuels play a relatively modest role, with drop-in diesel reducing emissions by up to 1.5Mt by 2050 under the Kea scenario. This is because of the high production costs for biofuels, resulting in the model preferring electricity for road transport.

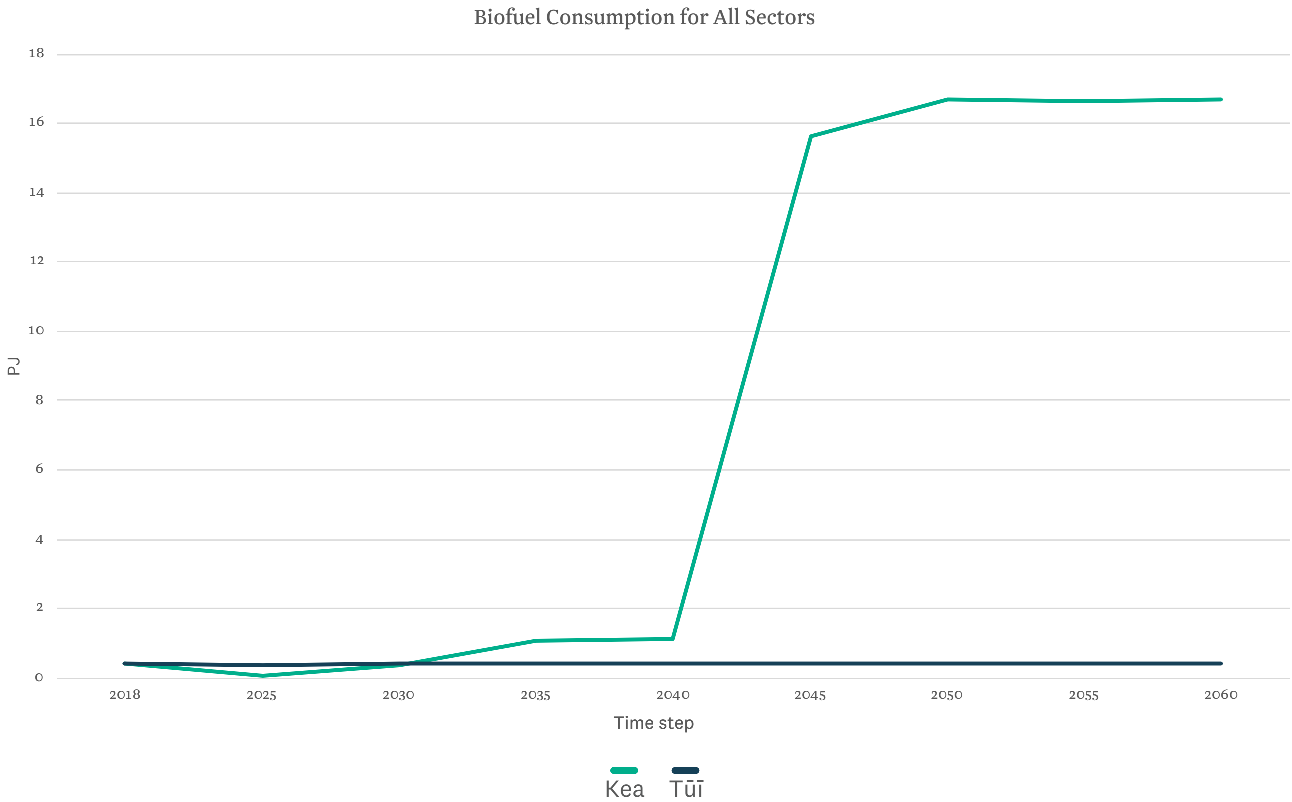


Figure 20: Biofuel consumption TIMES-NZ 2.0 Kea and Tūī scenarios

3.14 Electricity prices

TIMES-NZ produces estimates of energy costs, which are not the same as market prices. Shadow prices for electricity show electricity costs that are around ten times cheaper in summer, and around twice as expensive in winter, relative to current long-term averages, reflecting the increased use of solar and wind, and the move from baseload to peaking for thermal generation. Kea assumes Tiwai closes in 2024, with an associated demand reduction, and Tūī assumes it stays open indefinitely or is replaced by new demand of the same size.

3.15 New technology and innovation will be needed to address residual emissions

In both scenarios, most of the residual emissions are from sectors where the model did not have economically viable low-emission technology options to select. Approximately half of these residual emissions come from aviation, shipping and fishing sectors. While there are some other potential low-emissions options in these areas, these were either not well-enough defined to include in the model inputs, or were more expensive than the options selected by the model. Further technological improvements and innovation will be needed so that low-emission options are available at a lower cost.

3.16 Solar plays a role, mostly in grid-scale form

Both scenarios pick up a lot of solar PV from 2040 onwards, with up to 50 PJ in Tūī by 2060. In both scenarios, the model picks grid-scale solar as more economic and cost-effective than rooftop systems.

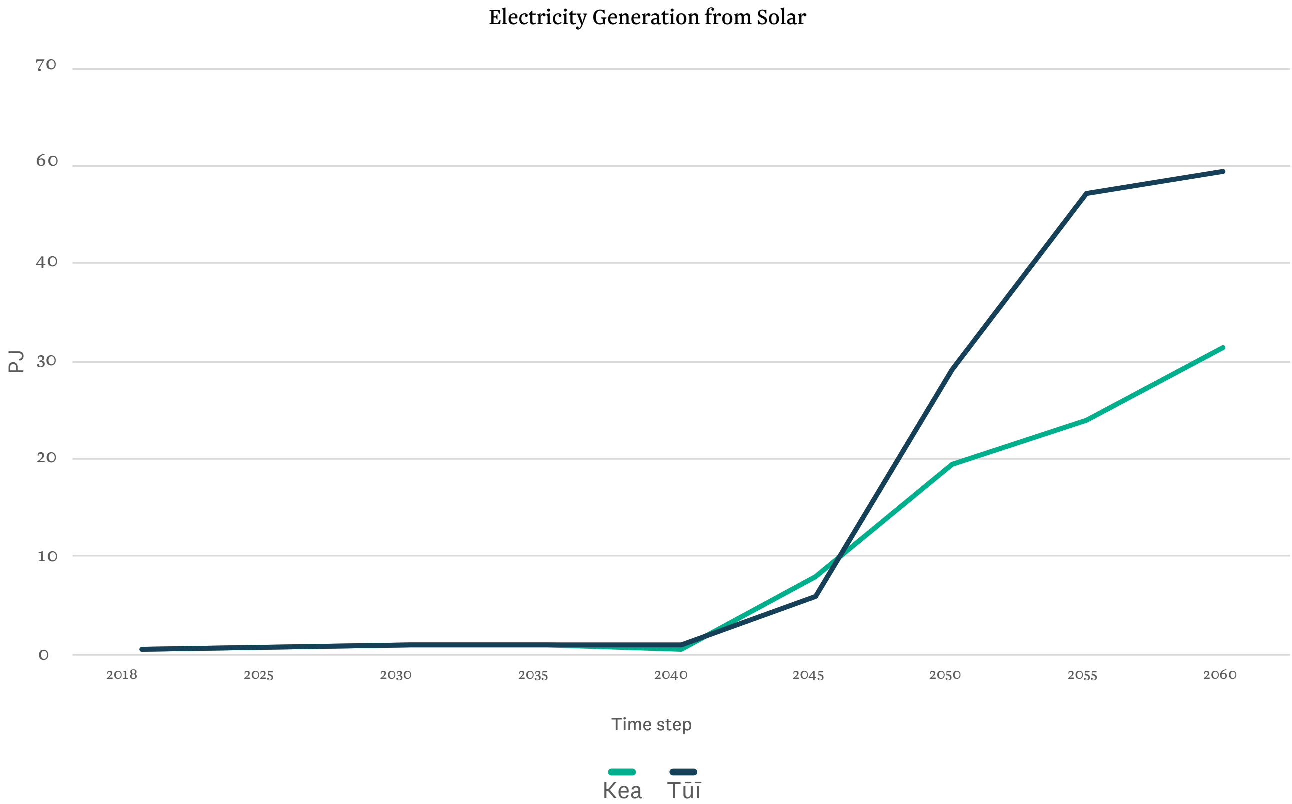


Figure 21: Electricity generation from solar TIMES-NZ 2.0 Kea and Tūī scenarios

CHAPTER 4

Macro-economic assumptions

4. Assumptions - New Zealand Energy Scenarios TIMES-NZ 2.0

A conventional TIMES model is driven by estimations of service demand within available supply constraints, which involves the forming of robust input assumptions. TIMES-NZ considers two scenarios each with different economic, social, carbon and energy-related inputs that lead to the distinct outcomes modelled.

Below the key assumptions such as GDP, population, and carbon prices for each scenario are described. We note that these assumptions are not predictions or forecasts, rather they illustrate two possible pathways for each of the parameters.

4.1 Gross Domestic Product (GDP)

GDP growth is often used to indicate the performance of an economy and is well understood even though economic health and well-being are not solely captured by GDP. In the case of scenarios focused on the energy system, GDP is a key driver of the demand for energy services, and thus is a core component of the quantification of the scenarios. The two narratives are essentially two strongly different economic paths that governments might take towards a sustainable economy in the long term.

Kea:

- New Zealand takes the risk of transforming its economy with climate change being the catalyst.
- New Zealand pursues global leadership in the energy transition.
- Difficult structural change occurs through to 2040, with socioeconomic impacts as a result of the economic transformation leading to lower GDP growth in this period.
- While generating international respect, initially this does not translate into economic benefits.
- After decades of change, from 2040 onwards, New Zealand begins to return to higher GDP growth with a new low-emissions economy and improving productivity resulting from the transformation.
- Economic well-being, as measured by GDP, rises above Tūī before the end of the period.

Tūī:

- New Zealand continues to capitalise on its natural assets and the pursuit of GDP growth.
- New Zealand balances its international emissions targets with protecting its key wealth-generating sectors from the full effect of international carbon prices[6].
- Strong economic growth occurs in the early part of the period, however midway through the scenario period New Zealand becomes less desirable as a trading partner, and – to some extent – as a tourist destination.
- The world starts to be more selective about how it buys from New Zealand, especially since New Zealand has consistently lagged behind at this point.
- Domestic political inertia resulting from two decades of conservative policy making is such that New Zealand can't adapt as quick as hoped.
- These two factors mean that growth of GDP in the Tūī scenario tapers off after 2040.

In TIMES-NZ, specific sub sector estimates are built up of activity in the following sectors:

1. Agriculture and Forestry based on land use projections
2. Industrial activity
    a. Methanol
    b. Aluminium
    c. Agriculture related processing (meat/dairy)
    d. Steel (capped at current capacity)

3. Population-driven
    a. Domestic households
    b. Healthcare
    c. Education

The remaining sectors then apply GDP growth assumptions given below:

	2020	2025	2030	2035	2040	2045	2050	2055	2060
Kea	2.0%	2.0%	2.0%	2.5%	2.5%	3.0%	3.0%	3.0%	3.0%
Tūī	4.0%	4.0%	4.0%	2.5%	2.5%	1.0%	1.0%	1.0%	1.0%

The impact of all GDP assumptions considered by the model results in the assumed composite GDP growth which is approximately:

	2020	2025	2030	2035	2040	2045	2050	2055	2060
Kea	2.5%	1.6%	1.6%	2.0%	2.5%	2.6%	2.6%	2.6%	2.7%
Tūī	2.4%	3.4%	3.3%	2.1%	0.8%	0.8%	0.8%	0.8%	0.9%

4.2 Population

Population growth is another key driver of the demand for energy services, and thus is another core component of the quantification of the scenarios.

Kea:

- Population grows at only 0.6% p.a. during the period of transformation 2021 – 2040.
- Most growth has been in the major cities, fuelled by the prospect of service sector and technology jobs.
- Some rural areas suffer as a result of being left behind by the transforming economy.
- Immigration in the early years of the Kea transformation is limited by reduced employment prospects in primary industries.
- Governments will actively limit immigration to those with the skills to contribute positively to the economic transition away from dependence on fossil fuels and towards low emissions activities.
- Later in the scenario period, as the transition is nearly complete, future governments are more receptive to wider immigration, and NZ's world-leading economy is highly attractive to people offshore who want to play a part.
- Net population grows at around 0.8% during the economic boom later in the period.

Tūī:

- Due to the continued growth in the New Zealand economy, migrants are initially attracted to the wealth generation prospects in New Zealand.
- Governments are open to immigration, seeing it as a way to continue fuelling economic growth, and hoping for increasing productivity as well.
- In the first part of the scenario period, immigration and thus population growth, grows strongly at 1.2%.
- However, as New Zealand's international reputation begins to be eclipsed by other countries who are making greater strides to reduce emissions and transform their economies, immigration, and population growth wanes.

4.3 Number of households

TIMES-NZ estimates the number of new occupied dwellings under each scenario up to 2060, by dividing population increase projections by the ratio of the number of new residents per new occupied dwelling, which was calculated from historical data.

MBIE's Construction Pipeline Report forecasts 39% of dwelling consents to be joined dwellings in 2025. In order to differentiate the projections between dwelling types, TIMES-NZ assumes the proportion of 39% joined dwelling consents continues beyond 2025.

4.4 Carbon price

The assumed international carbon price trajectories are based loosely around the World Energy Council's 'Modern Jazz' and 'Unfinished Symphony' scenarios[7] as they reference global prices in Tūī and Kea respectively, but 'spread' the prices to reflect how New Zealand positions itself relative to the rest of the world.

Kea:

- Consistent with the global leadership aspiration, the domestic carbon price is allowed to run ahead of the global price of carbon (which itself is rising rapidly) as policy settings constrain the supply of carbon units.
- Access to international units is constrained.
- Over time, carbon prices rise to levels required for significant emissions reductions to be incentivised.

Tūī:

- Global efforts to combat climate change are, on average slower than they are in Kea; hence the scenarios tend to mirror this global narrative.
- Tūī lags the international carbon price, reflecting the effort to protect strategic wealth-generating industries from the full effect of the carbon price.

4.5 Discount rate

The computation of the present value of future investments and costs requires a discount rate, which is entered exogenously. The discount rate is in fact a key parameter in energy system models, with sensitivity studies showing its strong impact on the technological preferences selected by the model.

Discount rates considered in TIMES modelling exercises are typically social discount rates and, in some cases, they also include hurdle rates to account for barriers for certain technologies. The lower the social discount rate is, the higher the renewable contribution in the resulting energy mix[8].

In TIMES-NZ, discount rates were defined as follows:

- Under Tūī, a discount rate of 5% p.a. is assumed for energy demand technologies, as per Treasury CBA guidance[9] , reflecting an investment environment that continues to prioritise relatively short-term economic investment.
- Under Kea, a discount rate of 2.5% p.a. is assumed for energy demand technologies, reflecting the scenario assumption that long-term outcomes such as avoiding climate change receive higher priority than short-term returns. The lower discount rate helps to incentivise capital intensive investments.
- For both scenarios, a discount rate of 2.5% is used for for biomass and hydrogen production technologies, to mitigate the risk and barriers associated with the installation of these available technologies.

4.6 Energy service demand projections

Table 5 shows the sources for the exogenously determined energy service demand projections that have been considered in each subsector of the model. For some cases, demand projections were calculated based on key drivers.

Table 5: "Drivers" for energy service demand projections that have been considered in each subsector of the model

Sector	Subsector	Source (or driver) for energy service demand projections
Residential	Detached dwellings	Number of households (detached)
Residential	Joined dwellings	Number of households (joined)
Commercial	Education Healthcare	Population projections
Commercial	Office blocks Warehouses, Supermarkets and Retail (WSR) Other	Sub sectoral GDP
Industrial	Aluminium Construction Food Processing Metal Product Manufacturing Methanol Production Mineral Production (includes non-metallic minerals e.g. cement/lime) Mining (of aggregates/metals) Petroleum/Chemicals (includes plastic/pharmaceutical manufacturing) Refining of petroleum products Urea Production Wood Product Manufacturing	Sub sectoral GDP
Industrial	Dairy Product Manufacturing Meat Processing	MPI land and animal projections
Industrial	Iron/Steel Manufacturing Wood Pulp and Paper Processing	None
Transport	Road Transport	VFEM scenarios from MoT adjusted due to different population assumptions between MoT's scenarios and the BEC2060 scenarios
Transport	Aviation	MoT's Air Passenger Forecasts, adjusted by energy efficiency improvements and behavioural change
Transport	Shipping	MoT's Freight Model, population projections and domestic GDP projections
Transport	Rail	MoT's Updated Future State Model results and MoT's Freight Model
Agriculture, Forestry and Fishing	Dairy Farming Livestock Farming Outdoor Horticulture & Arable Farming Forestry	Land use projections
Agriculture, Forestry and Fishing	Indoor Cropping	Population projections
Agriculture, Forestry and Fishing	Fishing	None

CHAPTER 5

Primary energy resources

5. Primary energy resources

TIMES-NZ includes present and future sources of primary energy for use in New Zealand, including domestic extraction of fuels, capture of renewable energy potentials, and imports and exports in the case of fossil fuels. Data inputs associated with primary energy resources are:

- Extraction costs
- Import/export prices
- Constraints regarding domestic extraction potentials
- Constraints regarding the availability of imports

Key assumptions associated with each type of fuel are summarised below.

5.1 Coal

Costs

- Domestic extraction potential takes into account existing coalfields of each region (North Island and South Island).
- Export of coal is enabled from the South Island region, since the majority of bituminous coal extracted on the West Coast of the South Island is exported for metallurgical applications.
- Import of coal is considered in the North Island.
- Base year costs for domestic extraction of coal were derived from the assumptions behind the Electricity Authority's Generation Expansion Model (GEM).
- International energy prices are used for imported and exported coal.
- Cost projections are based on international price trends from the IEA.

Potentials and constraints

- The model includes a constraint on annual extraction limits. This bound was set equal to the maximum historical figures.
- Other constraints, such as preventing the use of coal in low and medium temperature boilers are included on the demand sectors of the model.

5.2 Oil

Costs

- Domestic oil extraction cost was set at 80% of world market prices.
- International energy prices are used for imported and exported oil.
- Cost projections are based on international price trends according to the International Energy Agency (IEA).

Potentials and constraints

- The model limits total oil extraction to the cumulative available reserves of oil according to MBIE estimates.
- The model assumes that all domestic oil production is exported, as it is not suited to current refining capabilities in New Zealand.
- The model calculates imports of crude oil and refined oil products such as diesel and petrol.
- The model includes a constraint to account for annual extraction and import limits. This bound was set equal to the maximum historical figures.

5.3 Natural gas

Technological parameters

- In the model natural gas is only produced (and consumed) in the North Island.
- For each of the gas fields an emission factor accounts for greenhouse gas emissions produced during the extraction process.

Costs

- Domestic gas production costs were assigned per resource type based on BEC assumptions.
- Cost projections are based on international price trends according to the International Energy Agency (IEA).

Potentials and constraints

- The model limits gas extraction to the cumulative available gas reserves according to MBIE estimates.
- The model includes a constraint on annual extraction limits. This bound is set equal to the maximum historical figures.
- In the base year New Zealand meets all its energy needs for natural gas through indigenous production, however the model is able to implement construction of liquefied natural gas terminals for imports if domestic resources are depleted. Model outputs show that this option is not preferred.

5.4 Renewables

For renewable sources of energy, i.e. solar, hydro, tidal, geothermal, and wind, technological parameters and costs are defined downstream in the model, both in the electricity generation module and in the final energy demand modules. The primary energy resources module is where these resources are defined, and it includes their capacity potentials as described below. It is worth noting that biomass resources are considered separately, in the fuel production module.

Potentials and constraints

- The potentials for renewable energy sources are included as maximum capacity curves by region (NI and SI) based on MBIE generation stack updates[10].
- Availability factors for hydro and wind energy were calculated per time slice based on nine years of half-hourly dispatch data from EMI (2009-2017).
- For solar availability factors, irradiation data from NIWA's Solarview tool was used.
- The mean, min and max availability factors were calculated for all time slices, resources, and regions. The minimum availability factors values are assumed for peak time slices, and adjusted mean values are used for all other time slices.
- For hydro schemes with controllable storage, availability factors are defined at the seasonal level, allowing TIMES to dispatch these resources more flexibly.
- The model includes technical parameters for a number of alternative renewable sources that are not selected, for example tidal energy.

CHAPTER 6

Fuel production

6. Fuel production

In some cases, primary energy resources are subsequently converted into more refined commodities. This is described by fuel processing technologies such as the production of wood pellets or biodiesel from wood waste and hydrogen production from electrolysis, as illustrated in Figure 22. Fuel processing technologies require additional data inputs such as:

- Technical parameters e.g. efficiencies and lifetimes.
- Operation and maintenance costs
- Investment costs

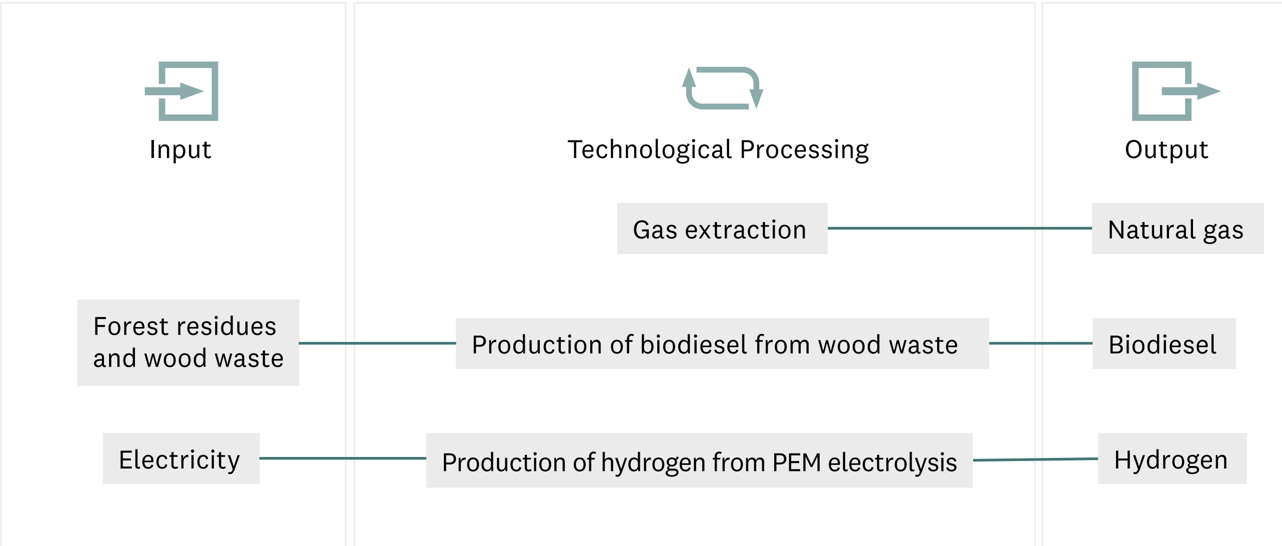


Figure 22: Examples of technological processes described in TIMES-NZ. "Gas extraction" is a primary energy supply process and thus it does not require an input fuel in TIMES. The other two examples describe the conversion of an input commodity (fuel) into a more useful output.

6.1 Hydrogen

Technological parameters

Only green and blue hydrogen are considered in TIMES-NZ. Green hydrogen is produced from electrolysis and blue hydrogen is produced from SMR with CCS.

- Grey and brown hydrogen (produced by steam methane reforming without CCS) are not considered due to their high carbon emissions.
- The potential pathways in TIMES-NZ for hydrogen production, transportation, and demand are shown below in Figure 23. TIMES-NZ may choose one or more of these pathways because they each supply the same hydrogen fuel to the end use demand.
- These pathways represent both centralised[11] and decentralised[12] production of hydrogen and can provide sector specific costs. This enables differentiation of sectors based on their needs of hydrogen, e.g. some sectors may require hydrogen at different specifications such as gaseous hydrogen at 350bar or 700bar pressures.
- Electrolyser efficiencies were obtained from Element Energy's report: "Hydrogen Supply Chain Evidence Base"[13].
- Availability factors were assumed as 80% as an upper bound for an electrolyser, allowing TIMES-NZ to be able to target times where electricity prices are lower.
- Lifetimes of electrolysers are dependent on how many hours the electrolyser is used. In TIMES-NZ, the number of hours used will vary between years therefore an accurate lifetime cannot be obtained. The electrolyser lifetimes in TIMES-NZ were obtained from the IEA: "Future of Hydrogen" report[14] and extent to reflect that electrolysers can only be used 80% of the time as per the upper bound of the availability factor.

- Blue hydrogen (Hydrogen from steam methane reforming of natural gas) is another production method of hydrogen available in TIMES-NZ. This utilises CCS to mitigate most emissions from natural gas reforming. The emissions factor from blue hydrogen is assumed as 8.33 kg CO_2/GJ which is approximately a 90% capture rate of the CCS.
- SMR efficiencies were derived from Collodi et al[15] by taking the ratio between input and output streams.

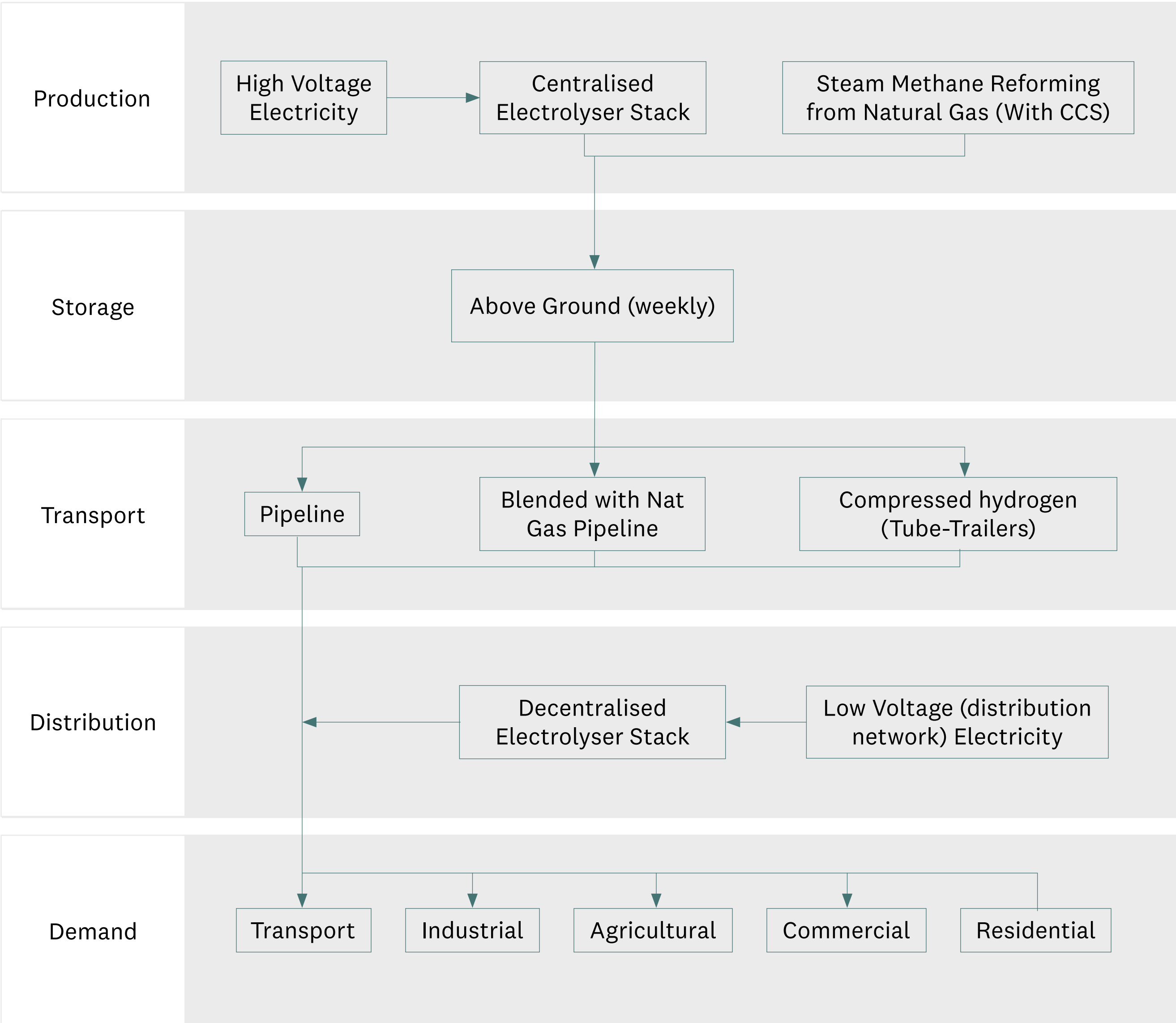


Figure 23: Potential Hydrogen Pathways in TIMES-NZ 2.0

Cost

- Centralised electrolysers receive electricity from the generation source/high voltage transmission grid. This has a lower cost than decentralised electrolysers which draw electricity from the distributed grid.
- Centralised electrolyser capital costs and projections were derived from Element Energy using the base case as assumptions for the Kea scenario and the upper case for the Tūī scenario.
- Centralised and decentralised electrolysers currently cost the same due to the modular nature of electrolyser stacks in today's market. However, as electrolyser technology develops, larger electrolysers in a centralised case will be cheaper on a $/kW basis than smaller units. We estimated cost differential for decentralised electrolysers over centralised electrolysers as 40% as noted in the the IEA – Future of Hydrogen Report.

- Decentralised electrolysis has a throughput cost representing the process between production and delivering the hydrogen and includes on-site compression, storage, and refuelling. This cost was estimated as $29/GJ derived from Assumptions Working Group feedback.
- Fixed Operation and Maintenance costs for all electrolysers were obtained from the World Energy Council which uses data from the IEA.
- The capital cost of the production of blue hydrogen includes the cost of carbon capture and storage. The capital cost of the technology was obtained from Collodi et al. and adjusted based on the cost of carbon storage from MBIE[16].
- The costs of new hydrogen pipelines were obtained (on a $/km basis) from Element Energy which were dependent to the diameter of the pipe.
- Due to the currently limited available cost data on blended pipelines, the costs were estimated on a throughput basis from NREL[17]. The maximum hydrogen blending ratio assumed was 20%.
- In the absence of recent data, costs of tube trailers were based on estimates from the IEA-ETSAP community[18] and include compression.

Hydrogen technology costs assumptions will need to be frequently reviewed.

Potentials and constraints

- Hydrogen exports have not been considered in the current version of the model, due to uncertainties around potential processing technologies for export. The model could be easily adapted to account for export should this uncertainty reduce.
- New hydrogen pipelines cannot be implemented on a partial basis to service the whole of the North Island. Thus, an iterative approach helped identify the proportion of pipeline being chosen by TIMES-NZ, and if the proportion was deemed unrealistic, then the new pipeline technology was excluded in future runs.

6.2 Bioenergy

The components of bioenergy in TIMES-NZ are: biomass supply, biogas production, and liquid biofuel production, where the latter includes biodiesel and drop-in biofuels (drop-in diesel and drop-in jet fuel).

The available Biomass transformations in TIMES-NZ 2.0 are presented in Figure 24. Additional liquid biofuel production pathways[19] are expected to be included in future iterations of the model.

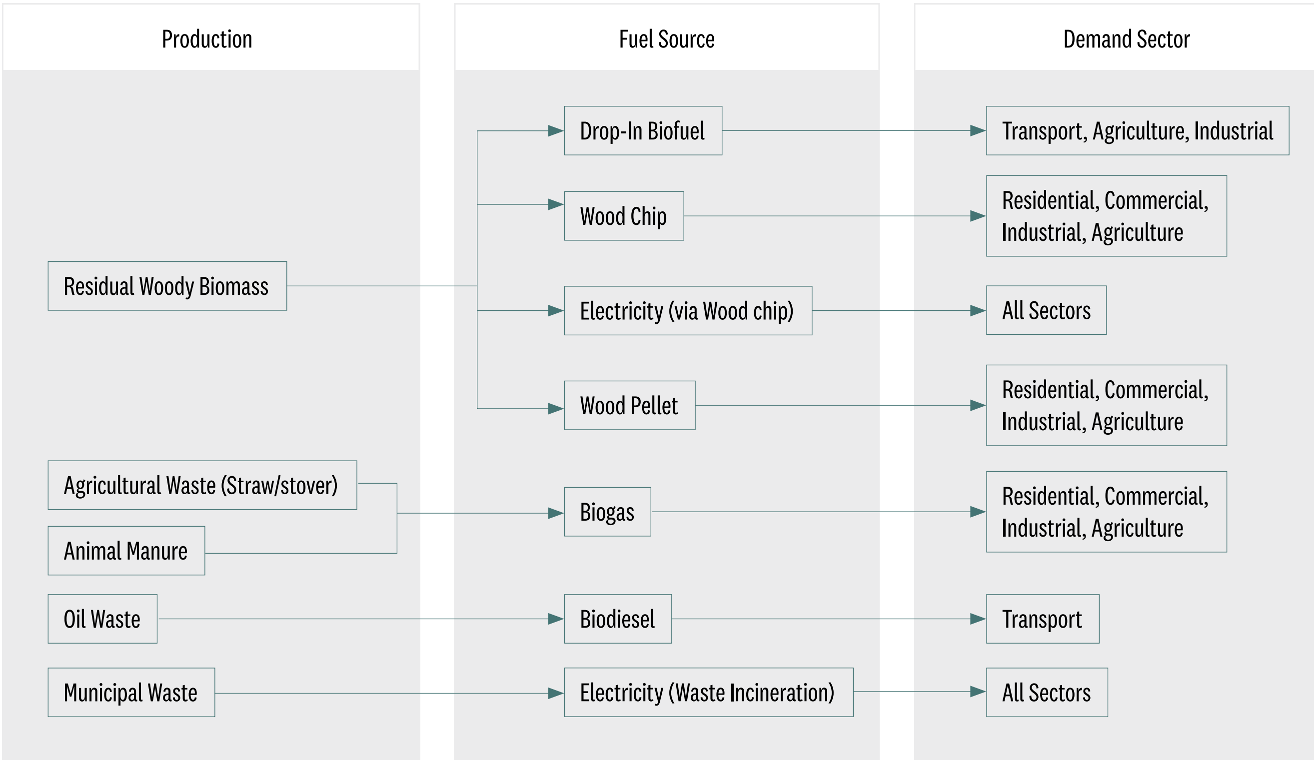


Figure 24: Biomass transformations in TIMES-NZ.

Technological parameters

- Biomass primary energy resources in TIMES-NZ represent the total potential amount of available biomass for use in all sectors.
- For woody biomass, primary energy has been defined as the current biomass supply of 51 PJ (MBIE) plus the amount of residual biomass supply still available in New Zealand current forest regimes[20].
- In addition to this, the model can select to use woody biomass from purpose grown forests on marginal land.
- Agricultural wastes include straw and stover, as well as fruit and vegetable culls.
- Oil Wastes (including tallow) and municipal solid wastes were estimated from SCION.
- Efficiencies of conversion technologies for biofuel production were provided by SCION.
- The current process in the model which produces drop-in diesel also produces drop-in bio-jet as a by-product at a proportion of 60% drop-in diesel and 40% bio-jet.
- Biodiesel can be blended up to 7% with fossil diesel as per regulation[21].
- All drop-in fuels can be blended up to 100% with their fossil counterparts. The exception to the blending limit is aviation where only 50% is allowed. However, it is expected that this 50% limit will become 100%[22].
- No marine biofuels have been identified in this iteration of TIMES-NZ.

Costs

- Two tranches of biomass were outlined to the model to account for the fact that not all biomass can be delivered at a single cost due to the diseconomies of scale when collecting forest residues. The tranche split was developed by region where regions that can deliver residual biomass at low cost formed one tranche, and all other residual biomass formed the other tranche.
- Costs of conversion technologies for biofuel production were provided by SCION.
- Purpose grown woody biomass has a cost of $16/GJ which is comparable to sawn timber logs, which were identified as the key competitor for usage of marginal land along with permanent afforestation.
- Imported renewable diesel and bio-jet are also available to TIMES-NZ at $60/GJ.

Potentials and constraints

- For woody biomass, the available supply has been defined as the current biomass supply plus the amount of residual biomass supply still available in New Zealand current forest regimes.
- Woody biomass from purpose grown forests has been assumed as having 50 PJ resource potential and is available for the model to select from 2040 which allows sufficient time for the forests to grow on a 15-20 year cycle.
- In TIMES-NZ woody biomass is considered carbon-neutral and liquid biofuels are considered as 90% carbon neutral, due to the auxiliary heating and transport required in order to produce and deliver the fuel.

Other Remarks

- Biomass use in New Zealand has regional constraints that cannot explicitly be expressed in TIMES-NZ. The biomass costs in TIMES-NZ include transport and therefore is a delivered cost. However this transport cost could be significantly higher if the availability is in a region far away from the demand.
- Due to current data availability, only one pathway has been considered for the production of drop-in biofuels. Future updates will include a wider array of biofuel production pathways that could be chosen by TIMES-NZ.
- Both imported liquid biofuels and woody biomass from purpose grown forests are treated in TIMES-NZ as dummy variables which can be used as back-up opportunities in future deep decarbonisation scenarios.
- It is noted that niche opportunities such as pelletizing agricultural straw pellets in Canterbury could eventuate, however TIMES-NZ has a sparse regional resolution, so these niche region-specific opportunities are not accounted for.

6.3 Oil refining

The model includes refining processes that convert imported oil into refined products at the Marsden Point oil refinery (North Island). Oil refinery outputs are Petrol, Diesel, Fuel Oil, Aviation Fuel, and Other, which were calibrated for the base year 2018 in accordance to the MBIE Energy Balance. Techno-economic parameters describing the refinery include lifetime, efficiency, emission factor, investment cost, fixed and variable operational and maintenance costs. Economic data was obtained from Refining NZ (the operator of the Marsden Point oil refinery) annual reports.

CHAPTER 7

Electricity generation

7. Electricity generation

The electricity generation module in TIMES-NZ 2.0 defines all existing power plants, as well as future technologies for electricity generation which can be selected by the model to expand capacity to meet future electricity demands.

7.1 Existing technologies

The TIMES-NZ model considers electricity capacity from all existing New Zealand power plants in operation, which are described in Appendix 2 (Table 10). Decommission dates are included for each plant, such that their end of life can be considered in a timely manner.

Capacities provided in Table 8 were derived from the Electricity Authority[23], with updated values since 2015 from the generator owners and industry associations where appropriate.

Existing technologies have a specified output in TIMES-NZ such that the electricity generation in 2018 is known to the model for each different technology type in each TIMES-NZ time slice. The source data for this was the Electricity Authority Generation dataset[24] combined with grid import data[25] for the smaller generators.

The remaining lifetime for each generation technology is outlined in TIMES such that existing plants can reach their end of life appropriately. Repowering of existing plants was not modelled explicitly although may be likely in reality for wind generation. In the model these are treated as new windfarms.

7.2 Winter energy and capacity margins

Winter Energy Margin (WEM) and the Winter Capacity Margin (WCM) are modelled using a combination of constraints and the TIMES peaking equation. The Winter Energy Margin is defined for two seasons (Autumn and Winter) for the whole of New Zealand and for the South Island specifically with corresponding coefficients (α).

$$\Sigma(\text{Availability Factor}_i \times \text{Installed Capacity}_i) \leq \alpha \times (\text{Electricity Production}_i)$$

where i refers to the resource type (hydro, geothermal, etc.), α=1.13 for the whole of New Zealand, and α=1.3 for the South Island only. The TIMES model increases capacity to satisfy the constraint. This additional supply causes capacity factors to decrease.

The WCM is modelled using the TIMES peak equation. This equation ensures that the secured available capacity installed is sufficient to meet the highest demand in any time slice plus a reserve margin of 15%.

7.3 Technology capacity constraint assumptions

In addition to the existing electricity capacity, the model will deploy additional capacity to meet electricity demand by selecting between technologies. Capacity constraints for new electricity technologies are outlined in Appendix 2 (Table 9) according to the nature of the resource.

7.4 Future technologies

Future technologies - Wind

Future wind technologies have been split into the following six tranches:

- Onshore Wind – Consented/planning underway
- Onshore Wind – Small/locally embedded
- Onshore Wind - Large, high capacity factor (>40%)
- Onshore Wind – Large, low capacity factor (<=40%)
- Offshore Wind – Fixed foundation offshore wind farms
- Offshore Wind – Floating foundation offshore wind farms

Costs of existing onshore wind technologies are estimated based on the MBIE Wind Generation Stack[26]. There are a range of capital costs relevant to consented and near-consented projects which were used to derive the costs of non-consented wind tranches.

Cost projections for all wind tranches were derived from National Renewable Energy Laboratory's (NREL) Annual Technology Baseline (ATB)[27]. The NREL ATB has cost data and projections for most electricity generation technologies and projections vary in magnitude through three definitions: advanced, moderate, and conservative. Wind cost projections used a conservative projection for Tūī and the moderate projection for Kea. Advanced projection was not chosen as there have already been significant advances in installation techniques, therefore installation cost improvements will likely be lower than the United States. For onshore wind the NREL ATB relative projections were applied to current estimated costs for each tranche. For offshore wind the absolute costs (converted to 2018 NZD) were used for both fixed and floating foundations as there are no cost estimates for offshore wind farms in New Zealand.

Capacity factors for all wind tranches were estimated for time slices and for both the North Island and South Island. Each onshore wind tranche has a mean capacity factor based on estimations from the MBIE Wind Generation Stack. The distribution of capacity factors by time slice and region were achieved from current wind generation trends as per the Electricity Authority generation data. As current generation is dependent on the location of current wind farms, it is noted that detailed wind mapping would help improve estimates for a region-weighted island-wide distribution.

Obtained MetOcean wind speed data helped inform capacity factor estimations for offshore wind in New Zealand[28]. Eight locations offshore New Zealand were selected, of which three were only suitable for floating foundations, the remaining five were suitable to be used in either fixed or floating foundation analysis.

The amount of capacity available for each onshore wind tranche was determined from the MBIE Wind Generation Stack for each island. The capacity potential for fixed foundation offshore wind farms was estimated by finding the amount of offshore area between 10 and 50 metres below mean sea level. Floating foundation wind turbines were assumed to have unlimited capacity potential.

Future technologies - Solar

Future Solar Photovoltaic technologies were split into the following five tranches:

- Residential Solar - rooftop
- Commercial Solar - rooftop
- Distributed/Community Solar – ground mount
- Utility Scale Solar – Fixed Panels – ground mount
- Utility Scale Solar – Tracking Panels – ground mount

Capital cost and projections for utility scale (tracking) and distributed generation were derived from MBIE's Utility-Scale Solar in New Zealand Report[29]. These cost projections were only assumed to be applicable to 80-90% of the project costs as many cost components of a solar project may not reduce with time e.g. land/grid connect costs. Kea and Tūī cost projections were split based on two projection curves which represent the rates at which global solar production may slow.

Current capital costs for utility (fixed) were derived using the ratio of capital costs between fixed and tracking systems for the U.S from Lazard[30]. Future capital cost projections for fixed utility solar use the relative decrease from NREL ATB projections for tracking systems.

Capital costs for residential and commercial systems were derived from the ratio between them and utility tracking systems from NREL ATB30. This ratio was compared on a $/Wp-AC basis to align with the utility scale costs. Capital cost projections for residential and commercial solar used the relative decrease from NREL ATB projections.

Fixed operation and maintenance costs and projections for all solar tranches were taken from NREL ATB as absolute values.

Solar resource profiles by island and time slice were estimated from PVWatts[31] data. Twelve locations across New Zealand were selected, with each location assumed suitable for at least one tranche, e.g. Auckland would be suitable for residential/commercial solar but not for utility scale. Solar resource was transformed into a capacity factor by applying relativities about a mean capacity factor. The mean capacity factor was estimated from MBIE's Utility-Scale Solar in New Zealand and scaled down to the other tranches according to the relative differences in Lazard.

Solar capacities for utility and distributed scale were estimated from the MBIE Utility-Scale Solar in New Zealand report. Kea and Tūī estimates vary based on the same two global production scenarios used in the cost projections. Solar capacities for residential and commercial rooftop installations were based on estimated rooftop area availability by island.

Future technologies - Geothermal

Geothermal technologies were split by the following tranches, based from the MBIE Geothermal Stack[32]:

- Large Consented Flash Plants
- Consented Binary Plants
- Large Non-consented Flash plants
- Non-consented Binary plants

Geothermal costs and emissions were derived from the MBIE Geothermal Stack. Costs were assumed to be constant throughout time for all geothermal projects in both scenarios. Steam flashing plant emissions were assumed to be the same as the field emissions. Binary plant emissions were assumed to be zero due to the heat exchanging technology used.

As geothermal is usually run as baseload, the capacity factor was applied on an annual time slice and constant for all tranches, this means the model will decide when (intra-annually) to dispatch geothermal whilst still meeting the annual capacity factor. The model is constrained such that geothermal must have a capacity factor higher than 90% in all time slices. This helps constrain geothermal plants to running as a baseload.

The capacities for geothermal uptake were estimated from the MBIE geothermal stack. The stack outlines project capacities and estimated earliest start dates for all projects within every tranche. The model can choose between steam flashing and binary plants from their earliest start date, without exceeding the overall geothermal capacity defined as 1.035 GW by the MBIE Geothermal Stack.

Future technologies - Hydro

Hydro is split into the following three tranches, defined using information from the MBIE "Embedded Hydro Generation Opportunities in New Zealand"[33] and the "Hydro Generation Stack Update for Large-Scale Plants"[34] reports:

- New Dams
- New Run-Of River – Embedded Small
- New Run-of-River – Large

Capital costs for all hydro plants were derived from the MBIE EDGS model used in BEC2060. The tranche break for run-of-river is 30 MW as most run of river would likely be smaller projects. These costs were assumed to stay constant over time.

Hydro capacity factors were estimated from existing generation dispatch data from the Electricity Authority. Existing inflexible run-of-river projects have capacity factors split by all 24 time slices. Existing flexible run-of-river projects have capacity factors split by eight time slices, therefore it can be dispatched at any time of day. All existing/new dams have capacity factors split by four time slices such that it can generate electricity at any time of day/week. For reference a power plant with no defined capacity factor in any time slices can run with 100% flexibility. To the reasoning behind flexible run of river and dams being restricted is to account for expected water availability.

All of the hydro capacities were derived from MBIE. As many large-scaled hydro projects have major consenting issues, only consentability ratings (as per the MBIE large-scale hydro report) higher than 7 were considered for the Tūī scenario, and higher than 5 for the Kea scenario. All new run-of-river hydro is assumed to be inflexible.

Future Technologies - Thermal

New thermal plants available for consideration by the model include:

- Natural Gas Turbines – CCGT, OCGT (with/without CCS)
- Coal Plants (with/without CCS)
- Oil Plants
- Biomass Plants
- Biogas Plants

Capital and fixed operation and maintenance costs for natural gas, coal, and diesel power plants were derived from a collation of sources including the Ministry for the Environment and the Electricity Authority[35]. Capital and fixed operation and maintenance costs for all thermal technology was chosen to not vary over time based from the NREL ATB projections.

CCS is included as an option for all fossil fuel generation. The carbon capture power plant data has been derived from the Swiss TIMES model, due to a lack of NZ specific data. CCS storage data was derived from MBIE's CCS in New Zealand report[36].

Future Technologies - Batteries

Battery tranches include:

- Distributed (commercial scale 0.5-1 MW, into LV network) batteries – Li-Ion
- Utility scale (100 MW, into HV network) batteries – Li-Ion
- Utility scale (100 MW, into HV network) batteries – Flow

Costs for batteries were composed of three aspects: battery cell, balance of plant (including inverters), and installation. Li-Ion cell costs and projections were identical to the assumptions used for battery electric vehicles. Balance of plant current costs were estimated from Lazard's battery system cost[37] less the battery cell cost mentioned above. Installation costs were estimated from an NREL residential solar[38] study for distributed batteries and from the U.S Department of Energy[39] for utility scale installation. Both installation and balance of plant have the same relative cost projections, both based from the NREL ATB.

Future Technologies - Pumped Hydro

Pumped hydro tranches include large and small projects with large projects "mimicking" the estimated parameters of a Lake Onslow scheme.

- Large Pumped Hydro (Lake Onslow)
- Small Pumped Hydro (other potential projects)

Costs for large pumped hydro were assumed as an average of the Government's estimate for a potential Lake Onslow scheme of $4 billion[40] and general industry feeling of approximately $8 billion. As with previous hydro projects, the landed cost tends to be higher than the initial estimate. Costs for small pumped hydro were based from MBIE's EDGS model and BEC2060 assumptions. Costs for both small and large pumped hydro were assumed to stay constant throughout time.

Capacities for large pumped hydro was the same as the capacity being proposed for the Lake Onslow scheme. Large pumped hydro therefore is only available in the South Island. Capacities for small pumped hydro schemes were considered to be available in both North and South Islands.

CHAPTER 8

Fuel distribution

8. Fuel distribution

Delivery of fuels to the demand sectors where they are needed is described by sectoral distribution technologies, which are characterised by parameters such as investment cost, variable operational and maintenance costs, and an efficiency that accounts for losses.

8.1 Fuel distribution costs

Delivery of hydrogen is split into decentralised and centralised processes, and the costs depend upon the type of delivered hydrogen and the energy sector.

Liquid biofuels include transport costs which represent the transportation of pyrolysis oil to a central bio-refinery, and then distribution of the refined liquid biofuel across New Zealand. This transport cost was estimated as $2.5/GJ.

Biomass distribution costs have not been split out as the costs in the biomass extraction is the delivered cost. An exception to this is the residential sector where it was assumed that the delivered cost would incur an additional $10/GJ.

Natural gas distribution costs were assumed on a sectoral basis, based on actual prices of natural gas, excluding any levies and GST from MBIE's Energy Prices.

Coal distribution costs have not been split out as the costs of coal extraction are delivered costs.

Oil distribution costs for the transport sector were estimated from a bottom-up approach using EECA's internal data.

TIMES-NZ uses a simplified approach with a high-voltage, medium-voltage, and low-voltage lines for modelling electricity transmission and distribution networks. In TIMES-NZ, large centralised electricity generation such as hydro dams inject into the high voltage grid, and smaller generation e.g. rooftop solar inject into the distributed (low-voltage) network. The TIMES-NZ model will build transmission capacity in order to meet supply exactly. As only two regions are specified in TIMES-NZ, no regional 'bottlenecks' can be identified in the model. The cost to build new transmission in TIMES-NZ was assumed as $500/kW, $1500/kW, and $1700/kW for high, medium, and low voltage lines respectively. These figures were estimated from internal expertise as well as analysis of Transpower and various distribution companies' annual reports. There is also a HVDC link between the North and South islands. The cost to increase the capacity of the link was assumed from Transpower.

CHAPTER 9

Energy demand sectors

9. Energy demand sectors

Each energy demand sector is described by a detailed technoloy database consisting of the following technology parameters:

- Efficiency
- Lifetime
- Availability Factor (AF)
- kW output
- Investment Cost
- Maintenance Costs.

It is important to note that the concept of end use efficiency in the context of TIMES is best defined as an efficacy, since the output of an energy service demand cannot always be quantified in units of energy.

An example of this in the residential sector is clothes washing, where the desired energy service is 'clean clothes' and a device with higher efficacy will deliver the same service for less input energy.

Annual Availability Factors are calculated as the ratio between the number of hours the technology is typically used in a year and the total number of hours in a year (8760).

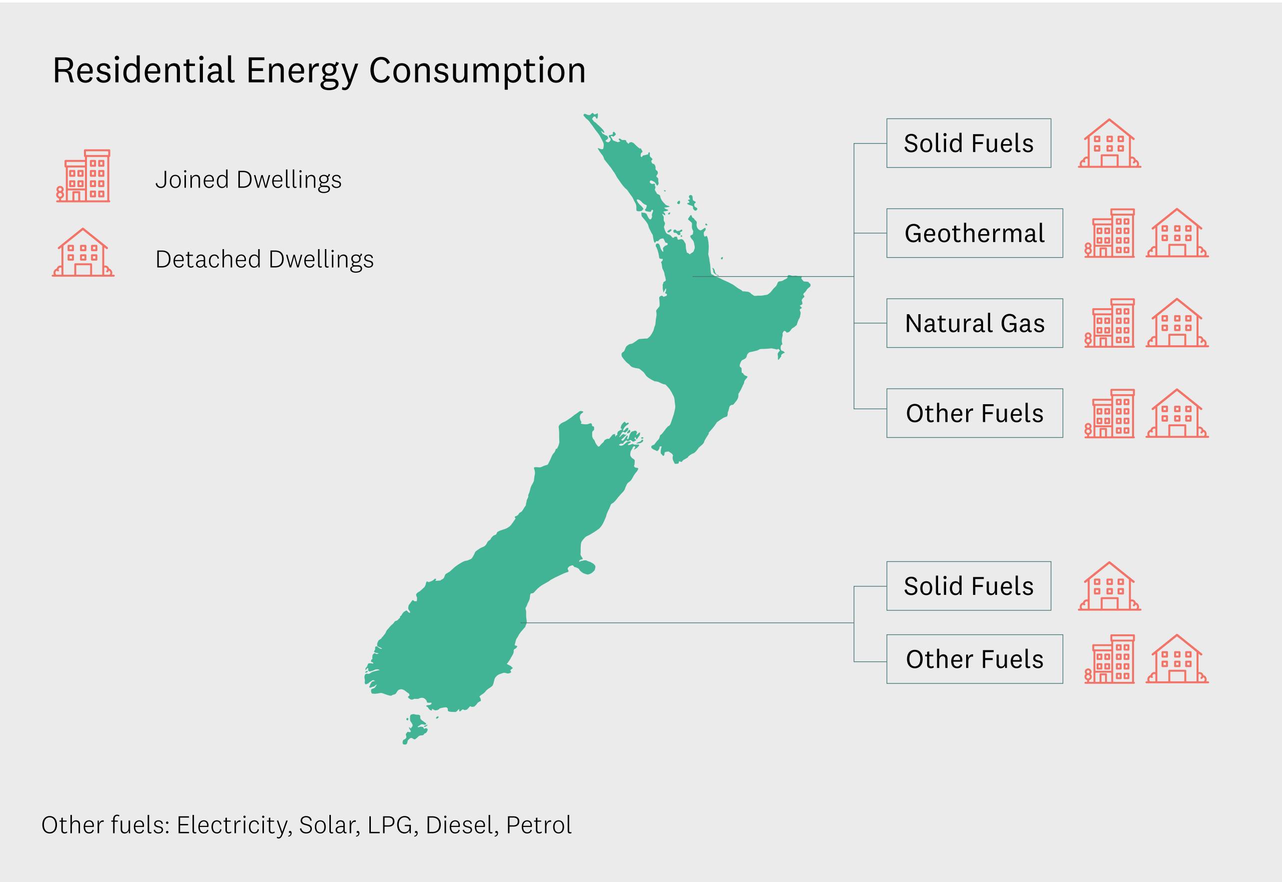


Figure 25: Residential energy consumption split according to region, fuel, and dwelling types

9.1 Residential sector

TIMES-NZ considers that residential energy consumption depends upon the characteristics of the dwellings. Two dwelling types are defined in TIMES-NZ "detached" and "joined", with the latter type encompassing medium density housing and apartments.

Detached Dwellings	Covers free-standing residential dwellings
Joined Dwellings	Includes medium density housing and apartments

Figure 25 shows how residential energy consumption at the national level (reported in MBIE's energy balance) was split in terms of fuel types. As shown in the figure, in TIMES-NZ Natural Gas and Geothermal energy are only available in the NI, and solid fuels (wood and coal) are only used in detached dwellings. Other fuels, encompassing electricity, solar, LPG, diesel, and petrol, are available in both islands and for both dwelling types.

In terms of energy end use, the residential sector includes the following groups or subsectors, from EECA's EEUD:

- Space Heating
- Space Cooling
- Water Heating
- Cooking
- Refrigeration
- Clothes Washing
- Clothes Drying
- Dishwashers
- Electronics and Other Electrical Uses
- Stationary Motors and Mobile Motors.

North Island/South Island Split

In order to determine the North Island/South Island energy split a top-down approach was carried out, where energy consumption for space heating and water heating was estimated in each of the eighteen climate regions defined by NIWA, to account for regional characteristics. This was achieved by scaling energy use for space heating and water heating across different regions through the criteria described below.

In the case of space heating the model takes into account that energy demand for this end use group depends on i) how cold the region is, ii) what heating technologies are being used, and iii) what the relative efficiencies are. The model calculates Heating Degree Days (HDD) (reference temperature of 18°C) for each climate region using climate data from NIWA, and HDD were used as a measure of the useful energy[41] requirement in each region. HDD where subsequently used together with the level of deployment of different heating technologies (from New Zealand 2018 Census data from Stats NZ) and the efficiencies of the technologies to calculate a factor that accounts for the regional variations.

For water heating, the model considers the number of occupants per dwelling as the main scaling factor. The number of occupants per dwelling was calculated using data from the 2018 New Zealand Census.

The model assumes that kWh delivered for other end uses such as cooking, refrigeration, lighting, etc. does not depend on the climate region or the number of occupants per dwelling.

Existing technologies were based upon the EECA EEUD. In the case of portable diesel burners, cooking ovens using coal, and open fires with or without wetbacks, delivered energy and efficiencies are provided for the reference year 2018, however the model assumes that no further deployment of these technologies will occur in the residential sector. In the present model iteration, we also assume no further deployment of the direct use of geothermal fuel given an absence of data.

Some energy related technologies that do not currently appear on the EEUD have been included in the TIMES-NZ database as "future technologies", to account for current market trends. Some examples are Heat Pumps for Water Heating and Clothes Drying.

Technology Parameters

For those technologies where efficiencies/efficacies have not changed over time, values were mostly gathered from the Household Energy End-use Project (HEEP)[42]. Efficiencies of heat pump technologies were provided by EECA's Standards and Regulations team. Lifetimes were obtained from previous EECA research work and in some cases from Consumer NZ.

With regards to the output power, for most technologies the input power is well known, and these values were converted to output power via the efficiency. The case of heat pumps is the reverse, because the rated power for this technology represents output power.

Load Curves

In the absence of intra-day consumption data on energy use from all fuels, load curves were calculated for each time slice using half-hourly electricity consumption data from EMI for a sample of residential dominated GXPs.

Costs

- Investment costs include installations costs and they were retrieved from online stores and the QV costbuilder database[43].
- The costs of some space heating technologies are differentiated between detached and joined dwellings.
- We have included a yearly maintenance cost only for technologies using natural gas and LPG, to account for repairs and maintenance of gas appliances.

Demand Projections

In the residential sector demand projections are considered to be driven by the number of households and their type, which are exogenous assumptions.

9.2 Commercial sector

In TIMES-NZ the commercial sector encompasses the following 5 subsectors:

Education	Includes childhood and tertiary education
Healthcare	Includes hospitals and health clinics
Office Blocks	Includes finance, insurance and real estate services, local and central government administration
Warehouses, Supermarkets and Retail (WSR)	Includes transport and postal services, wholesale and retail food, wholesale and retails goods
Other	Includes arts and recreation, and defence

These five subsectors were determined based upon the aggregation of EEUD subsectors with similar businesses, demand profiles, expected growth, and their data availability.

North Island/South Island split

End use demands were inherited from the EEUD, with some amendments such as splitting cooking demand into elements and ovens, and pumping being combined with electronics due to only a minor amount being used.

Energy demand splits between the North and South Island were determined for each subsector using the following proxies:

- Education: Number of enrolled students by island
- Healthcare: Number of hospital beds by island
- Office Blocks: GDP
- WSR: GDP
- Other: Population

Technology parameters

Availability factors were determined for each subsector individually. These were primarily based upon load curves, as most technologies were assumed to be used concurrently while businesses were open. Some exceptions, such as mobile motive power (tractors, garden maintenance equipment) were assumed for each subsector, at a lower rate than the primary technologies.

Load curves

Load curves were built for each subsector using datasets developed by EECA working with relevant businesses. As the subsectors are still relatively broad due to the base data limitations, multiple representative load curves were built for each subsector, and averaged based on each end user's relative proportion of the sector.

Costs

- Costs for large items, such as boilers, were largely from previous EECA research efforts, verified against some of EECA's newer work programmes.
- For technologies where pricing is publicly available, such as ovens and lighting, costs were compiled from online stores.
- Relativity in costs between subsectors was taken into account. Some distinction between the costs of technologies were added, to represent the fact that some subsectors will pay significantly more than others for the same technology, due to their requirements or scale.

Demand projections

Macro-economic drivers for the estimation of demand projections for each sector across the time horizon are as follows:

- Education: Population
- Healthcare: Population
- Office Blocks: GDP
- WSR: GDP
- Other: GDP

9.3 Industrial sector

The industrial sub-sectors have been developed as:

Aluminium	Represents the Tiwai Point aluminium smelter
Construction	All construction including buildings and heavy civil engineering
Dairy Product Manufacturing	Includes production of milk, milk powders, cream, butter, cheese, ice-cream, and associated protein products
Food Processing	Includes processing of fruit, vegetables, cereals, and beverages
Iron/Steel Manufacturing	All iron/steel mills in New Zealand – most notably the Glenbrook steel mill
Meat Processing	Covers all meat processing plants, including fish and seafood preparation
Methanol Production	Production of methanol from Methanex
Metal Product Manufacturing	Includes galvanising, surface coating, can manufacturing, and metal forming processes
Mineral Production	Covers the manufacturing of glass and glass products, ceramics, cement, lime, plaster and concrete products
Mining (of aggregates/metals)	Includes mining of coal, oil, gas, metal ores and quarrying of non-metallic minerals
Petroleum/Chemicals	Covers petroleum product manufacturing, basic chemical and chemical product manufacturing, polymer and rubber manufacturing
Refining of petroleum products	Includes all energy use such as process heat from the Marsden Point refinery
Urea Production	Represents the Kapuni urea/ammonia plant
Wood Product Manufacturing	Covers log saw milling, timber dressing, veneer and plywood manufacturing
Wood Pulp and Paper Processing	Includes pulp, paper and paperboard manufacturing

Fuel demands for 2018 have primarily been sourced from the EECA's EEUD, for the period ending 2018. End uses relating to process heat were adjusted to describe the type of heat produced, rather than the temperature (as per the EEUD). For instance, process heat produced by boilers is assigned to end use 'Process Heat: Steam/Hot water', while process heat produced by an oven is reassigned to 'Process Heat: Oven'.

Additional data for non-energy uses of fuels were sourced from various MBIE outputs[44]. These include natural gas to produce methanol and urea, and coal to produce iron/steel. Although the current iteration focusses on energy use, these are important to include for modelling and balancing fuel supply and demand, as well as the ability to count IPPU emissions.

North Island/South Island split

The fuel consumption island splits were estimated as follows:

- Construction: reflects regional GDP splits for the subsector as per Stats NZ data[45]
- Dairy: reflects regional GDP splits for the subsector as per NZIER data[46]
- Meat: same exact split as per dairy
- Metal manufacturing: reflects relative GDP contribution of NZ Steel and Tiwai Smelter
- Other: reflects the GDP split for the manufacturing sector overall based on regional GDP data from Stats NZ
- Pulp and paper: reflects actual regional plant fuel consumption based on EECA data.

To develop the split, all natural gas use is assigned to the North Island (by subsector and end use). Remaining energy use is then apportioned between the two islands, so the total energy use is split as per the weighted average split.

Technology parameters

The sector/end use combinations were further disaggregated by the combinations of technologies and fuels providing current end uses for both North and South Islands.

A principal source of data was the University of Waikato (UoW) work for the EECA/MBIE Process Heat in New Zealand (PHiNZ) project in 2018/19. This focussed on the sectors consuming the most energy, but is limited to process heat only. It provided technical and cost data for a range of alternative technologies in addition to those currently employed.

Because of the nature of the demand sectors that UoW covered, these are primarily boilers producing steam or hot water from coal and natural gas. In the case of the EEUD these combinations tend to be more varied due to the large number of businesses and activities in the general industrial market.

New technologies which potentially can compete with existing technologies are added to each sector/end use combination. The new technology options generally focus on electrification, boiler fuel switching and energy efficiency improvements.

Demand projections

Future end use demand was considered to be driven by:

- National or Sector GDP projections
- Capacity or part-capacity constraints of large existing plants, for example the Glenbrook Steel Mill
- Other drivers are used for cases where GDP growth may not realistically reflect a subsector's growth, for example pulp and paper manufacturing.

The major transformations across industrial subsectors reflect the narratives in BEC60 Energy Scenarios. Key points:

- The iron and steel industry is assumed to have no direct link with GDP growth, and zero growth is assumed for the entire time horizon.
- Dairy Product Manufacturing and Meat Processing decline in output based on MPI land and animal projections for the subsectors. This correlates to the end use demand projections for the agricultural sector disregarding energy productivity improvements.
- Methanex exit reflects assumptions on available supply of natural gas, and business impact from increasing carbon prices.

    a. In Kea Methanex exits in 2032
    b. In Tūī Methanex exits in 2047

- The significant underperformance of chemical subsectors (refining, urea, petroleum products) reflects the business impact from increasing carbon prices, and societal shift away from carbon intensive products.
  a. In Kea, urea makes an exit in 2027. The refinery becomes an import terminal in 2042.
  b. In Tūī, the demand for urea, petroleum refining, and other petroleum/chemical based product manufacturing are driven by a reduction of GDP contribution.
- The Tiwai exit development has been ongoing during the enhancement of the model.
  a. Currently it has been assumed that Tiwai exits in 2025 in the Kea scenario and the electricity it would have used is available to the model to use elsewhere.
  b. In the Tūī scenario it was assumed that Tiwai would remain or be replaced by some other non-hydrogen (as it is an option to the model already) industry such as data centres. Therefore, the demand in Tūī stays constant.
- Pulp and Paper industry growth was assumed to be flat from 2018 due to the potential reduction in paper demand. In reality pulp and paper production may actually decrease as shown by Whakatane Mill's recent closure.
- The subsector labelled 'Other' represents all the other subsectors in the industrial sector (such as printing and other manufacturing not already specified). Its purpose is to maintain consistency between TIMES-NZ, the EEUD, and MBIE's Balance tables for 2018. The projections for the 'Other' fuels outline that all fossil fuels will not increase in use. All non-fossil fuels will increase according to the national GDP increase assumptions.
- Structural change away from emissions-heavy energy consumption means that metal product manufacturing under-performs national GDP growth during low-growth period (and half of transition period in Kea). This assumption was used for all other subsectors (mineral, mining, construction) but to a much lesser extent.
- In both scenarios, wood product manufacturing outperforms the economy during the low-growth period, as timber and associated products become an important domestic and global commodity.

Table 6 and Table 7 provide the overall growth assumptions for the GDP driven industrial subsectors in Kea and Tūī respectively.

Table 6: Industrial sub-sector growth assumptions, Kea

TIMES-NZ 2.0 industrial sub-sector	2020	2025	2030	2035	2040	2045	2050	2055	2060
National economy growth stage	Low growth			Transition		High growth			
Other Food Processing	2%	2%	2%	2.5%	2.5%	3%	3%	3%	3%
Wood Product Manufacturing	2.7%	2.7%	2.7%	2.5%	2.5%	3%	3%	3%	3%
Metal product Manufacturing	-1.2%	-1.2%	-1.2%	2.5%	2.5%	3%	3%	3%	3%
Petroleum/Chemical Product Manufacturing	-10%	-10%	-10%	0%	0%	0%	0%	0%	0%
Mineral, Mining, Construction, Other	0.6%	0.6%	0.6%	2.5%	2.5%	3%	3%	3%	3%

Table 7: Industrial sub-sector growth assumptions, Tūī

TIMES-NZ 2.0 industrial sub-sector	2020	2025	2030	2035	2040	2045	2050	2055	2060
National economy growth stage	High growth			Transition		Low growth			
Other Food Processing	4%	4%	4%	2.5%	2.5%	1%	1%	1%	1%
Wood Product Manufacturing	4%	4%	4%	2.5%	2.5%	2.7%	2.7%	2.7%	2.7%
Metal product Manufacturing	4%	4%	4%	2.5%	2.5%	-1.2%	-1.2%	-1.2%	-1.2%
Petroleum/Chemical Product Manufacturing	4%	4%	4%	2.5%	2.5%	-10%	-10%	-10%	-10%
Mineral, Mining, Construction, Other	4%	4%	4%	2.5%	2.5%	0.6%	0.6%	0.6%	0.6%

Constraints

Constraints can be imposed on the model to avoid outputs inconsistent with the current policy context. As a 'least cost' model, TIMES can still choose carbon intensive fuels going into the future. In many subsectors this was deemed unrealistic with respect to their current operations. These are summarised below:

- The uptake of new coal boilers was constrained in all subsectors as many subsectors do not use coal currently, therefore it could be seen as unrealistic that they would use coal in the future. This constraint excludes the use of high temperature heat (>300 degrees) in non-metallic mineral processing and also the coal use as feedstock in Iron and Steel production.
- Wood product manufacturing and pulp and paper subsectors use by-products of wood as their fuel (e.g. sawdust, bark, black liquor). The cost of biomass supply was reduced in these subsectors to represent the cheaper cost of the by-products compared to conventional biomass. The availability of these by-products are constrained proportionately to the end use demand growth of the subsectors.
- The uptake of new natural gas technologies in the food processing and metals subsectors were constrained. Organisations in these markets are expected to be hesitant to build more natural gas boilers to meet demand from 2040 onwards as policy context will make building fossil fuel infrastructure increasingly difficult.

Other remarks

- There are not sufficient low emission alternatives for many technologies. An example of this is the diesel used by the mining sector. Mining requires a lot of machinery that consumes diesel but no electric/hydrogen alternatives have been defined as not enough techno-economic information is available. Advanced drop-in biofuel alternatives have been defined to the model but these are blended into the diesel supply and therefore not shown explicitly in the results.

9.4 Transport sector

The following transport subsectors were defined by types of energy service demand: Road Transport (including Light Road and Heavy Road), Aviation, Shipping and Rail. The Ministry of Transport's Vehicle Fleet Emissions Model (VFEM)[47] was the main source of information for this sector, which estimates vehicle types by numbers, fuel consumption and VKT through to 2055.

Light Road	Includes cars, sports utility vehicles (SUVs), motorcycles, and vans/utes.
Heavy Road	Includes medium trucks, heavy trucks, and buses.
Aviation	Includes domestic and international aviation.
Shipping	Includes domestic and international shipping.
Rail	Includes passenger rail and freight rail.

North Island/South Island split

The split of energy service demand between the North and South Islands was determined using the following criteria depending on the subsector:

- Road Transport: MoT Regional VKT data was used as the basis for calculating the North Island/South Island split.
- Aviation Domestic: MoT Arrival/Departures by Airport was used as a proxy for fuel consumption in absence of detailed trip length data.
- Aviation International: Stats NZ international arrival data and MoT International Arrivals/Departures data were used to estimate fuel consumed by airports.
- Rail Freight: the regional split was based on rail freight tonnages from MoT freight demand study report[48].
- Rail Passenger: Assumes all electricity is consumed in Auckland and Wellington. Diesel was split as per freight.

Technology parameters

Average vehicle life expectancies were taken from MoT's annual Vehicle Fleet Statistics.

The availability factor (AF) for the transport sector represents the amount of vehicle kilometres travelled for each technology. The AFs for existing and future technologies were calculated using projections for 2018 and 2050 (from MoT's VFEM).

Because liquid biofuels are typically blended with an existing fuel, there is no significant change to the underlying technology. Liquid biofuels are included in the model as a blending percentage with diesel.

Load curves

Load curves for EV's were implemented in TIMES to represent charging profiles for each TIMES time slice. In Tūī, it was assumed that all EV charging will stay the same as historic charging patterns (i.e. night charging for light vehicles). In Kea, it was assumed there will be a transition toward smart charging therefore the charging profile was assumed flat.

Costs

Light vehicle purchase and operating costs were obtained from EECA's Total Cost of Ownership Tool[49]. Based on the costs of a light petrol passenger ICE vehicle, capital and operating costs for other technology/fuel combinations were estimated.

For EVs we consider technology-specific capital and operating costs such as:

- Capital costs of chargers per vehicle, which are added to the vehicle purchase cost.
- Operating costs include an annuity to allow for the mid-life replacement of batteries.

Capital and operating costs of ICE, electric, and hydrogen trucks and buses are taken from a variety of reputable sources[50] including feedback form the BEC Assumptions Working Group with basis from BNEF, ICCT, and EPA.

Light electric vehicles were modelled explicitly based on battery cost projections from BNEF[51] and were assumed constant after 2030. The non-battery cost projections were used as variables (relative to costs projections of ICEs) in order to obtain certain years of parity for LPVs and LCVs. The years of parity for LPV EVs are 2025 for the Kea scenario and 2035 for the Tūī scenario.

Costs of ICEs, Hybrids and electric motorcycles were projected from the report: "A review of the efficiency and cost assumptions for road transport vehicles to 2050"[52].

Investment costs of Hydrogen LCVs, LPVs, Medium Trucks and Heavy Trucks were estimated in a similar sense to that of electric vehicles. The same relative base costs (non-battery/fuel cell costs) were used for hydrogen vehicles as were used for BEVs. Fuel cell and fuel tank costs were estimated for 2018 and projected to 2030 from feedback from the Assumptions Working Group with underlying sources from BNEF. Beyond 2030, the fuel cell costs were assumed from De Vita et al[53].

The investment cost of BEV chargers were estimated from EECA's Low Emission Contestable Fund, MoT's VFEM, and Greater Wellington Regional Counci[54]. Chargers were assumed to have the same cost for both Tūī and Kea, and not to change throughout time. Charger costs were included for EV LCVs, Medium Trucks, Heavy Trucks, and Busses. LPV charger costs were assumed to be negligible as these would likely be trickle feeders as most private EVs are charged overnight.

Where applicable, the fixed O&M costs were taken from the Existing Technologies. For the future technologies (not currently existing in today's fleet), the predominant source was the book "100% Renewable Energy Transition: Pathways and Implementation"[55].

Demand projections

All road transport demands were projected from the two VFEM scenarios from MoT. The VFEM scenario 'Golden Triangle' was used for Tūī data inputs and the 'Staying Close to the Action' was used for Kea data inputs. The selection of these two MoT scenarios enable the narrative that in the Kea scenario, people will generally travel less due to increased urban infrastructure such as cycleways etc (not modelled in TIMES). In Tūī, people will continue to increase their travel as population and GDP increases.

The VFEM demand projections were adjusted to reflect the difference in population assumptions between MoT's scenarios and the BEC2060 scenarios. The relative increases in billion VKT in 2018 from the adjusted VFEM results were applied to the actual 2018 historic demand.

The splits of available technologies between North Island and South Island were applied according to the existing technologies split for different modes of road transport.

Passenger rail demand projections were modelled from MoT's Updated Future State Model results as a proxy. The Golden Triangle scenario was used for Tūī and the Staying Close to the Action was used for Kea.

Freight rail demand projections were modelled from MoT's Freight Model as part of their updated future model results. The Golden Triangle scenario was used for Tūī and the Staying Close to the Action was used for Kea.

Domestic aviation energy demand projections were obtained by using MoT's Air Passenger Forecasts as a proxy. These forecasts provide projections to the year 2030 but were assumed in the TIMES-NZ model to be valid until 2060.

Efficiency improvements from IATA[56] were subtracted from the passenger demand projections to give fuel energy demand. The splits between North Island and South Island were applied according to the existing technologies split for aviation.

International aviation energy demand projections were obtained from MoT's Air Passenger International Forecasts as a driver. This was adjusted by energy efficiency improvements in planes from IATA. In Kea, there was an assumption applied that introduced the concept that less flights will occur due to behavioural change.

Domestic coastal shipping energy demand projections were obtained from MoT's Freight Model. The Golden Triangle scenario was used for Tūī and the Staying Close to the Action was used for Kea. As with rail freight, the model was re-run for the BEC2060 work with the BEC2060 population and GDP assumptions.

International shipping energy demand projections were estimated using Domestic GDP projections as a proxy.

Constraints

The import of new light EVs were constrained such that only a certain amount can be imported per year. The EV supply constraint was assumed as:

Table 8: Maximum proportion of BEV imports allowed in TIMES-NZ

Year	Tūī	Kea
2025	3%	11%
2030	11%	42%
2035	42%	100%
2040	100%	100%

9.5 Agriculture, Forestry and Fishing

The Agriculture, Forestry and Fishing is assessed up to the "farm gate", and it only accounts for energy use[57]. It has been split into the following subsectors:

Dairy Cattle Farming	Includes all dairy cattle and associated pasture required for feed.
Livestock Farming	Includes all other farmed animals (e.g. sheep, beef, deer, pigs, poultry etc.) and associated pasture/crops grown for feed.
Outdoor Horticulture	Includes all outdoor grown fruit, vegetables, and arable crops (excluding ones grown on livestock farms)
Indoor Cropping	All fruit, vegetables, flowers that are grown in both heated and unheated greenhouses.
Forestry	All forest operations from planting, silviculture to harvesting trees, extracting logs and chipping wood residues.
Fishing	Includes all commercial fishing and aquaculture.

As in all other sectors, the delivered energy in TIMES-NZ was reconciled with the MBIE Energy Balance Tables. The description of the subsectors in TIMES-NZ exhibit some key differences with respect to EECA's EEUD, which are the following:

- Irrigation
    a. Irrigation is considered in all outdoor agricultural subsectors in TIMES-NZ. The energy use for irrigation in dairy farming from the EEUD acted as a baseline reference in deriving irrigation energy use for the other subsectors.
    b. Irrigation application areas were obtained from Irrigation NZ[58] where the relative irrigation land use proportions for livestock farming and arable and outdoor horticulture in comparison to dairy farming were multiplied by the energy use from irrigation in dairy farming.
    c. This assumes that the irrigation intensity (energy use per hectare) is constant throughout all subsectors. We would expect this to be suitable for pastoral livestock production because the irrigation requirement is similar for dairy pastures; and also for arable and vegetable production as most irrigation systems, such as for cereal growing, have similar requirements to pasture.
- Splitting of non-dairy agriculture (from the EEUD) into livestock farming and outdoor horticulture and arable farms.
    a. The energy technologies outlined by the EEUD for non-dairy agriculture could be split into livestock farming and/or arable and outdoor horticulture depending on the technologies used in each subsector.
    b. An example is stationary engines, which would be expected in outdoor horticulture for use in frost protection and grain drying but not in livestock farming.

In addition to conventional technologies, many alternative decarbonisation technologies have been accounted for in the reference year of the model using proportions estimated from in-house expertise and extrapolation of estimates from Massey University[59]. In the optimisation process the model can identify further opportunities to deploy such energy efficient alternatives.

Diesel use was split into different types of off-road vehicles, such that the model can identify decarbonisation potentials in different subsectors. Such split of diesel fuel was produced from in-house expertise except for forestry which was estimated from the University of Canterbury[60].

Off-road vehicles, tractors and machinery were assumed to be decarbonised through the introduction of alternative fuels by using either renewable electricity or green hydrogen. Both these options are available in TIMES-NZ.

Electrification of agricultural machinery can be difficult due to the requirement for exchangeable battery packs to allow for the versatility needed in tractors with regard to charging times. This is less of an issue with fuel cells.

Space heating is required predominantly for indoor cropping in heated greenhouses. Heat for grain drying is included in arable farming/outdoor horticulture. The following technologies are allowed for selection in TIMES-NZ:

- Coal boiler
- Natural gas boiler
- Wood pellet boiler
- Electric heat pump (Air to water)
- Hydrogen boiler

Electric motors and vacuum pumps have been included in the model with and without variable speed drive (VSD). VSDs allow for greater efficiency but at increased capital cost.

Both biodiesel and drop-in diesel are allowed to be selected in TIMES-NZ for all diesel consuming technologies within the agricultural technologies.

North Island/South Island split

The island splits for irrigation were all derived from irrigated areas according to Irrigation NZ[61].

All other non-irrigation energy demands for Dairy Farming, Livestock Farming, Outdoor Horticulture, and Forestry island splits were derived from land areas according to Stats NZ Infoshare portal[62].

The island split for indoor cropping was identified from the PHINZ programme by MBIE and EECA[63]. This was manipulated by fuel type using a weighted average to reflect the fact that natural gas and geothermal fuels are only available in the North Island.

The island split for Fishing was derived using the economic contribution by fishing region from Seafood NZ[64].

Technology parameters

The efficiency of batteries was assumed to be 0.8. The battery size for agricultural machinery was determined by dividing the maximum energy requirement (kWh) per machine per day by the number of battery packs per machine.

Efficiency and lifetime data for space heating options were predominantly derived from the University of Waikato work on identifying decarbonisation options for process heat[65]. These figures were adjusted for the fact that indoor cropping only needs hot water for heat rather than steam.

Irrigation has identical parameter inputs assumed whether for dairy farming, livestock farming, arable and market garden horticulture. This is based on the simplification that all irrigation types are similar.

As large-scale fishing vessels have multiple energy end uses (e.g. for winching, propulsion, refrigeration, electronics), as well as an often long voyage length, the decarbonisation opportunities presented to the model are limited to a comparison between a diesel engine and a diesel hybrid engine.

All subsectors have a lighting energy use component. Albeit a relatively small energy demand, LEDs are still considered as an alternative low-energy technology.

Water heating in dairy sheds is split by two technologies: hot water cylinders and heat recovery with air to water heat pumps. Techno-economic data for both of these technologies was established from Massey University and available market data.

Costs

The assumptions for electric or hydrogen fuelled trucks (<10 tonnes), utes, and farm quads and bikes were all derived from the transport sector assumptions. Electric or hydrogen tractors, ground-based forestry equipment, and cable based forestry equipment were derived differently as they operate differently to trucks.

A productivity penalty was applied to tractors and harvesters based on their net weight and how much the additional weight of a battery may affect the overall power of the machine. Hydrogen powered machines do not have a productivity penalty as their mass is comparable to an ICE.

The charger cost for recharging an electric vehicle is assumed to be $1000/kW[66].

The hydrogen fuelling station cost was supplied by the World Energy Council originally derived from the IEA[67].

Battery costs were derived from BNEF until 2030 then are assumed constant, since battery costs are highly uncertain long term with respect to the amount of lithium and cobalt available and therefore new chemistries may emerge. Also as BEVs become cost competitive with ICEs there may be less interest in improving the technology as new technologies may emerge. We note that battery cost assumptions will need to be frequently reviewed.

The fuel cell costs were provided from a member of the Assumptions Working Group with the original source also being BNEF.

The additional non-battery/non-fuel cell system costs have been estimated from EECA's internal data for an electric tractor. This cost was altered to be reflected as a cost per unit power and is decreased by an annual percentage per year which were formed from the reduction in non-battery costs for medium and heavy trucks from the transport sector development.

Because the non-battery costs are reflective of the global economies of scale for a specific technology, agricultural tractors and machinery would not realise these cost reductions until sufficient demand exists.

Costs data for space heating options were predominantly derived from the University of Waikato work on identifying decarbonisation options for process heat.

Demand projections

The end use energy demand for each timestep (2018, 2020, 2025…) was calculated by multiplying the energy end use demand for 2018 by the proportion for land use and energy productivity for every timestep relative to 2018.

$$\text{Demand}_{\text{year}} = \text{Demand}_{2018} \times \frac{\text{Land Use}_{\text{year}}}{\text{Land Use}_{2018}} \times (1 - \text{CAGR})^{(\text{year - 2018})}$$

where CAGR is the Compound Annual Growth Rate. The CAGR for energy productivities were assumed to be 0.25%/year improvement in Tūī and 0.5%/year in Kea for most technologies.

The land use projections were obtained from MPI for livestock farming, dairy farming, outdoor horticulture/arable farming, and forestry.

Indoor cropping is driven by the TIMES-NZ population projections.

Fishing demand for energy is assumed to be constant throughout time.

The end uses that have a greater improvement in energy productivity are space heating in indoor greenhouse cropping, off-road vehicle use, and irrigation. These have energy productivity improvements assumptions of up to 1.5%/year due to the potential introduction of technologies such as Artificial Intelligence which can reduce energy consumption.

Constraints

Off road electric vehicles were constrained in TIMES for 2020 and 2025 due to supply limitations. This covers the fact that there are limited amounts of electric utility vehicles (utes) available on the market, so having them enter the solution was implausible for the near-term.

Load curves were applied for dairy sheds, heated greenhouses, off road vehicles, and irrigation systems helping encompass seasonal farming and climatic trends. Dairy shed and heated greenhouse load curves were obtained from EECA's internal data. Off road vehicle load curves were estimated by assuming charging would avoid peak periods. Irrigation load curves were estimated from the University of Otago[68] and are heavily weighted toward dryer seasons. Because irrigation use is dependent on climatic conditions, irrigation was only modelled on a seasonal level.

Other remarks

Aquaculture is growing very quickly in New Zealand but its energy use appears to be dwarfed by the whole fishing industry therefore its growth was considered negligible in terms of energy use. However, this may be revisited at a later date.

It is recognised that irrigation cannot be encompassed by one set of techno-economic data due the variety of schemes and the specificity of those schemes to the purpose e.g. drip irrigation for viticulture. The fairly coarse grouping of many agriculture subsectors in TIMES misses several of these specific opportunities. With greater data availability, these may be revisited in a future update.

Arable farming was grouped with outdoor horticulture due to a lack of specific data availability and to show the general trend of food production, for which meat, dairy, and other food have different outlooks. It is recognised that horticultural operations such as vineyards have different energy use requirements and intensities to arable farms.

Tractors in TIMES-NZ reflect a portion of energy use for the end use: 'Motive Power. Mobile' in the EEUD, thus the label tractor also includes other agricultural machinery on farms such as harvesters.

Hydrogen for use in ICE vehicles/machinery have not yet been considered in TIMES-NZ.

CHAPTER 10

New Zealand Energy Scenarios TIMES-NZ 2.0 app

10.1 New Zealand Energy Scenarios TIMES-NZ 2.0 app

TIMES-NZ 2.0 represents a comprehensive model of NZ's energy system, with two contrasting future scenarios in the form of Kea and Tūī. This guide has explained the model development, and provided key insights from the scenarios, and the Project Team are proud to release the New Zealand Energy Scenarios TIMES-NZ 2.0 results to the community as an R Shiny app: www.eeca.govt.nz/times-nz

The New Zealand Energy Scenarios TIMES-NZ 2.0 results are provided in the app in order to make it accessible to researchers and communities as well as enabling researchers and communities to develop their own insights. This allows users to 'drill down' through sectors, fuels, technologies, and energy end uses, and to output a wide range of data from the scenarios. A short introduction to the tool is included in Section 10.2 of this document.

We now invite the community to explore the model outputs, and collaborate in transitioning New Zealand to a low-carbon future.

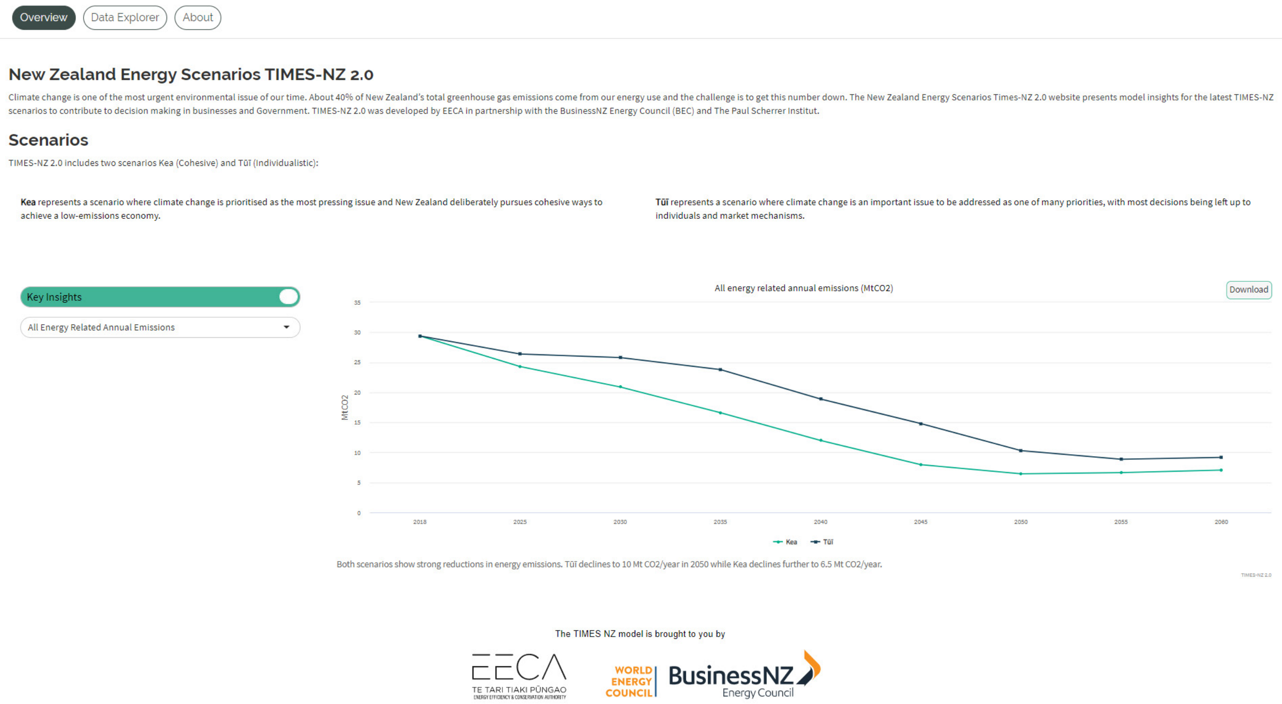


Figure 26: New Zealand Energy Scenarios – TIMES-NZ 2.0 app

10.2 New Zealand Energy Scenarios TIMES-NZ 2.0 User Guide

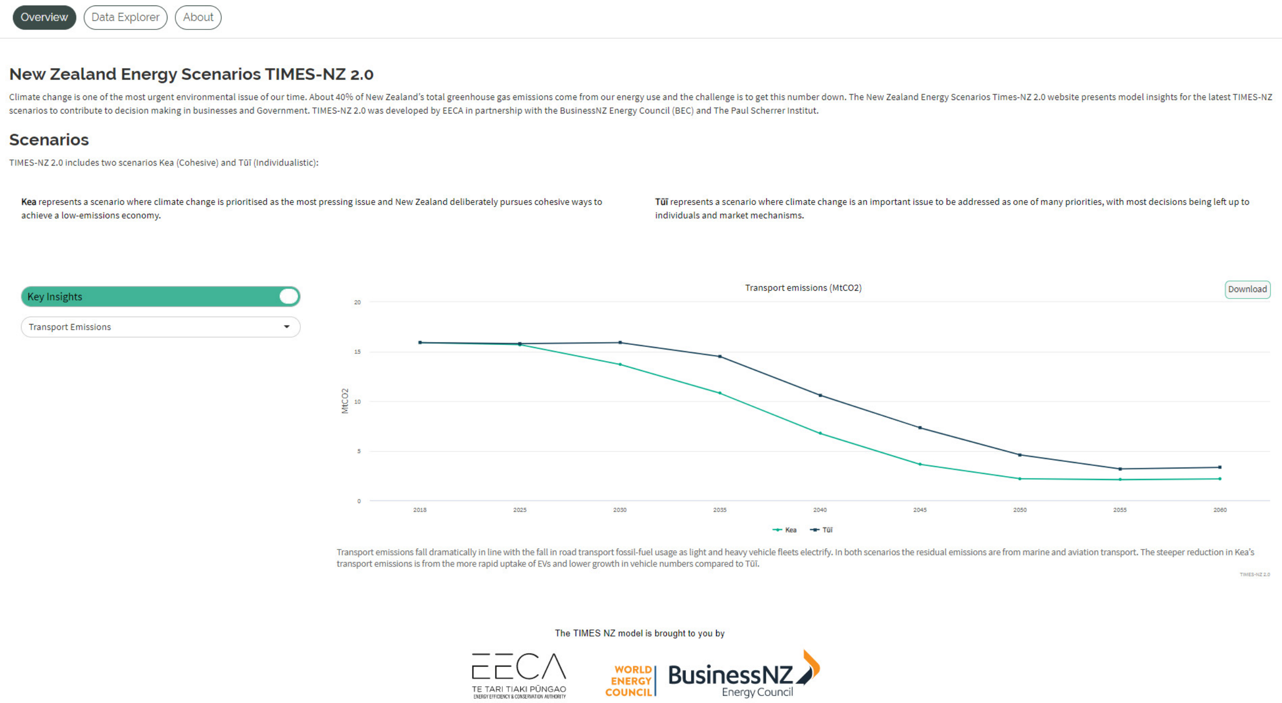
TIMES-NZ App

The TIMES-NZ app allows users to interact with the model outputs, so they can dig deeper into any areas of interest across each sector.

The Overview provides an outline of the key insights and assumptions used in both the Kea and Tui scenarios.

The Data Explorer allows drill down by subsector, technology and end use, generating interactive graphs to display key data such as emissions, fuel consumption and installed technology capacity.

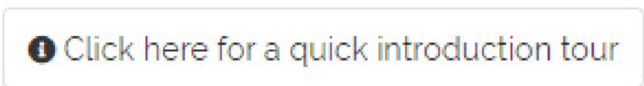
The About page provides an overview of the model and the scenarios used.



In-app guide

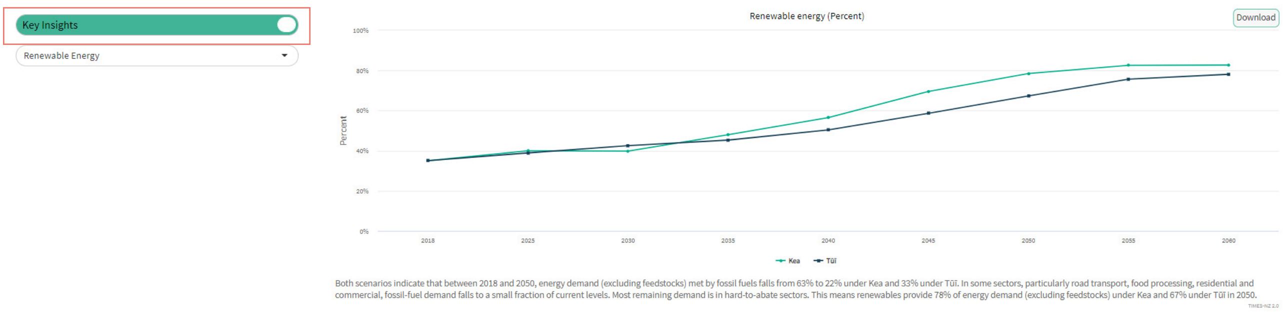
For a quick guide, there is an interactive introduction tour to the tool available on the About page of the app. The pages of the tool can be navigated between using the buttons in the top left.

See this button for the quick introduction tour



Overview

On the Overview page, users can find information on both our key insights and assumptions. Use the toggle on your left to switch between the two.

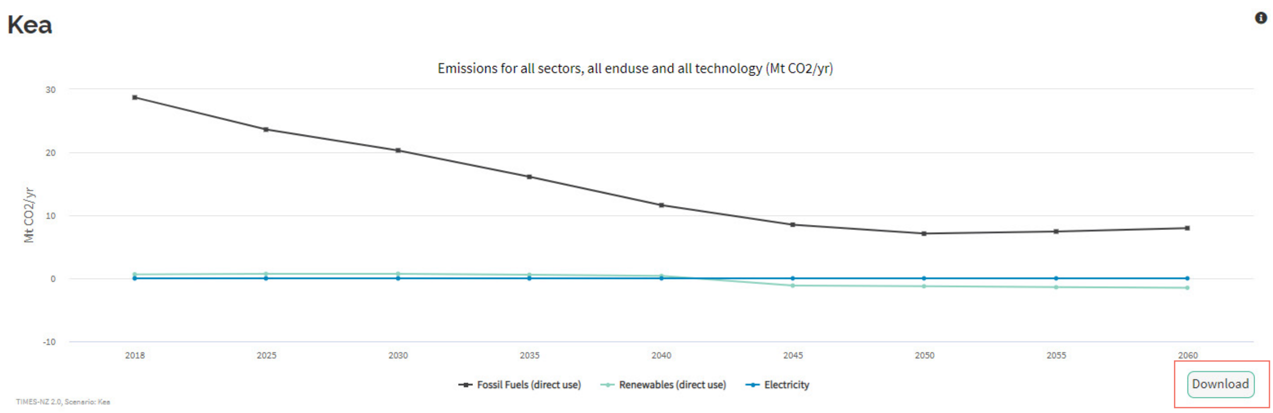


Key insights: these are some of the bigger picture findings from New Zealand Energy Scenarios TIMES-NZ 2.0, such as total energy emissions and renewable electricity percentage, compared between the Kea and Tūī scenarios. Use the drop-down box to choose the insight you are interested in.

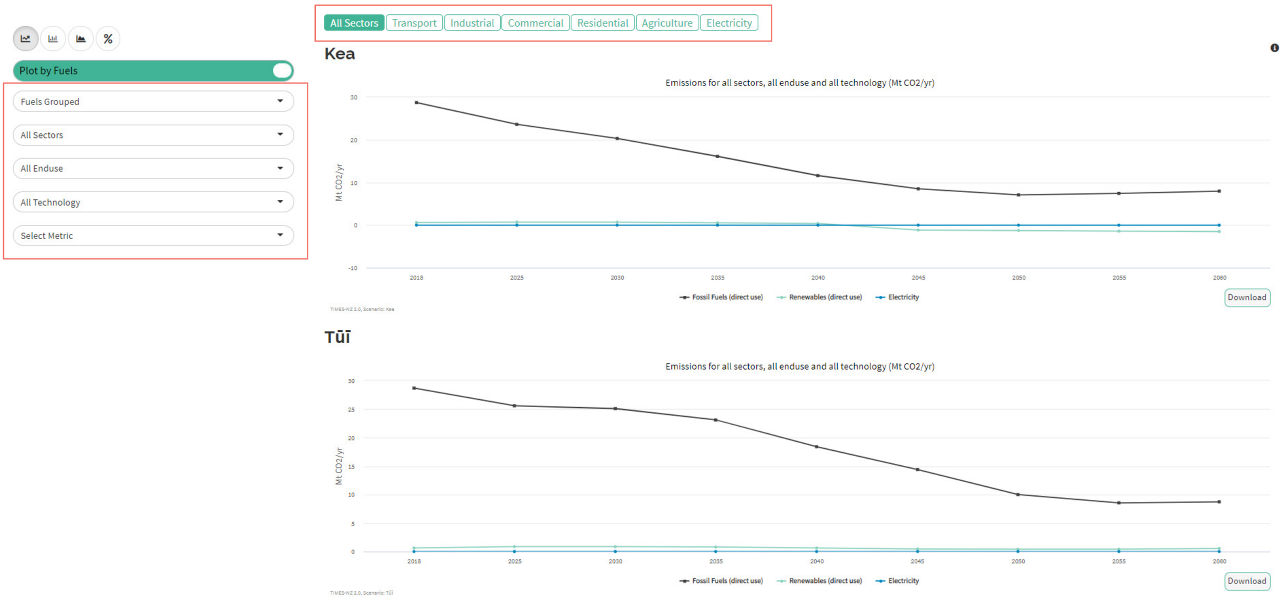
Assumptions: to run the scenarios out to 2060, some assumptions were needed, such as population and GDP growth, electric vehicle costs, and carbon price. These vary between Kea and Tūī, to represent the different approaches of each scenario to tackling climate change. Using the drop-down box will allow users to select the assumptions to be displayed.

Data Explorer

The Data Explorer page allows users to look deeper into the results of TIMES-NZ 2.0, drilling down into categories such as sub-sectors, technologies, and end-uses. All selections on this page will generate graphs for both Kea and Tūī. Using the download button below each graph, the graph can be downloaded as a .PNG or .PDF file. The data for each graph can be download as a .CSV file.



To generate the desired graph, we have two key areas – the sectors above the graphs, and the drop-down boxes to their left.



The sectors used in New Zealand Energy Scenarios TIMES-NZ are:

- Transport
- Industrial
- Commercial
- Residential
- Agriculture, Forestry and Fishing
- Electricity Generation.

By choosing one of these sectors at the top of the page, the graphs will automatically recalculate based upon the selection.

The two key metrics to be displayed in the data explorer are Fuels and Technologies.

Fuels:

These are the energy carriers used to power everything in the model, such as electricity, coal, and oil. When 'Fuels Grouped' is selected, these are grouped into the categories of:

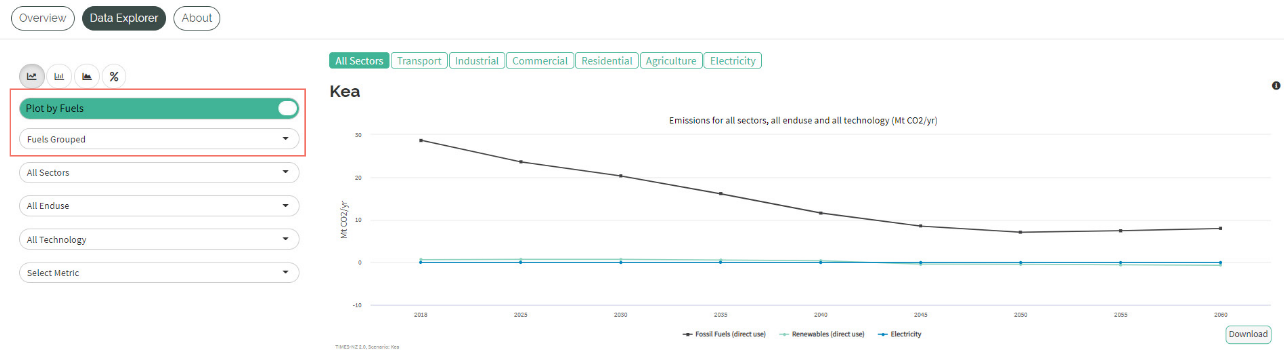
Fossil Fuels (direct use) – such as coal, oil, and natural gas

Electricity – electricity sourced from the grid (this also includes 'green hydrogen')

Renewables (Direct Use) – fuels such as biomass and geothermal.

When 'Fuels Separated' is selected, each individual fuel will be displayed.

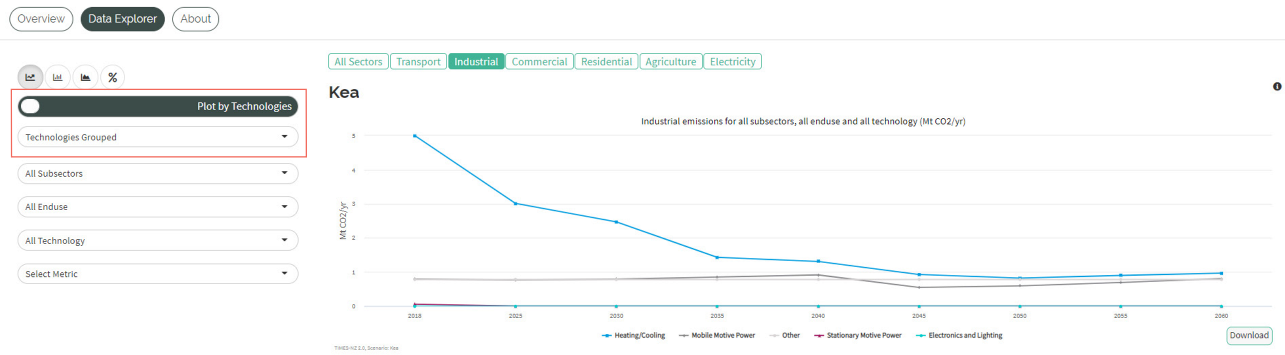
Use the toggle and first dropdown in the Data Explorer to view Fuels grouped or separated.



Technologies:

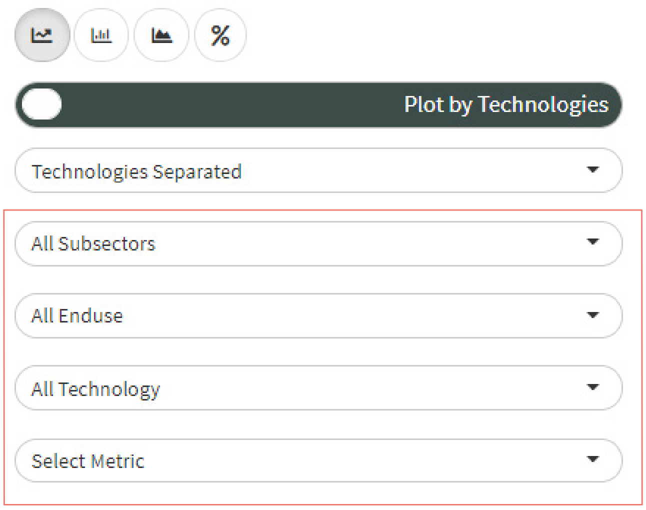
Like fuels, technologies can be displayed as either grouped or separated. When grouped, they will be displayed as the end use they are providing – such as Heating/Cooling, Electronics and Lighting, or Mobile Motive Power. When separated, they will be displayed as the individual technology – such as boilers, heat pumps and resistance heaters.

Use the toggle and first dropdown in the Data Explorer to view Technologies grouped or separated.



Drop-downs:

The four drop-down boxes highlighted below allow for further analysis of the TIMES-NZ 2.0 results.



Subsectors:

Each of the sectors mentioned previously can be split into further subsectors. For example, the Commercial Sector consists of Education, Healthcare, Office Blocks, Warehouses/Supermarkets/Retail, and Other Commercial. Further detail on these breakdowns for each sector can be found in the full TIMES-NZ documentation.

End use:

This shows what the energy is being used for such as space heating, stationary motors, or lighting.

Technology:

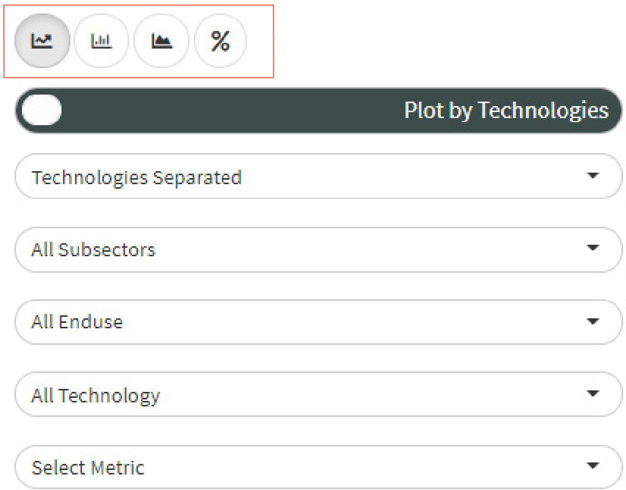
The technology being used to satisfy this end use demand. For example, lighting can be broken down into the amount provided by incandescent, fluorescent or LED bulbs.

Metric:

This changes what is displayed on the graph, which by default is emissions. Other common metrics are fuel consumption, and demand. There are some sector specific metrics, such as number of vehicles in Transport, and feedstock use in Industrial.

Graph type:

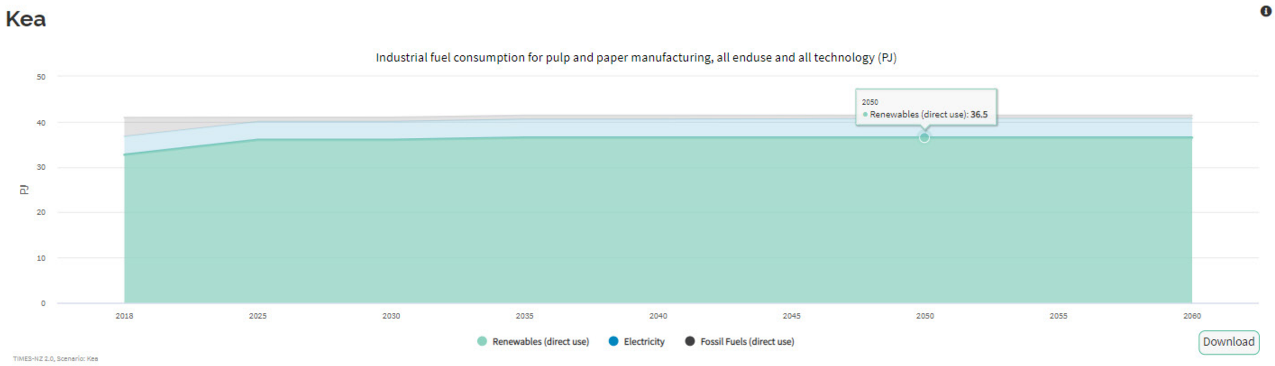
By selecting one of the four icons highlighted below, the type of graph displayed can be changed.



The four options are:

- Line chart
- Column chart
- Area chart
- Column percent chart.

These can be changed at any time, without resetting the previous selections. All graphs are interactive, so hovering over a point will show the user the value being displayed.



By clicking on an individual category in the legend below each graph, they can be removed from being displayed.

About

This page gives a more detailed description of the TIMES-NZ 2.0 model, the Kea and Tūī scenarios used for this modelling, as well as the detailed documentation covering input assumptions and underlying information. An introduction tour is also available which will highlight many of the key areas for navigating the tool.

CHAPTER 11

Appendices

Appendix 1: Main data sources

Table 9: Main data sources

Dataset	Source	Content
Energy balance calendar year 2018	"Energy in New Zealand 2019", MBIE	National energy supply and demand by fuel type
Energy end use	EECA's EEUD	National energy consumption broken down by fuel type, sector, end use and technology
ETSAP energy technology data	IEA-ETSAP	Sets of data on energy demand and supply technologies
Population estimates and projections	Stats NZ	Estimates and projections of natural population increase and migration
Regional gross domestic product	Stats NZ	Primary industries' share of GDP
Fuel prices trends	IEA	Fuel cost projections
Green Hydrogen production data	"Future of Hydrogen", IEA "Hydrogen Supply Chain Evidence Base", Element Energy "Blending Hydrogen into Natural Gas Pipelines", NREL	Techno-economic data for electrolysers and blended pipelines
Blue Hydrogen production data	"Techno-economic Evaluation of Deploying CCS in SMR Based Merchant H2 Production with NG as feedstock and fuel" Collodi et al., 2017	Techno-economic data for SMR without and with CCS
Biomass processing technologies	SCION	Techno-economic parameters for biomass processing technologies
Blue Hydrogen production data	"Techno-economic Evaluation of Deploying CCS in SMR Based Merchant H2 Production with NG as feedstock and fuel" Collodi et al., 2017	Techno-economic data for SMR without and with CCS
Biomass processing technologies	SCION	Techno-economic parameters for biomass processing technologies
Existing technologies electricity generation	"Wholesale Datasets – Generation Fleet", EA	Capacities of existing power plants
Renewable energy potentials	"New Zealand Generation Stack Updates", MBIE	Potentials for renewable energy sources
Irradiation data	Solarview, NIWA	Estimation of solar energy that can be collected by solar capture devices
Future technologies electricity generation	"The Generation Expansion Model" (GEM), MBIE	Possible capacity expansion pathways in the New Zealand electricity sector

Table 9: (continued)

Dataset	Source	Content
Wind power costs	"Wind Generation Stack", MBIE	Estimated costs and capacity factors for onshore and offshore wind power
NREL's electricity technologies data	NREL ATB	Techno-economic data electricity generation technologies
Techno-economic data utility-scale solar	"Economics of Utility-Scale Solar in Aotearoa New Zealand", MBIE	Capacities, capital cost and projections for utility scale and distributed solar generation
Solar resource profiles	NREL's PVWatts calculator	Solar resource profiles by region and time slice
Geothermal techno-economic data	"Future Geothermal Generation Stack", MBIE	Geothermal capacity potentials, costs, and emissions
Hydro techno-economic data	MBIE EDGS model "Embedded Hydro Generation Opportunities in New Zealand", MBIE "Hydro Generation Stack Update for Large-Scale Plants". MBIE	Hydro capacity potentials, costs, and emissions
Battery costs	"Lazards Levelized Cost of Storage Analysis – Version 5.0", Lazard "Installed Cost Benchmarks and Deployment Barriers for Residential Solar Photovoltaics with Energy Storage: Q1 2016", NREL "Energy Storage Technology and Cost Characterization Report" Mongrid et al.	Costs of balance of plant and battery installation
Energy use in New Zealand households	"Energy Use in New Zealand Households", Final Report on the Household Energy End-use Project (HEEP)	Technological parameters residential sector
Housing stock	CoreLogic dataset, with analysis from HUD	Number of detached and joined dwellings in each climate region, grouped by floor area
Census 2018	Stats NZ	Population totals in each TLA Main sources of space heating in each TLA, by dwelling type
Auckland energy consumption	"Towards customer-centric energy utilities - A granular data-driven bottom-up approach to understanding energy customer trends", Heinen et al., 2020	Mean metered annual energy consumption in Auckland for "electricity only" and "electricity + NGA" customers (Vector)
Regional electricity consumption	EA	Annual consumption of electricity in each regional council
Climate data	NIWA	Heating Degree Days (calculated)

Table 9: (continued)

Dataset	Source	Content
Dwelling types in new consents	"National Construction Pipeline Report 2020", MBIE	Proportion of detached and joined dwellings in new consents
Process heat in New Zealand	The University of Waikato (UoW) work for the EECA/MBIE	Technical and cost data for a range of alternative process heat technologies
Subsectoral GDP	NZIER	Contribution from the dairy sector to New Zealand's total GDP
Vehicle fleet data	"Vehicle Fleet Emissions Model" (VFEM), MoT	Vehicle types by numbers, fuel consumption and VKT projections through to 2055
Aviation data	MoT Stats NZ	Heating Degree Days (calculated)
Rail freight data	"National Freight Demand Study 2017/2018", MoT	Rail freight regional split
Vehicle fleet technological data	"Vehicle Fleet Statistics", MoT	Vehicle lifetimes expectancies
Transport investment costs	EECA's Total Cost of Ownership Tool	Light vehicle purchase and operating costs
Battery cost	BNEF	Battery costs and cost projections
Vehicle costs projections	"A review of the efficiency and cost assumptions for road transport vehicles to 2050", AEA Technology	ICEs, hybrids and electric motorcycles cost projections
Irrigation data	"2015 New Zealand Irrigation Industry Snapshot", Irrigation NZ	Irrigated Land Use by Region

Appendix 2: Electricity generation

Table 10: Capacities from existing power plants

Generation Technology	North Island Capacity (MW)	South Island Capacity (MW)
Natural Gas Open Cycle Turbine	453	0
Natural Gas Combined Cycle Turbine	788	0
Coal Generation	500	0
Diesel Generation	155	0
Wind Generation (into HV network)	577	78
Wind Generation (into MV network)	0	36
Geothermal Generation	1016	0
Hydro Generation – Dam	1547	3387
Hydro Generation – Flexible Run of River	206	125
Hydro Generation – Inflexible Run of River	206	49
Solar Generation	118	58
Biogas	35	0

Table 11: Capacity constraints for new electricity technologies (GW)

Resource	Tranche	2020	2030	2040	2050	2060
Solar	Utility-scale	0.6	8.1	9.7	9.8	9.9
Solar	Distributed-scale	0.3	1.7	1.7	1.7	1.7
Solar	Commercial Rooftop	0.3	3.3	5	6.8	6.8
Solar	Residential Rooftop	0.6	1.9	3.6	5.4	5.4
Wind	Consented	2.3	2.3	2.3	2.3	2.3
Wind	High Capacity Factor	4.4	4.4	4.4	4.4	4.4
Wind	Low Capacity Factor	4.1	4.1	4.1	4.1	4.1
Wind	Distributed/Locally Embedded	0.5	0.5	0.5	0.5	0.5
Wind	Offshore - Fixed	7.0	7.0	7.0	7.0	7.0
Geothermal	Consented Binary	0.0	0.3	0.7	0.8	0.8
Geothermal	Non-Consented Binary	0.1	0.1	0.1	0.1	0.1
Geothermal	Large Consented Flash	0.1	0.3	0.3	0.3	0.3
Geothermal	Small Flash	0.0	0.3	0.6	0.6	0.6
Geothermal	Maximum Geothermal	0.2	0.6	1.0	1.0	1.0
Hydro	Dam	1.0	1.0	1.0	1.0	1.0
Hydro	Large Run-of-River	0.7	0.7	0.7	0.7	0.7
Hydro	Small Run-of-River	0.2	0.2	0.2	0.2	0.2
Pumped Hydro	Large - Lake Onslow	1.3	1.3	1.3	1.3	1.3
Pumped Hydro	Small Schemes	0.9	0.9	0.9	0.9	0.9

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