

Waikato Regional Energy Scenarios

December 2025

The logo for 'concept' features a stylized bar chart with five vertical bars of increasing height from left to right, positioned above the word 'concept' in a white, lowercase, sans-serif font.

concept



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Contents

1	Purpose	4	A.1	End-use categories	28
2	Scope	4	A.2	Energy sources	28
3	Scenario Development.....	5	A.2.1	Electricity.....	28
3.1	Business As Usual.....	5	A.2.2	Liquid fuels.....	29
3.2	Static Scenario	6	A.2.3	Gas	30
3.3	Dynamic Scenario	7	A.2.4	Coal	30
4	Modelling approach.....	10	A.2.5	Biomass	31
5	Modelled Outcomes	10	A.2.6	Geothermal direct heat.....	31
5.1	Energy demand by fuel.....	11	A.3	GHG Emissions	31
5.2	Energy demand by sector.....	12	Appendix B.	CGE Data and Methods	32
5.3	Prices	13	A.4	Production.....	33
5.3.1	Carbon price.....	13	A.5	Consumption.....	34
5.3.2	Electricity prices.....	14	A.6	Sectoral representation	34
5.3.3	Reticulated gas.....	14	A.7	Dynamic process.....	36
5.4	Transport.....	15	A.8	Closure	36
5.5	Greenhouse Gas Emissions	17	A.9	GHG markets	37
5.6	Summary of energy flows	19	A.10	Advanced and emergent industries	37
6	CGE results	24	A.11	References.....	39
6.1	Impacts on regional GDP for both the Waikato and rest of NZ	24			
6.2	Household consumption and income through wages.....	25			
6.3	Vulnerability to sudden oil price hikes	25			
7	Conclusion	27			
Appendix A.	Regionalisation process and data sources.....	28			

1 Purpose

The purpose of this report is to provide a robust, evidence-based foundation to inform the development of the Waikato Regional Energy Strategy. The report presents a set of forward-looking energy and emissions scenarios for the Waikato region, designed to improve understanding of how different policy settings, market conditions, and technology pathways could shape the region's energy system over time.

This report explains why particular modelling approaches were used, how national and regional data were combined, and how internal consistency across energy, emissions, and economic dimensions was maintained. It also highlights key insights that help orient readers to the scale and direction of change implied by the scenarios.

The report also includes results from a computable general equilibrium (CGE) analysis, used to assess the broader macroeconomic implications of changes in regional energy production and use. Large-scale shifts in energy supply, prices, and technologies influence production costs, household expenditure, investment, labour demand, and trade across the economy. These interactions cannot be captured through partial or sector-specific analysis alone. The CGE framework provides a coherent way to trace how energy system changes propagate through the Waikato economy and interact with the rest of New Zealand, ensuring that scenario insights reflect economy-wide adjustment rather than only direct energy-sector effects.

2 Scope

The scope of this report covers the methodological framework used to develop a set of energy and emissions scenarios for the Waikato region over the period 2026 to 2050, and the presentation of selected illustrative insights derived from those scenarios.

The scope includes:

- Description of the business-as-usual scenario and two alternative scenarios, including the assumptions, boundaries, and consistency across population, economic growth, and policy settings.
- Documentation of the energy system modelling approach used to project regional energy supply, energy demand, energy transformations, and associated greenhouse gas emissions.
- Description of the data sources and regionalisation methods used to translate national projections and datasets to the Waikato context.

This report includes a summary of the computable general equilibrium (CGE) analysis undertaken by Market Economics. This includes:

- The CGE model structure and its multi-regional, recursive dynamic characteristics.
- How selected energy scenario outputs were incorporated into the CGE framework.
- The types of macroeconomic and sectoral indicators produced by the CGE analysis, including GDP, employment, prices, investment, consumption, trade, household income, and welfare measures.

The scope does not include comprehensive presentation of all quantitative results, detailed policy evaluation, or project-level assessment. Detailed scenario outputs and numerical results are provided in an accompanying Excel workbook and interactive Sankey diagram.

3 Scenario Development

To explore how the Waikato region's energy system could evolve under different futures, three scenarios were developed. The scenarios are not forecasts. Instead, they are structured representations of plausible pathways that reflect contrasting policy settings, market responses, and societal priorities. Each scenario is internally consistent and is applied using the same underlying population and economic projections, allowing differences in outcomes to be attributed to assumptions about energy policy, technology uptake, and investment behaviour rather than to external drivers.

Overall, the scenarios span a range of transition speeds and strategic approaches, from a continuation of market-led change, through a pathway dominated by short-term energy security concerns, to a co-ordinated and proactive transition. This framing enables comparison of energy, emissions, and economic outcomes under different decision-making environments.

The policy and economic environment will continue to evolve over time, and the realised pathway may combine elements from more than one scenario. Taken together, however, the three scenarios are intended to span the range of plausible futures.

3.1 Business As Usual

The BAU scenario represents a continuation of current policy settings and government projections, and serves as a reference pathway against which alternative futures are compared. It reflects existing legislation, confirmed policy commitments, and central projections for key drivers of energy demand and supply.

The ETS price follows the Government's most recent projections trajectory¹, rising through to 2030 due to short-term projected unit supply constraints. After 2030, the price is projected to gradually fall due to increased supply from forests planted in recent years.

Technology uptake and fuel switching are largely market-driven, responding to relative cost changes arising from higher gas prices and continued improvements in the cost and efficiency of electric alternatives.

Electricity demand and new generation build follow central projections, with investment in renewable electricity occurring in response to observed market signals rather than in anticipation of future demand. Moderate consenting costs and delays cause renewable build to be slower than optimal.

Domestic gas supply is assumed to continue declining due to ageing fields and limited successful new development². This tightening supply places upward pressure on gas prices. Under BAU conditions, gas continues to play an important role as a flexible backstop for electricity supply and as a fuel for existing industrial users, but with steadily declining demand over time. Industrial demand continues to fall through a combination of fuel switching, curtailment, and exit by less profitable gas-intensive users.

Transport demand and activity are based on Ministry of Transport projections, with electric vehicle uptake proceeding at projected rates. There is no significant change to travel behaviour or mode shift.

Aside from the ETS, a significant non-market intervention in this scenario is the Industrial Heat National Environmental Standard, which requires existing coal-fired boilers to be phased out by 2037. Outside this requirement, the energy transition proceeds gradually.

¹ <https://environment.govt.nz/assets/publications/climate-change/Annual-updates-to-NZ-ETS-limits-and-price-control-settings-for-units-2025-technical-annex-to-the-consultation-document.pdf>

² <https://www.bcg.com/publications/2025/energy-to-grow-securing-new-zealands-future>

The policy and economic environment is constantly evolving so the actual trajectory may end up being a mix of features from the other two scenarios. However, we believe that the 3 scenarios together encompass likely futures.

3.2 Static Scenario

In this scenario, short- and medium-term concerns about energy security and energy affordability – driven by recent “dry years” for hydro power generation and disappointing domestic gas production output – result in the sustainability limb of the energy trilemma being significantly sidelined.

The government’s energy policies focus on shoring up the security of fossil fuel supplies (replacing “like for like”) – e.g., gas for power generation in dry years and industrial heat, coal for power generation in dry years.

Diversification away from fossil fuels for the long term through investment in renewable electricity and fuel switching is deprioritised. Policy activities remain highly reactive and a national energy strategy (that might have outlined a nationwide renewable energy target) is not finalised.

The government underwrites investment in an LNG import terminal and domestic gas exploration onshore and offshore. Coal mining in both the Waikato region and other parts of New Zealand expands due to the renewed focus on energy security and affordability. Coal demand is also boosted by the reversal of the National Environmental Standards to ban new coal boilers and phase out existing boilers. Increased confidence in gas and coal supplies means that the Huntly power station and gas generators continue to operate to 2050.

The renewed focus on fossil fuel investment – entailing long lead projects like LNG imports and expanded gas exploration underwritten by the government – deters both domestic and foreign investors in renewable power generation. The lack of a national energy strategy target for renewables is also a contributing factor.

In the long run, New Zealand’s energy prices fail to benefit from renewable power cost declines compared to overseas peer nations. This is due to the costs associated with investment in LNG (and associated volatility in global LNG prices), investment in domestic fossil fuels and associated long lead times. The opportunity to access cheaper energy through greater investment in renewables and electrification is missed compared to the other scenarios.

The ETS remains the primary policy lever through which decarbonisation is encouraged by placing a price on carbon emissions. However, the carbon price is kept low due to unconstrained forestry supply and measures that undermine the integrity of and participant confidence in the ETS (e.g., high industrial allocation). International climate obligations are met more through the purchase of overseas emissions units rather than domestic abatement than in other scenarios.

Decarbonisation incentives to complement the ETS are not pursued, as are initiatives to regulate, encourage and educate in relation to energy efficiency, conservation and decarbonisation. The prospect of increased coal and gas supplies also deters end users (e.g., for process heat and/or space heating) from investing in more efficient lower carbon technologies such as heat pumps, locking them into less efficient processes and higher lifetime total costs of ownership. Energy efficiency in newly constructed homes and buildings does not keep up with international best practices either.

Transport policy and the transport system largely remains heavily dependent road transport. Investment in public transport, rail and active transit initiatives is not prioritised ahead of roading. Government policies towards electric vehicles are ambivalent, resulting in global vehicle manufacturers considering New Zealand to be a lower priority in a world where EVs are in relatively high demand. EV uptake is further discouraged in New Zealand through relaxed vehicle emissions standards and consumers favouring the beguilingly low upfront cost of used internal combustion engine vehicles that are increasingly unwelcome in other markets.

New Zealand lags other countries on climate change action and environmental sustainability in general. Exports suffer as a consequence – demand for dairy declines as both consumers and large brands perceive New Zealand milk as not sufficiently aligned with sustainability benchmarks.

Despite the availability of LNG and some new domestic gas fields, Methanex exits New Zealand due to the high costs of such gas. The aluminium smelter at Tiwai remains open, backed by legacy hydro power. New Zealand misses out on opportunities to diversify and expand its industrial base – e.g., data centres seeking large quantities of affordable renewable power are deterred by high wholesale power prices and a relatively slow cadence to renewable generation investment.

Communities are less resilient and energy independent due to poorer uptake of rooftop and agri-solar. This occurs due to less support from lenders, electricity suppliers (e.g., buyback rates) and electricity distributors (e.g., lack of streamlined connection processes.)

3.3 Dynamic Scenario

In this pathway, society envisages decarbonisation and the path to net zero carbon as a major imperative. Governments and citizens alike also view the journey as a long-term investment in more affordable, sustainable and secure energy supply. Climate policy is thus proactive, bipartisan and takes a long-term view.

Market signals (through the ETS), technological advancements and consumer preferences set the pace of the energy transition in tandem with complementary measures. ETS auction price corridors provide durable signals to invest in decarbonisation, backed by regulatory settings that encourage emissions reductions at the source over afforestation or international carbon units.

Key drivers of emissions reductions include:

- Investment in renewable power is large (from 38 TWh in 2025 to 96 TWh in 2050) and anticipatory of demand growth, backed by supportive consenting processes and a willingness from central government to promote revenue stability to large investors, including new entrants.
- Biomass is used at scale for power generation at Huntly, and industrial heat users switch to biomass to fuel their boilers.
- Small scale renewable energy development is supported by local and central government via incentives leading to strong growth in rooftop solar, agri-solar and community solar projects.
- Declining domestic gas production due to fields reaching the end of their useful lives.
- Transport policy and the transport system gradually diversifies away from road transport to include greater focus on active transport, shared transport, rail and coastal shipping.
 - Spatial planning evolves to give greater priority to opportunities to integrate active transit and public transport.
 - The aviation sector (backed by sustainable fuel mandates to keep New Zealand's tourism sector competitive with expectations of peer nations and major tourism markets) sees use of electric planes for short domestic routes and some biofuel and hydrogen for longer domestic routes.
 - The proportional uptake of electric vehicles, including electric buses and trucks is strong but the total vehicle fleet plateaus and declines as people see more opportunities to take advantage of active modes and shared transportation. The freight industry also makes greater use of rail and shipping over road transport.
 - Fossil fuel imports are 34% of 2025 levels by 2050.

- Improved energy efficiency in newly constructed homes and buildings is prioritised with energy efficiency as the “first fuel” of choice, alongside retrofitting existing infrastructure.

The affordability of electricity is further supported through national consensus on standards, regulations and commercial arrangements for demand flexibility (e.g., smart EV charging, vehicle-to-grid technology, hot water load control, etc.) that generate savings for consumers and reductions in transmission and distribution investment costs.

The large investment in renewable energy attracts more data centres to New Zealand, by parties who value affordable, reliable and sustainable electricity.

This scenario may also result in stronger demand for New Zealand export, as some consumers and brands increasingly value alignment with sustainability benchmarks. However, this potential effect is not explicitly modelled, in order to avoid confounding changes in commodity demand with the economic impacts of the energy transition.

Green hydrogen is produced in New Zealand primarily for very heavy transport, long-distance transport, and aviation, where direct electrification is less feasible. For modelling purposes, large-scale hydrogen production is assumed to occur outside the Waikato region, reflecting the likely co-location of production with major renewable resource areas, ports, and export or distribution infrastructure. Regional impacts are captured through higher electricity demand.

Table 1 provides a summary of the key features of each scenario.

Table 1: Comparison of energy transition scenarios

Dimension	Business As Usual (BAU)	Static	Dynamic
Overall framing	Continuation of current policy settings and central government projections;	Energy security and affordability prioritised over sustainability; transition slows	Decarbonisation treated as a long-term economic opportunity with coordinated action
Climate policy stance	ETS is the primary decarbonisation lever; no new policies	Weak commitment to emissions targets; decarbonisation sidelined	Proactive, bipartisan climate policy supported by complementary measures
ETS price trajectory	Rises until 2030, then gradually declines	Remains low	Rising ETS price provides a strong, reliable signal
Renewable electricity investment	Market-led build responding to demand; moderate consenting delays slow deployment	Renewable investment deprioritised; consenting uncertainty deters new projects	Large, anticipatory renewable build supported by streamlined consenting and revenue stability
Electricity system outcomes	Renewables grow steadily; gas remains a firming fuel	Continued reliance on gas for security; higher long-run electricity prices	Affordable high renewable penetration with storage, transmission and demand flexibility
Gas supply and use	Domestic supply declines; gas prices rise; demand falls gradually through switching and exit	Expanded gas development and LNG imports; gas use sustained longer	Gas pro-actively displaced by electricity and biomass
Coal use	Coal phased out of boilers by 2037 under Industrial Heat NES	Coal boilers remain; coal mining expands; Huntly continues operating	Coal phased out of boilers and Huntly switches to biomass
Industrial heat and efficiency	Gradual fuel switching driven by relative costs; limited efficiency improvements	Minimal efficiency gains; continued reliance on gas and coal	Biomass and electrification dominate; energy efficiency prioritised
Transport demand and behaviour	Transport demand follows MoT projections; limited mode shift	Higher private vehicle demand	Greater mode shift to rail, active and public transport
EV uptake and vehicle efficiency	EV uptake in line with projections; gradual efficiency improvements	Low EV uptake; weak emissions standards; slow efficiency gains	Strong EV uptake; declining vehicle fleet size; improved efficiency
Energy efficiency in buildings	Incremental improvements in new builds	Little improvement	Energy efficiency treated as the “first fuel”, including retrofits
Distributed energy and resilience	Moderate uptake of rooftop and agri-solar	Low uptake; weaker community resilience	Strong growth in rooftop, agri-solar and community energy
Industrial development	Some gas-intensive industries exit over time	Gas-intensive industries exit a few years later; limited diversification	Increased attractiveness for data centres and electrified industries
Hydrogen	None	None	Some use for heavy transport and aviation; production outside Waikato

4 Modelling approach

The analysis draws on a suite of complementary models to capture interactions across the electricity system, the broader energy sector, and the wider economy. Concept Consulting's electricity market model (ORC) is used to assess generation cost curves, capture rates, and resulting wholesale electricity prices under each scenario.

These outputs are incorporated into the Emissions in New Zealand (ENZ) model³, which simulates national energy supply, demand, and emissions pathways over time, capturing changes in electricity generation, fuel use, technology uptake, and energy prices. As ENZ operates at a national level, a regionalisation process is applied to isolate the Waikato region from the rest of New Zealand, drawing on multiple region-specific datasets described in Appendix A.

The resulting regional energy pathways are then used as inputs to an economy-wide computable general equilibrium (CGE) model, which assesses the implications of the scenarios for the wider economy, including impacts on GDP, sectoral output, investment, prices, and trade.

5 Modelled Outcomes

Total energy inputs are estimated at around 140 PJ in 2025, with total final energy use in the range of approximately 106 to 113 PJ (Figure 1). Some variation across the three scenarios reflects uncertainty in 2025 activity levels, as final data are not yet available, as well as differences in underlying assumptions.

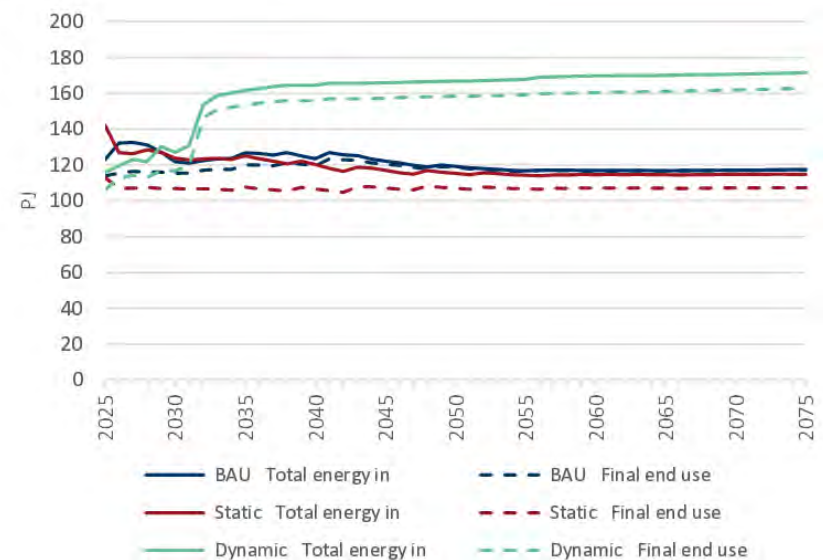
In the early years of the projection, total energy inputs decline across all scenarios. This reflects the projected continual decline of

domestic gas supply, leading to the exit of some higher-cost and uneconomic gas users.

Final energy use remains relatively stable over this period because the reduction in coal and gas primarily affects fuels associated with large transformation losses rather than end-use demand.

Under the Dynamic scenario, total energy inputs increase substantially through the 2030s, driven by large-scale renewable electricity build, of which the Waikato region captures a large share. By 2075, total final energy use is projected to reach approximately 110 PJ in the BAU scenario, compared with around 107 PJ in the Static scenario and 162 PJ in the Dynamic scenario.

Figure 1: Total energy inputs and final use for 2025 to 2075



³ For more information about ENZ, see <https://www.concept.co.nz/enz.html>

5.1 Energy demand by fuel

Under the BAU scenario, coal use increases in the early years as it is used for winter electricity firming in place of more expensive gas. Coal consumption then declines sharply by 2037 as existing coal-fired boilers are phased out under the Industrial Heat National Environmental Standard. Biomass use increases over time as industrial users progressively switch fuels for process heat. Liquid fossil fuel consumption declines gradually as the transport sector electrifies at a measured pace. Geothermal energy use grows more strongly than wind and solar, reflecting the Waikato region's relatively small share of new wind and solar generation build under BAU investment conditions.

In contrast, the Static scenario shows a slower transition away from coal, liquid fuels, and gas, reflecting weaker decarbonisation incentives and continued reliance on fossil fuels. Despite this, geothermal energy use continues to grow, driven by its relative cost competitiveness compared with new thermal generation options.

In the Dynamic scenario, coal is phased out more rapidly due to stronger carbon pricing. Gas use increases slightly in the early years to support system security and firming but is subsequently phased out for all but the highest-value applications. There is a substantial increase in both wind and solar generation as the Waikato region captures a larger share of renewable investment, including offshore wind. Geothermal energy use grows more strongly, reflecting expanded use for agricultural and commercial heat production alongside electricity generation.

Figure 2 - BAU energy demand by fuel for 2025 to 2075

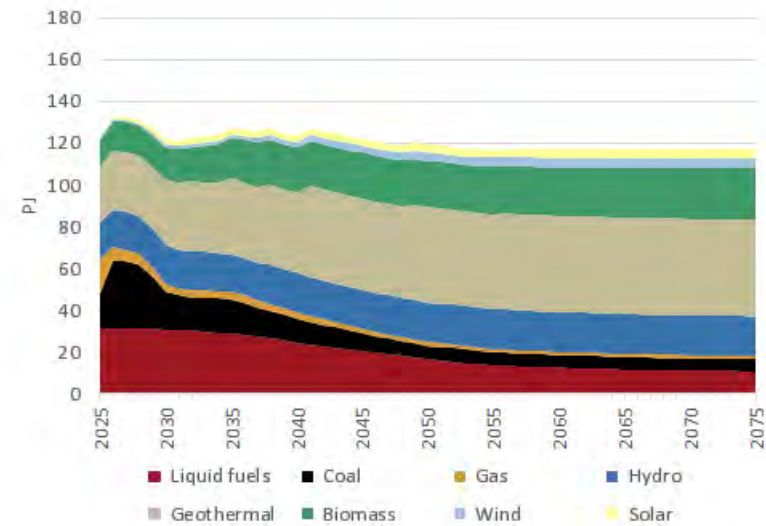


Figure 3: Static scenario energy demand by fuel for 2025 to 2075

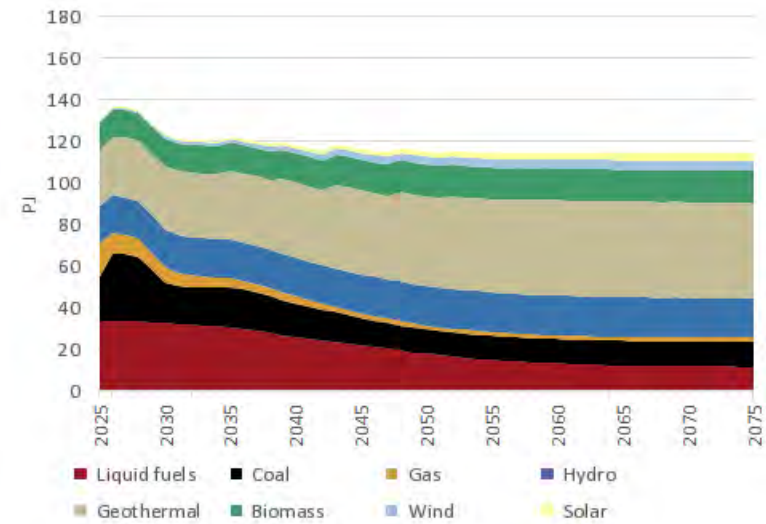
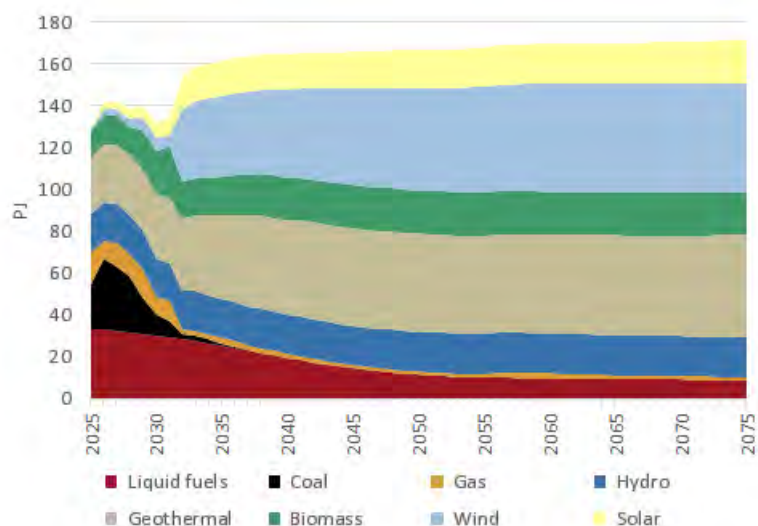


Figure 4: Dynamic scenario energy demand by fuel for 2025 to 2075



5.2 Energy demand by sector

The following three figures present total final energy demand by sector for each scenario. Underlying activity levels for major industries are assumed to grow broadly in line with GDP projections, including sectors such as wood processing. While this may not fully reflect future structural change in some industries, the ENZ model is not a macroeconomic model and does not endogenously adjust industry shares over time. Instead, it focuses on modelling changes in energy use and emissions for a given level of activity. Agricultural energy demand, including the dairy sector, is based on MPI projections of agricultural output. As a result, differences between scenarios reflect changes in energy intensity and fuel mix rather than changes in the scale of economic activity.

Electrification reduces the total amount of final energy required to deliver a given level of service, as electric motors, electric boilers, and heat pumps are substantially more efficient than fossil fuel technologies. This effect is most pronounced in the road transport sector, where total energy demand falls markedly across all three scenarios. In other sectors, changes are more subtle, reflecting the existing use of electricity and the fact that biomass boilers do not offer the same efficiency gains as electrification.

By 2050, total final energy use in the region is slightly higher in the Dynamic scenario, at around 56 PJ, compared with approximately 52 PJ under BAU. This reflects the additional electricity demand associated with data centre development and increased use of geothermal heat in the region.

Figure 5: End use energy demand by sector - BAU

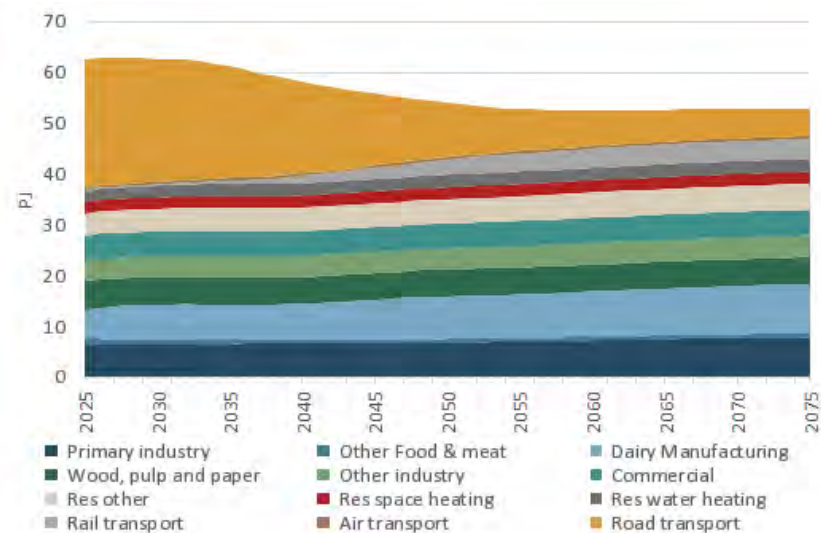


Figure 6: End use energy demand by sector - Static

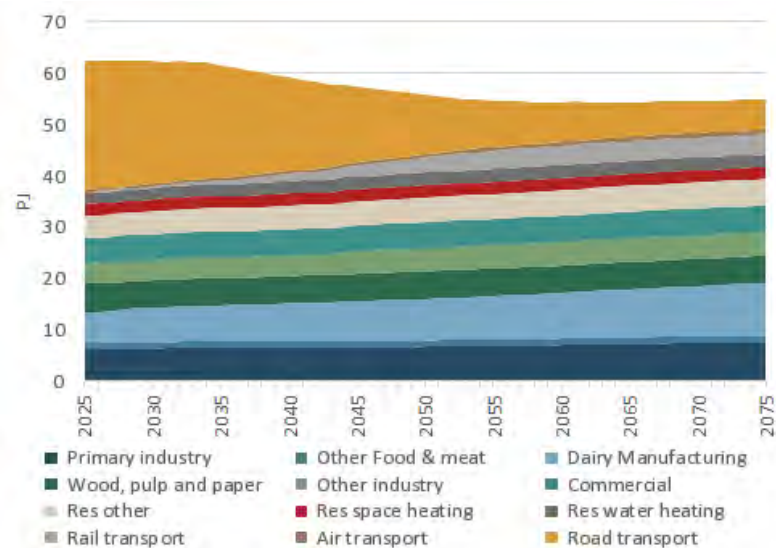
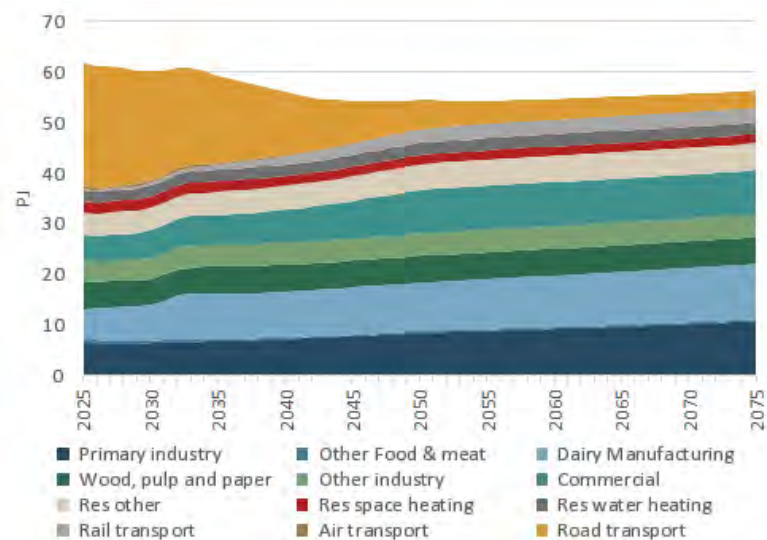


Figure 7: End use energy demand by sector - Dynamic



5.3 Prices

5.3.1 Carbon price

The carbon price is specified exogenously in each scenario to reflect different policy environments and market expectations.

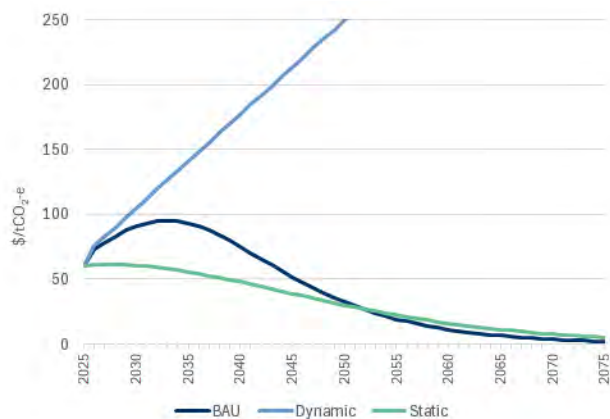
Under the BAU scenario, the carbon price follows Government ETS settings projections, which indicates NZU supply constraints emerging in the early 2030s, followed by a return to surplus supply as forests planted in recent years mature. This occurs even with farm conversion limits in place. The NZU price rises to around \$90 in the early 2030s before gradually declining thereafter.

In the Dynamic scenario, the carbon price follows the Climate Change Commission's 2023 demonstration price path, with NZU prices increasing by 3 percent per year. This trajectory delivers sufficient gross emissions reductions to achieve net zero by 2050 and provides a strong and durable signal for fuel switching and electrification within the model.

In the Static scenario, the carbon price follows a declining path, driven by unconstrained forestry supply and weak government commitment to emissions budgets and long-term targets. This undermines confidence in the ETS and weakens long-run decarbonisation incentives.

For context, following the November 2025 ETS changes, the spot NZU price fell to \$40, which is below even the low trajectory. However, a carbon price of \$40 versus \$50 makes little difference to modelled outcomes because neither price is high enough to drive significant fuel switching. The short-medium-term fuel switching in the scenarios is instead driven mostly by high gas prices and the Industrial Heat NES.

Figure 8: ETS price



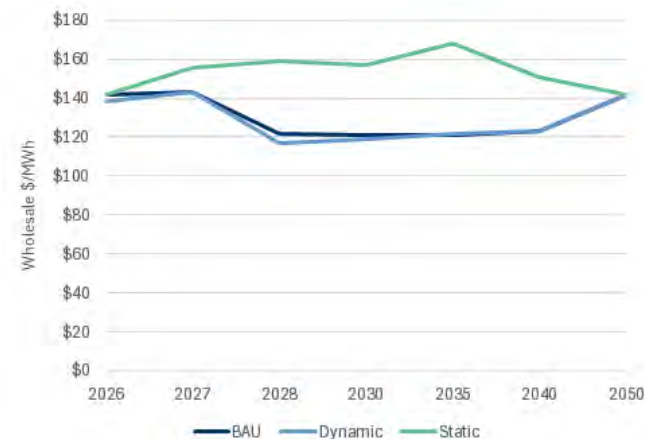
5.3.2 Electricity prices

Under the BAU scenario, wholesale electricity prices (modelled in ORC) reflect probable consented and planned new generation, with moderate demand growth and some system inefficiencies persisting over time.

In the Dynamic scenario, prices follow a similar early trajectory but are subject to much stronger demand growth, pushing generation further up the cost curve. This upward pressure is partially offset by fast, enabling consenting processes and effective demand flexibility and load management.

In the Static scenario, wholesale prices remain higher for longer due to prolonged reliance on gas-fired peaking plant, compounded by delays in consenting, grid connections, and renewable investment. Over time, wholesale prices converge across scenarios, although the underlying supply mix and system resilience differ markedly by 2050. After 2050, prices are assumed to be the same

Figure 9: Wholesale electricity prices \$/MWh 2025 to 2050



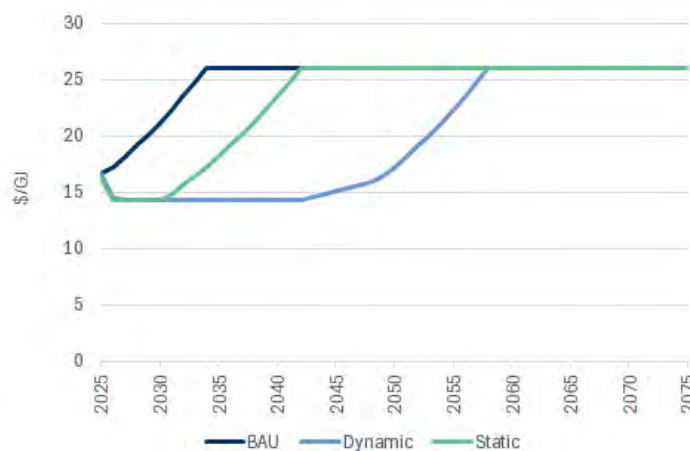
5.3.3 Reticulated gas

Wholesale gas prices diverge across scenarios in the medium term but tend to converge in the long run (Figure 10). This reflects the situation where domestic reserves are depleted and the cost of imported LNG (\$26/GJ), placing an effective ceiling on domestic prices.

In the Dynamic scenario, rapid electrification, fuel switching, and high renewable penetration significantly reduce wholesale gas demand, confining gas use to a small number of high-value applications.

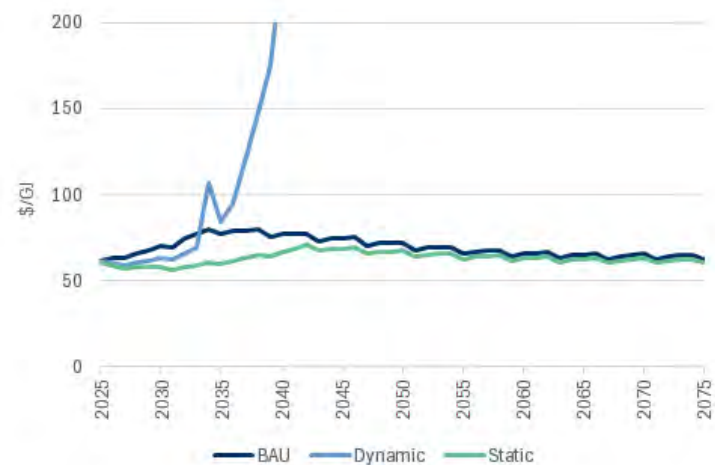
In the Static scenario, additional domestic gas development and a larger retained demand base keep wholesale gas prices relatively lower than in other scenarios, although still materially higher than levels observed over the past decade.

Figure 10: Wholesale gas price 2025 - 2075 (\$/GJ)



Retail gas prices follow these wholesale trends but are also influenced by network and retail cost recovery (Figure 11). As the number of pipe gas customers declines, fixed distribution and retail costs are spread across a smaller customer base. In the Dynamic scenario the declining consumer base results in extremely high retail prices for remaining consumers, assuming these costs are recovered from consumers. Large industrial users, particularly those connected directly to transmission or operating under bespoke supply arrangements, are less exposed to distribution cost increases. In the Static scenario, the larger consumer base keeps retail prices lower than in BAU, but still at a significantly higher level than in previous decades.

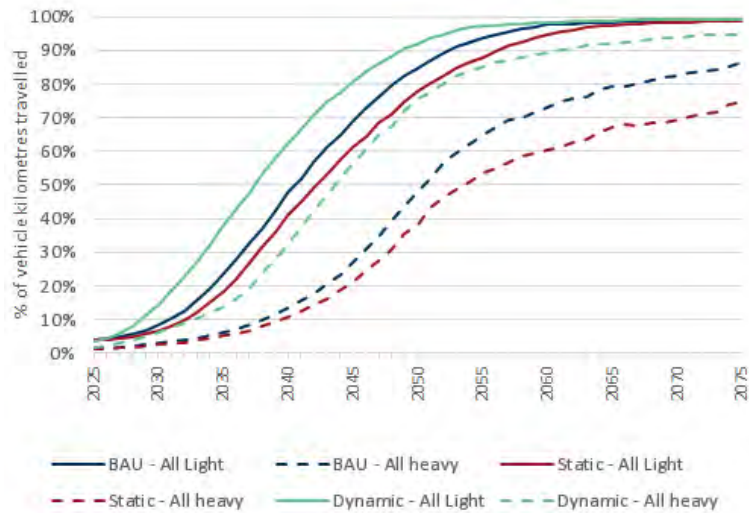
Figure 11: Retail gas price 2025 - 2075 (\$/GJ)



5.4 Transport

Across all scenarios, electrification of both light and heavy road transport increases over time, driven by growing consumer confidence, narrowing upfront cost differentials, and ongoing fleet turnover. The pace of uptake differs by scenario (Figure 12), with slower turnover and weaker incentives in the Static scenario. Around 50 percent of light vehicle travel is electric by 2041 under BAU, by 2038 in the Dynamic scenario, and by 2043 in the Static scenario. The modelling highlights that the most cost-effective interventions occur at the point of vehicle purchase, where relatively small incentives or efficiency standards compound over time to deliver substantial impacts on fleet composition and emissions.

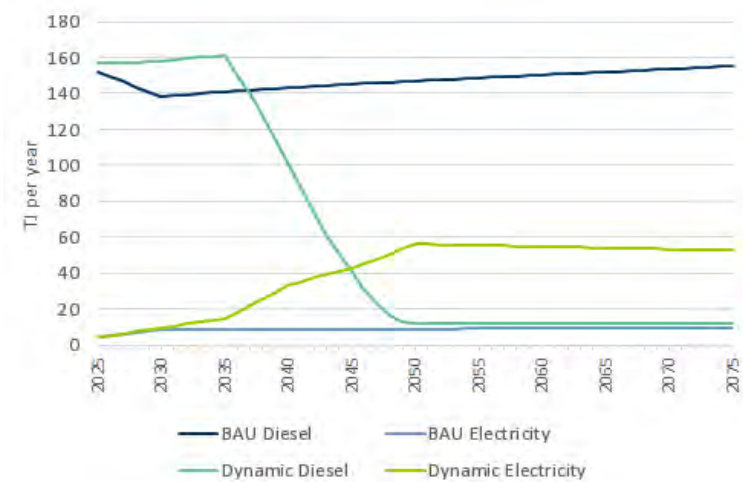
Figure 12: Electric Vehicle percent of kilometres travelled 2025 to 2075



There is limited rail electrification under the BAU scenario (Figure 13), and no substantial transition away from existing patterns. The Static scenario mirrors the BAU outcome.

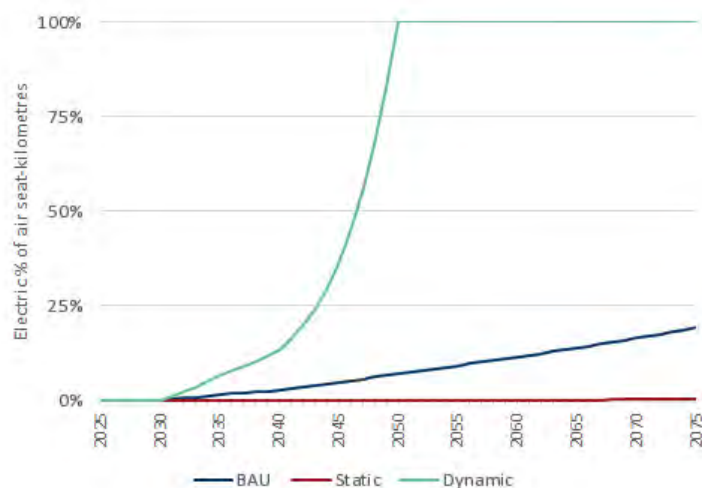
In the Dynamic scenario, rail electrification accelerates, particularly from around 2035 onwards. Electricity demand continues to grow through mid-century but declines after 2050 as efficiency improvements may outweigh underlying demand growth. In the short term, diesel use increases due to a shift of freight from road to rail before full electrification is achieved.

Figure 13: Rail energy use 2025 to 2075



Aviation electrification also differs across scenarios. Under the BAU scenario, limited electrification of short-haul regional flights emerges from the late 2030s. In the Dynamic scenario, electrification occurs earlier and at greater scale, broadly aligned with the Climate Change Commission's High Technology pathway. In the Static scenario, aviation electrification does not occur, with aircraft remaining fully reliant on conventional fuels throughout the projection period.

Figure 14: Air travel percent electric 2025 to 2075



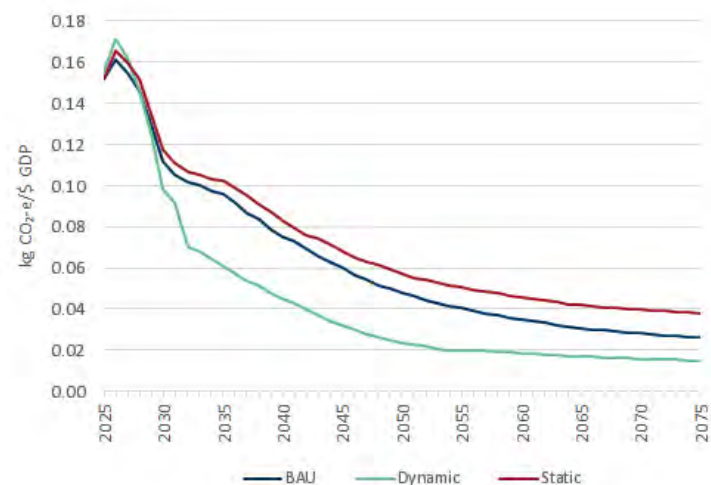
5.5 Greenhouse Gas Emissions

Energy-related greenhouse gas emissions in the Waikato region are estimated at around 5.7 Mt CO₂-e in 2025. Emissions are projected to increase slightly in 2026, reflecting unusually low coal generation at Huntly in 2025 and an expected return to higher coal use in 2026–27 under average hydro inflow conditions.

Over the long term, emissions decline in all scenarios, although at markedly different rates. Under the BAU scenario, energy-related emissions fall by approximately 69 percent, reaching around 1.76 Mt CO₂-e by 2075. In the Static scenario, emissions decline more slowly, falling by around 55 percent to approximately 2.53 Mt CO₂-e by 2075. The largest reduction occurs in the Dynamic scenario, where emissions decrease by around 82 percent to approximately 0.99 Mt CO₂-e by 2075, reflecting faster electrification, fuel switching, and renewable energy deployment.

Emissions intensity is estimated at around 0.16 kg CO₂-e per dollar of Gross Regional Product (2024 prices) in 2025. By 2075, emissions intensity declines to approximately 0.04 kg CO₂-e per dollar under the Static scenario, 0.038 kg CO₂-e per dollar under BAU, and 0.015 kg CO₂-e per dollar under the Dynamic scenario.

Figure 15: GHG emissions intensity (t CO₂-e/\$GDP)



In 2025, road transport accounts for almost half of Waikato’s energy-related emissions when emissions associated with exports are excluded. Under the BAU scenario, transport emissions decline substantially over time, falling to around 19 percent of total energy emissions as electrification accelerates (Figure 16). Emissions from dairy manufacturing also decrease markedly, reflecting the progressive decarbonisation of industrial heat.

In the Dynamic scenario, emissions reductions occur more rapidly across all major sectors, driven by faster electrification and fuel switching (Figure 17). By contrast, in the Static scenario, transport emissions decline more slowly, and emissions from dairy

manufacturing increase due to limited switching away from coal-fired boilers (Figure 18).

Figure 16: GHG emissions by sector - BAU

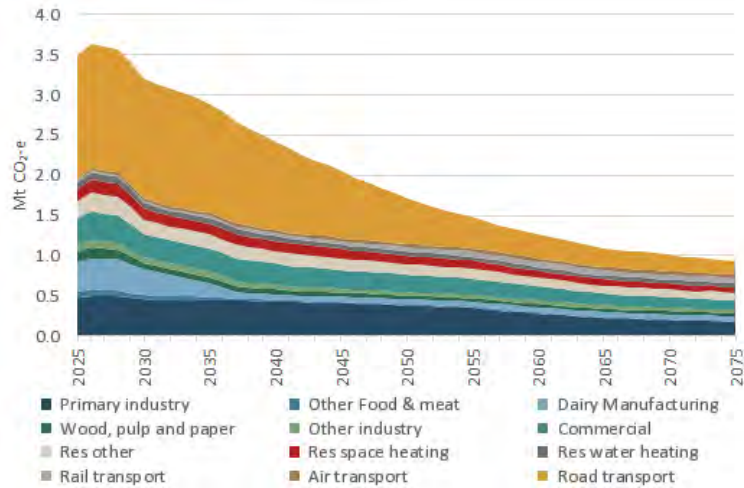


Figure 17: GHG emissions by sector - Dynamic

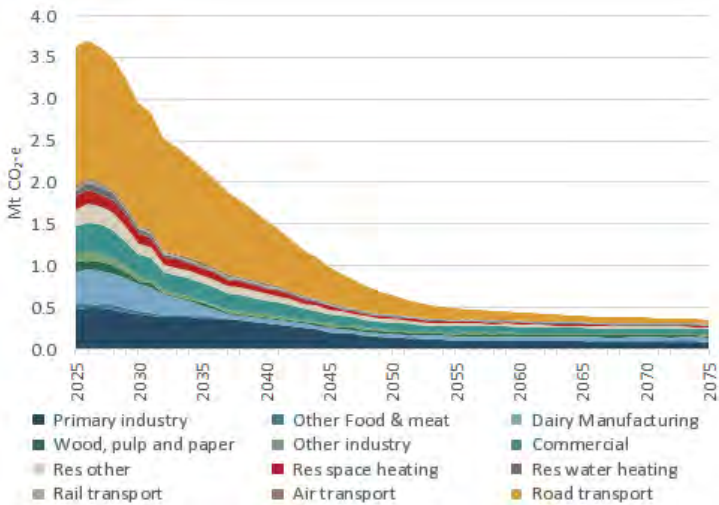
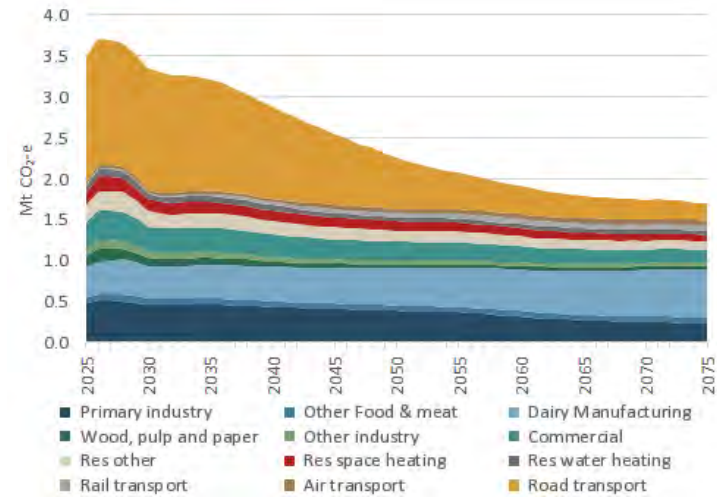


Figure 18: GHG emissions by sector - Static



5.6 Summary of energy flows

The following diagrams provide an overview of all energy flows in the scenarios.

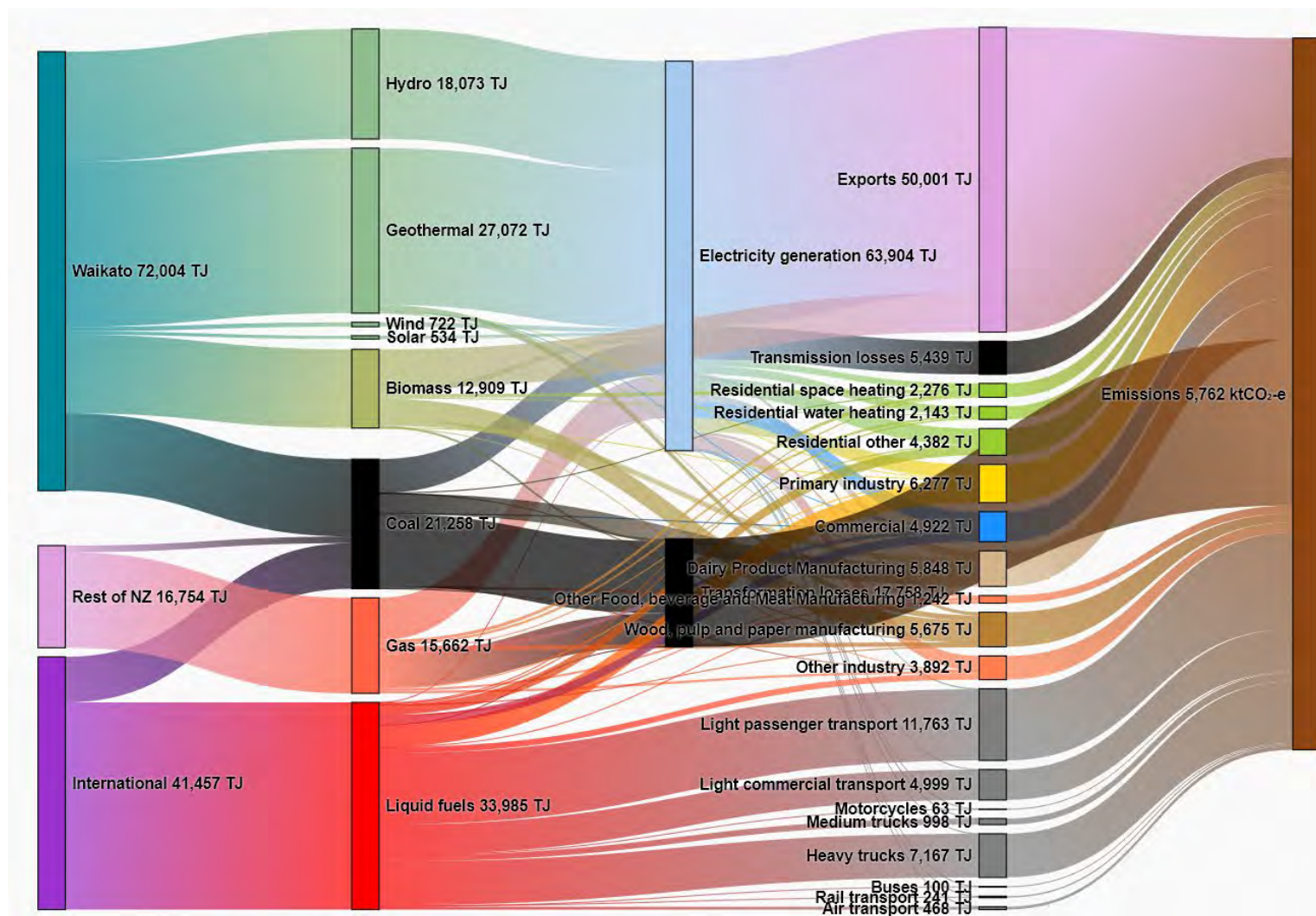
The Sankey diagrams should be read from left to right. The first set of nodes classifies energy by origin, distinguishing energy sourced from within the Waikato region, the rest of New Zealand, and overseas.

The next stage breaks that same supply down by fuel type. Some fuels are then shown passing through electricity transformation, while the remaining flows are allocated directly to end use within the region or to exports. The width of each flow represents the amount of energy in that pathway, so wider bands indicate larger flows.

Energy flows are shown in terajoules (TJ), while emissions are shown separately in kilotonnes of carbon dioxide equivalent (kt CO₂e). The final stage links energy use to associated emissions, showing which fuels and end uses contribute most to the region's energy-related emissions.

Figure 12 is a snapshot of 2025, and the following 3 figures display the year 2050 for each of the 3 scenarios.

Figure 19: 2025 energy flows and emissions⁴



⁴ An interactive version of the diagram is available at <https://econergy.earth/ConceptApps/WaikatoSankeyDynamic.html>

Figure 20: 2050 energy flows and emissions - BAU

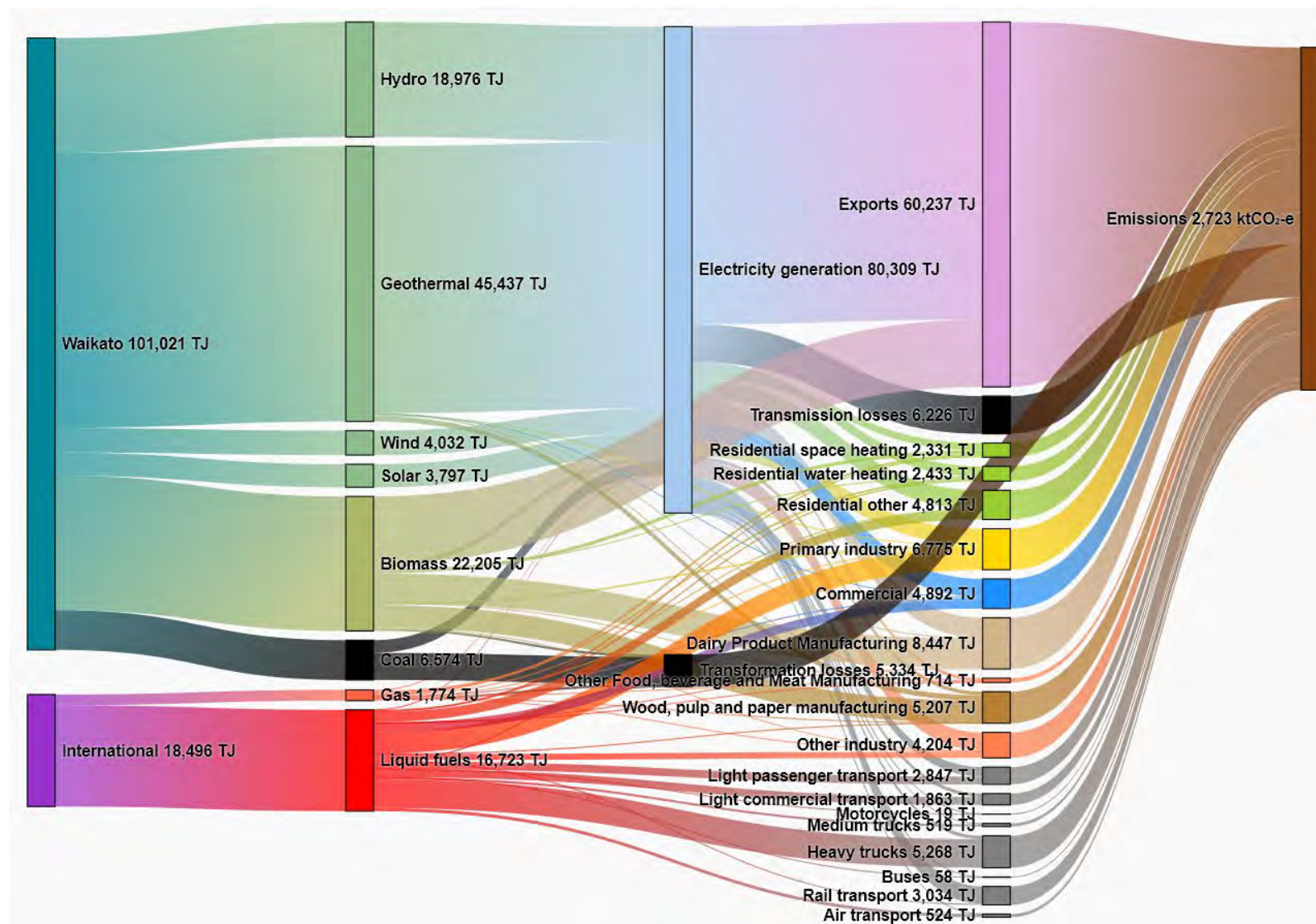


Figure 21: 2050 energy flows and emissions – Static

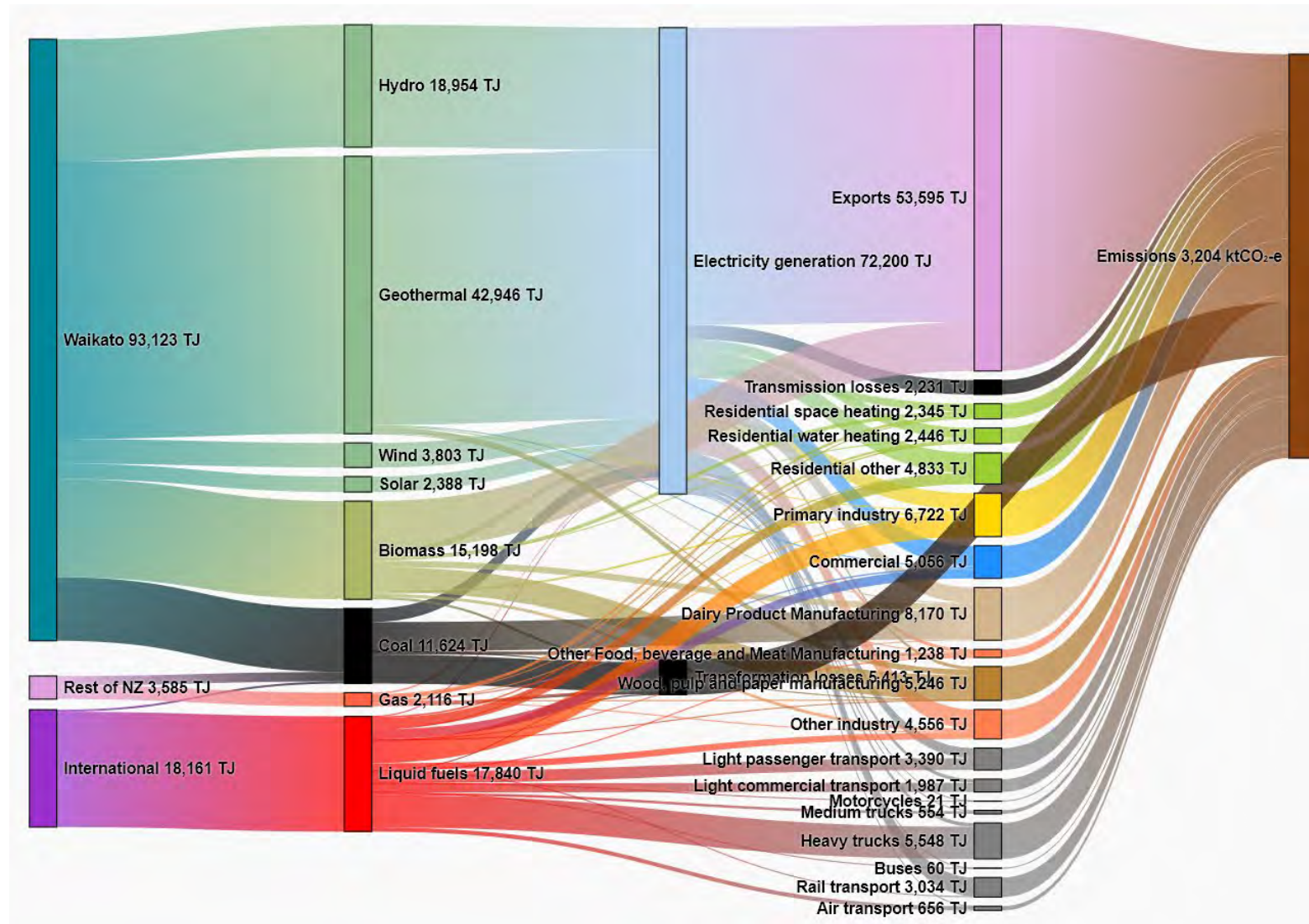
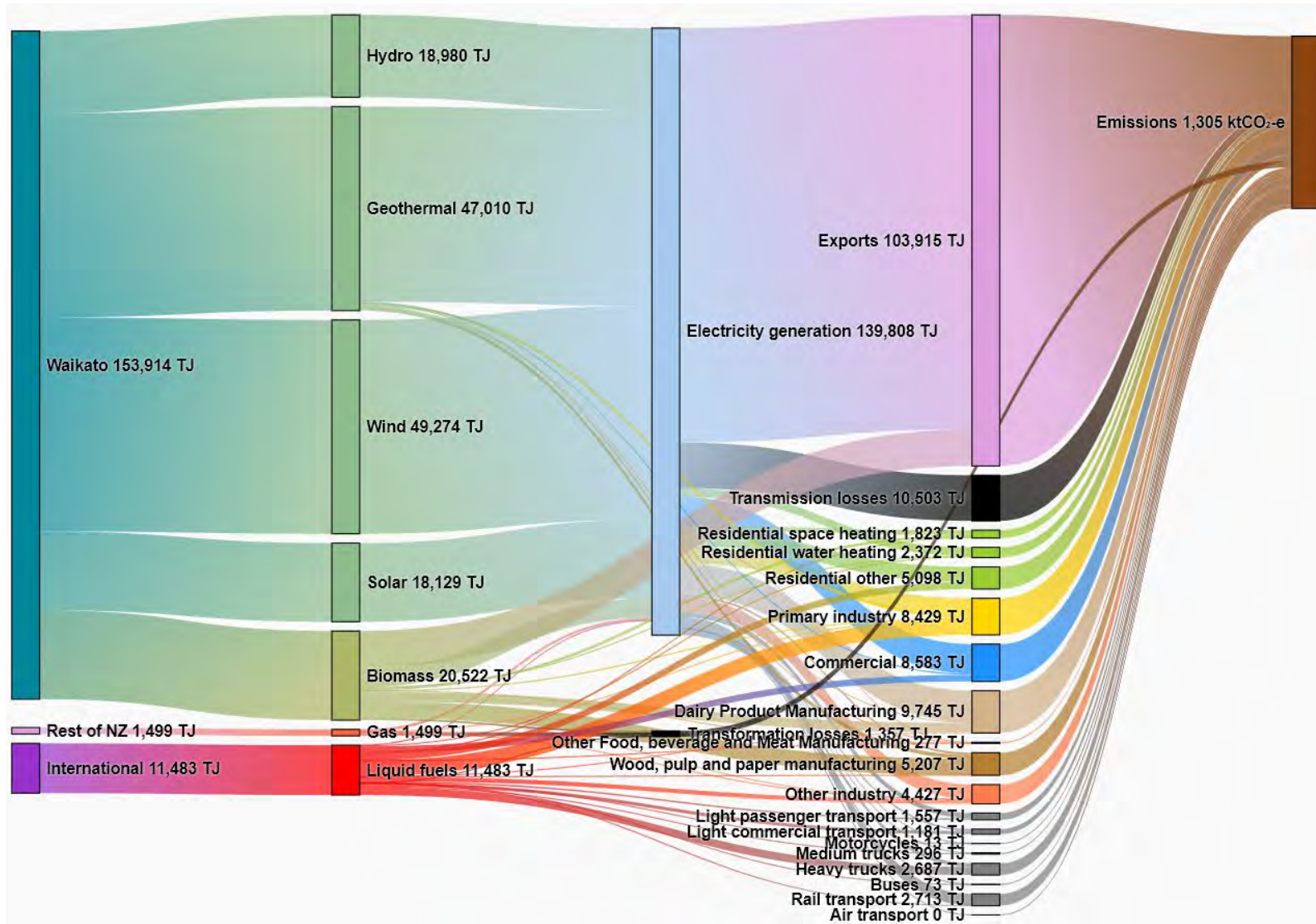


Figure 22: 2050 energy flows and emissions – Dynamic



6 CGE results

As explained in the methods section (Appendix B), there were various layers of impacts included in the simulation of each scenario. The list of impacts affecting the macroeconomic metrics presented in this section are the following ones:

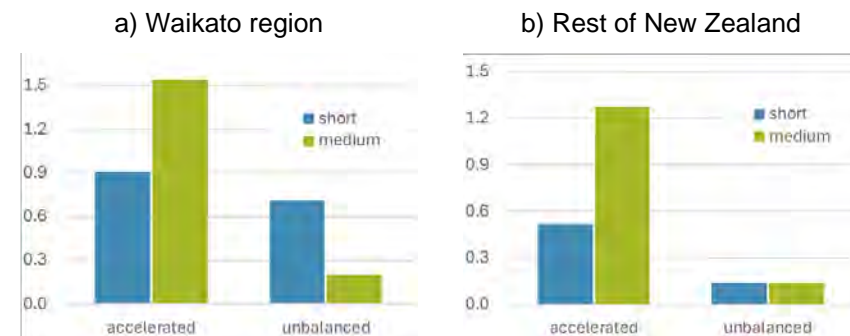
- 1) Introduction of electricity generation forecasts, cost efficiencies for electricity generation technologies, energy use efficiencies for electricity users, and GHG prices and emissions.
- 2) Introduction of advanced and emergent industries demanding electricity, namely commercial and private EVs, electric rail and air transport, and data centres.
- 3) Introduction of biomass heat as a substitute for coal and gas for industrial, commercial and residential sectors.
- 4) Introduction of an exogenous shock to regional oil imports from the rest of NZ to the Waikato region.

The results from the recursive dynamic CGE simulations highlight how the transition toward renewable electricity generation, combined with a carbon price on fossil fuel–using sectors, generates markedly different regional and temporal economic outcomes under the accelerated and unbalanced scenarios. Across both Waikato and the rest of New Zealand (RoNZ), the model captures the interaction between electricity generation expansion, price effects, household behaviour, and macroeconomic performance over the 2024–2050 horizon. These dynamics are particularly pronounced in the medium term (i.e., last 13 years of the horizon) when compared to the short term (i.e., first 13 years of the time horizon), as reflected in the GDP percentage changes relative to the reference scenario in Figure 23.

6.1 Impacts on regional GDP for both the Waikato and rest of NZ

The percent changes in GDP with respect to the reference scenario in both regions and scenarios is positive. The change in GDP is more pronounced under the accelerated scenario due largely to the substantial hike in renewable electricity generation occurring in the 2027–2032 window in both regions, largely driven by wind and solar capacity additions, and the higher uptake of electric transport alternatives (i.e., air, rail and road) and data centres. The change in GDP becomes more pronounced in the medium term (i.e., last 13 years) as the differences between the drivers of the accelerated and reference scenarios (e.g., renewable electricity generation forecasts, efficiency rates and uptake rates) become larger. The lower GDP change under the unbalanced scenario is due to the lower electricity generation forecasts with a higher reliance on fossil fuels (compared to the accelerated and reference scenarios) and the subsequent larger effect from the imposition of GHG prices on the sectors relying on fossil fuels, e.g., electricity, transport, etc.

Figure 23. Percent changes in GDP with respect to the reference scenario under two alternative counterfactual scenarios (accelerated and unbalanced) and time lengths (short and medium term) for: a) the Waikato region and b) the rest of New Zealand.

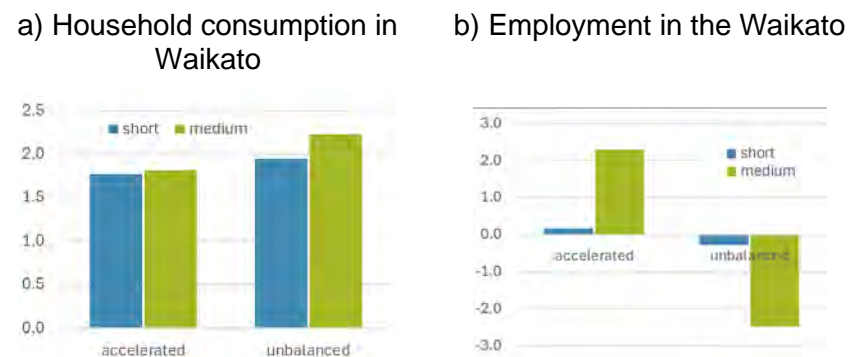


A key driver of the results is the substantial hike in electricity generation occurring in the 2027–2032 window in both regions, largely driven by wind and solar capacity additions. This surge in renewable generation exerts strong downward pressure on electricity prices, especially under the accelerated scenario where cost efficiencies in renewable technologies are assumed to materialise more rapidly. In Waikato, electricity prices remain consistently lower than the reference under the accelerated scenario, while under the unbalanced scenario they eventually rise above reference levels toward the end of the horizon. Similar price dynamics are observed in the rest of NZ. These electricity price movements are central to understanding the broader economic impacts, as they feed directly into production costs, household consumption, and factor incomes.

6.2 Household consumption and income through wages

Household outcomes closely mirror these price effects as shown in Figure 24 through the percent changes, with respect to the reference scenario, of household consumption and employment in the Waikato region. Total household consumption increases relative to the reference in the accelerated scenario, reflecting lower electricity prices, indirect price reductions in electricity-intensive goods and services, and higher employment/wages. Household consumption under the unbalanced scenario is slightly higher than the consumption under the accelerated scenario due to the lower GHG prices simulated under the unbalanced scenario, not income as employment/wages decrease under this scenario when compared to the reference (Figure 24b).

Figure 24. Percent changes with respect to the reference scenario in a) household consumption and b) employment under two alternative counterfactual scenarios (accelerated and unbalanced) and time lengths (short and medium term) in the Waikato region.



Labour market responses are positive under the accelerated scenario coinciding with the electricity generation expansion. Under the unbalanced scenario, employment/wage growth is lower than the reference due to the lower forecasted electricity generation, lower demand uptake from the nascent electric transport sectors and the more expensive reliance on fossil-based electricity due to carbon prices.

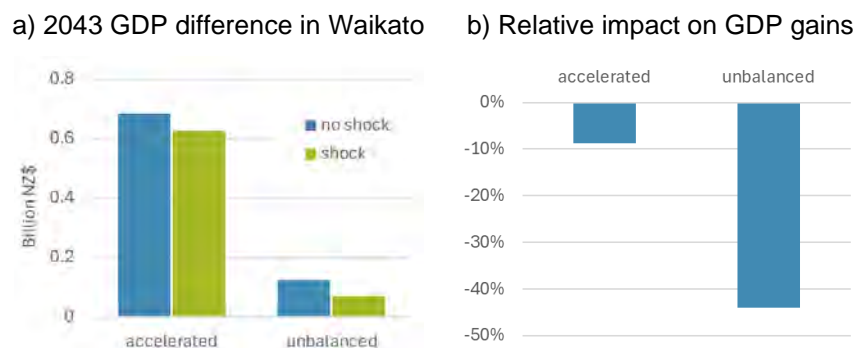
6.3 Vulnerability to sudden oil price hikes

To assess the resilience of the Waikato economy to adverse external energy shocks, the model introduces an exogenous oil price hike through a targeted import shock. Specifically, a 10% shock is applied to benchmark oil imports flowing from the rest of New Zealand into the Waikato region. Rather than directly imposing a price change, this approach increases the effective cost of imported oil faced by Waikato users, allowing the CGE model's price and quantity adjustment mechanisms to endogenously determine economy-wide responses. The shock is introduced in 2043, well into the simulation horizon, to ensure that both the optimistic (accelerated) and pessimistic (unbalanced) scenarios have sufficient time to transition

toward their respective long-run energy and production structures before being exposed to the disruption.

Resilience is evaluated by comparing GDP outcomes in 2043 under paired “shock” and “no shock” sub-scenarios. For each scenario, GDP gains relative to the reference path are first computed in the absence of the oil shock and then recalculated once the shock is applied (Figure 25a). The difference between these two outcomes provides a clean measure of vulnerability, capturing how much of the previously achieved GDP gain is eroded by higher oil import costs. To facilitate comparison across scenarios, this loss is expressed as a percentage relative to the no-shock GDP gain (Figure 25b). Under the accelerated scenario, the oil shock reduces GDP gains by about 9%, indicating a relatively modest sensitivity. By contrast, under the unbalanced scenario, nearly 44% of the GDP gain is wiped out by the same shock.

Figure 25. Resilience to shocks on oil imports in the Waikato region represented by a) the differences in the regional GDP in the Waikato in 2043 under four scenarios (accelerated and unbalanced with and without a shock) and b) the relative impact of the shocks with respect to the GDP gains under the ‘no shock’ scenarios.



The results indicate that, in the unbalanced scenario, the oil price shock offsets a substantially larger share of the baseline GDP gain relative to the reference case than in the accelerated scenario. This

suggests that an energy system with a higher penetration of renewable sources provides greater macroeconomic resilience to oil price shocks.

7 Conclusion

This report has provided modelling and assessment of how the Waikato region's energy system could evolve under different future pathways, and what those pathways imply for energy supply, demand, emissions, and the wider regional economy. By combining detailed technical-economic modelling with economy-wide CGE analysis, the scenarios provide a robust foundation for strategic decision-making that goes beyond individual interventions and instead reflects whole-of-system interactions and trade-offs .

Across all the three scenarios, several messages emerge. First, the Waikato region is already central to New Zealand's energy system and is a net exporter of energy, particularly electricity. This position means that changes in regional generation capacity, demand growth, and infrastructure investment have outsized economic effects. Investment in renewable electricity in Waikato not only supports local decarbonisation, but also supports the rest of the country to electrify and grow.

Second, the pace and direction of the energy transition are highly sensitive to policy settings, investment signals, and institutional coordination. Market-led change under existing settings delivers gradual progress, but materially different outcomes arise where barriers to renewable investment are reduced, demand flexibility is enabled, and complementary policies reinforce price signals. In these cases, electricity demand growth within the region, driven by electrification of transport and industry, interacts positively with large-scale renewable build, supporting higher utilisation of generation assets and more efficient network investment.

A key insight from the scenario comparison is the relationship between decarbonisation, affordability, and resilience. In the Dynamic scenario, accelerated electrification, improved energy efficiency, and reduced reliance on imported fossil fuels lower long-run energy costs relative to the other pathways. While this scenario involves higher upfront investment and adjustment costs in the short

term, over time it delivers greater exposure to low and stable-cost domestic energy sources. This improves affordability for households and businesses and materially reduces the impact of declining gas reserves and oil price shocks.

The modelling also highlights an important distinction between short- and long-term economic impacts. In the near term, faster investment in renewable generation, networks, and enabling infrastructure places requires capital expenditure and has transitional costs for some sectors. However, in the longer term, these investments support lower average energy prices, reduced import expenditure on liquid fuels, and higher economy-wide productivity. The CGE results indicate that these effects translate into stronger regional GDP over time, with positive spillovers beyond Waikato as lower energy costs, increased electricity supply, and improved energy security support national economic activity, trade competitiveness, and household real incomes.

In contrast, scenarios that retain higher dependence on imported fossil fuels for longer may appear less costly in the short term but expose the region and the wider economy to sustained affordability pressures, greater vulnerability to global fuel price volatility, and weaker long-run economic performance. In these pathways, higher energy costs act as a drag on both regional and national GDP, particularly for energy-intensive industries and export-oriented sectors.

These scenarios are not predictions. Rather, they are tools to support informed discussion about the consequences of different choices and the levers available to influence outcomes. The realised pathway is likely to combine elements from more than one scenario, shaped by evolving national policy, global markets, technological change, and local decision-making. The value of this work therefore lies in clarifying the scale of change involved, the timing of key decisions, and the risks associated with delayed or fragmented action.

Appendix A. Regionalisation process and data sources

This appendix documents the regionalisation process developed for Waikato Regional Council to represent the region's energy flows. The Emissions in New Zealand (ENZ) model operates at a national level and produces aggregate projections of activity, energy supply and demand, and emissions.

To derive Waikato-specific results, a range of regional and sectoral data sources is used to estimate the share of national activity occurring within the region. Unless otherwise stated, these shares are assumed to remain constant over time. They are calibrated using the most recent complete year of data available (2024), providing a consistent and comprehensive snapshot of the Waikato energy system against which future projections are applied.

A.1 End-use categories

These categories were selected to capture the major sources and uses of energy in the Waikato region while balancing detail with interpretability. They reflect both the structure of the regional economy and the main drivers of energy demand, with emphasis placed on sectors of particular significance to Waikato.

Industry categories represent aggregations of ANZSIC codes, grouped to highlight the most energy-intensive and regionally important activities. Transport categories are aligned with those used in Ministry of Transport (MoT) fuel use and emissions modelling, ensuring consistency with national datasets and comparability of results.

The full set of categories is:

- Primary industry
- Other food, beverage and meat manufacturing
- Dairy product manufacturing
- Wood, pulp and paper manufacturing

- Other industry
- Commercial
- Residential – other
- Residential – space heating
- Residential – water heating
- Light passenger transport
- Light commercial transport
- Motorcycles
- Medium trucks
- Heavy trucks
- Buses
- Rail transport
- Air transport

A.2 Energy sources

A.2.1 Electricity

- **Historical generation:** Sourced from the Electricity Authority's EMI data, which reports generation by fuel type and point of connection (POC).
- **Unit conversion:** Generation in gigawatt-hours (GWh) was converted to terajoules (TJ) using the standard factor of 3.6 TJ per GWh (consistent with MBIE and IPCC conventions).
- **Transformation losses:** The difference between fuel input (from MBIE coal, gas, and liquid fuel statistics) and electricity output was treated as transformation losses.
- **Transmission losses:** Line losses were taken from MBIE electricity statistics (2024).
- **Batteries:** generation and load from batteries are excluded as batteries are in general, relatively small net consumers of electricity due to round-trip losses associated with charging and discharging. The only large battery of note in the Waikato Region is the Rotohiko battery near Huntly, which is also

relatively small (35 MW / 35 MWh) in the context of grid generation and demand.

- **End-use allocation:** Sectoral electricity end uses were drawn from EECA's *Energy End Use Database (EEUD) 2023* and scaled to match 2024 regional electricity demand (generation minus transmission losses).
- **Regional industry consumption:** The EEUD reports electricity consumption across 27 ANZSIC industry groups. These were regionalised to Waikato using employment shares from Statistics NZ Business Demography tables, assuming electricity use scales with employment by industry.
- **Residential:** Residential electricity use was allocated to Waikato based on the region's share of national population.

New generation

For the first five years of the projection period, new electricity generation required by the ENZ model is sourced from Concept's database of proposed and consented generation projects, with the likelihood and timing of commissioning varying by scenario. Beyond this period, generic generation technologies are introduced to meet additional demand. The regional allocation of new generation is assumed to remain constant over time, based on the Waikato's share of generation capacity at the end of the initial five-year period.

Distributed generation

We did a reconciliation between EMI distributed generation capacity and generation figures.

Distributed wind and geothermal is all accounted for in EMI generation statistics, as is Oji's biomass-powered cogeneration activity at Kinleith.

Rooftop solar was added to grid-scale solar generation. Installed capacity (66MW) was sourced from EMI and multiplied by a capacity factor of 15% to get 87 GWh/year.

A.2.2 Liquid fuels

Transport

- **Fuel totals:** Total transport fuel use (land and air) was sourced from MBIE oil statistics (2024).
- **Mode breakdown:** The distribution of fuel use across transport classes was taken from the MoT VFM 2023 model output.
- **Scaling:** A scale factor of +4.1% was applied to VFM 2023 fuel use to align totals with MBIE 2024 oil statistics.
- **Road vehicles:** Fuel use by vehicle type was regionalised using NZTA's *Vehicle Kilometres Travelled (VKT)* data by region, which distinguishes between heavy and light vehicles.
- **Buses:** Allocated using regional public transport passenger-kilometre data from NZTA.
- **Rail:** Based on Freight Information Gathering System (FIGS) tonne-km by origin and destination. Legs beginning and ending in Waikato were counted in full. Legs with Waikato at either end were weighted at 50%.
- **Air:** Regional aviation fuel use was estimated using actual fuel consumption data sourced from Hamilton Airport. Taupō Airport fuel use was derived by scaling Hamilton's figure according to the relative difference in passenger numbers, based on annual report data.

Non-transport

- **Fuel totals:** non-transport fuel use, excluding for electricity generation, was sourced from MBIE oil statistics (2024).

- **Power generation:** Because EMI does not separately report Huntly's diesel use, we estimated it by taking MBIE's total reported diesel use for power generation and subtracting Whirinaki's diesel consumption (Whirinaki being New Zealand's only other large user of diesel for power generation.)
- **End-use allocation:** End-uses were drawn from EECA's *Energy End Use Database (EEUD) 2023*.
- **Scaling:** End-use totals were adjusted to 98% to ensure alignment with MBIE 2024 non-transport fuel totals.
- **Regional industry consumption :** The same approach as used for electricity.
- **Residential:** Residential fuel use was allocated based on Waikato's share of national population.

A.2.3 Gas

- **Power generation:** EMI data was the source of gas generation for E3P. Since the Rankine units can run on coal or gas, we referred to Genesis' operating reports to determine what proportion was coal and then triangulated gas use. Similarly, the Huntly P40 unit can run on diesel or gas so diesel was subtracted from P40 generation to calculate gas use.
- **Co-generation:** No gas co-generation is included, as the Te Rapa plant closed in 2023.
- **Transformation losses:** Losses are calculated using efficiency factors of 32% for Rankine and P40 units, and 56% for E3P.
- **Regional consumption:** Waikato's share of gas consumption was derived from gas gate data, after subtracting volumes associated with power generation and co-generation.
- **Sectoral disaggregation:** Sectoral consumption shares were taken from EECA's *Energy End Use Database (EEUD)*.

Waikato's share of each sector was estimated using regional employment data (Stats NZ Business Demography), on the assumption that gas use scales with employment. Dairy manufacturing was excluded, as there is no longer significant direct gas use in the region following the closure of Te Rapa co-gen.

- **Residential:** Residential gas consumption was allocated based on Waikato's share of the North Island population.

A.2.4 Coal

- **Fuel types:** Coal use was disaggregated into bituminous, sub-bituminous, and lignite categories.
- **Production and consumption:** Regional coal production by type was taken from MBIE coal statistics (2024), along with national consumption by coal type.
- **Electricity generation:** All coal used for electricity generation according to MBIE was assumed to occur at Huntly Power Station.
- **Co-generation:** No coal co-generation was attributed to Waikato, as the major facility is the Glenbrook steel plant in Auckland.
- **Transformation losses:** Losses were calculated on the basis of 32% efficiency of the Huntly Rankine units.
- **Regional industry consumption:** The same approach as used for electricity.
- **Residential consumption:** Residential coal use was split into space heating and water heating using EECA's *Energy End Use Database (EEUD)*, and then regionalised using Waikato's population share.
- **Imports and exports:** Exports and imports were calculated separately for each coal type. Any shortfall in bituminous and sub-bituminous coal was assumed to be met by international imports, while any shortfall in lignite was assumed to be

supplied by interregional transfers, as New Zealand does not import lignite.

A.2.5 Biomass

- **Production:** Biomass pellet production from the Nature's Flame plant (180,000 tonnes/year) was sourced from a company press release.
- **Regional industry and residential consumption:** Biomass consumption figures for the wood and paper industry and for residential use were taken from EECA's *Energy End Use Database (EEUD)*.
- **Dairy processing use:** Biomass use at Fonterra's Te Awamutu site was based on a company press release, which reported annual use of 50,000 tonnes.
- **Allocation:** It was assumed that the Te Awamutu plant uses Nature's Flame pellet output plus an additional 10,000 tonnes of miscellaneous local use. The remaining pellet production was assumed to be exported to other regions.
- **Wood, pulp and paper industry:** This sector was assumed to use locally sourced by-products such as black liquor, reflecting the low value and high transportation costs of these fuels.
- **Residential:** Residential users are assumed to rely on locally sourced firewood.

A.2.6 Geothermal direct heat

- **Data sources:** Consented takes were cross-referenced with the New Zealand Geothermal Use Database to establish the scale of direct use. Additional information was drawn from published reports (e.g. NZ Geothermal Association, GNS Science), with specific energy values identified for Tenon Ltd, Gourmet Mokai, Ohaaki Heat, and Arataki Honey.

- **Scope exclusions:** The estimates exclude energy provided by natural geothermal bathing sites and tourist attractions, which are not significant contributors to regional energy demand.
- **Dairy processing:** EECA's *Energy End Use Database (EEUD)* total was pro-rated across the three geothermal milk processing plants (Miraka at Mōkai, Fonterra Reporoa, and Fonterra Edgecumbe) according to relative milk production volumes.
- **Estimation methods:** Where installed capacity (kW) was reported by GNS, values were converted to terajoules (TJ) and adjusted with assumed capacity factors. Assumptions included 50% utilisation for pools and 50% for greenhouses. For pools with unknown kW capacity, energy use was estimated from bore temperature, consented volume, and assumed discharge temperatures (40°C for hot pools, 26°C for standard pools). Where bore temperatures were not reported, a conservative assumption of 55°C was applied.
- **Emissions:** Used the same emissions factor as for geothermal electricity production.
- **Validation:** Sectoral totals were checked against EEUD national totals as a plausibility test. Overall, estimated direct geothermal heat use in Waikato represented around 18% (1,368 TJ) of the EEUD national total (7,449 TJ).

A.3 GHG Emissions

The emissions represented in this Sankey diagram may be interpreted as approximately the Waikato region's share of Category 1: Energy in New Zealand's national greenhouse gas inventory. Category 1 covers all fuel combustion and fugitive emissions from energy production and use. It does not include emissions reported under other categories such as Industrial Processes and Product Use (IPPU), Waste, or Land Use, Land-Use Change and Forestry (LULUCF).

- Standard fuel emissions factors were sourced from the Ministry for the Environment's *Measuring Emissions: A Guide*

for Organisations, which is based on New Zealand's Greenhouse Gas Inventory.

- Fugitive emissions from geothermal power generation were calculated using emissions factors from the em6 Carbon Intensity Methodology⁵.
- For electricity end-uses, an average emissions intensity per unit of generation was applied.
- Biomass combustion was treated as having no net CO₂ emissions, consistent with inventory practice, on the basis that the carbon released during combustion was recently absorbed during the growth of the feedstock.

Appendix B. CGE Data and Methods

The macroeconomic model used for this study is a multi-regional recursive dynamic Computable General Equilibrium (CGE) model. The model defines the Waikato as the region of interest and relates it to rest of New Zealand (Figure 1) assuming that interactions with the rest of the world are exogenous. The model is based on the C-PLAN model used by the CCC for their draft recommendations (Winchester and White, 2022), a multi-regional CGE model for Auckland used to assess regional impacts from national climate policies (Monge and McDonald, 2023), and a multi-regional CGE model for Waikato used to assess the potential impacts from wildfires (Monge et al., 2023).

The model uses as its main inputs two inter-related SAMs: one for the Waikato region and one for the rest of New Zealand. The multi-regional SAMs were developed from 2020 national supply-use tables published by Statistics New Zealand using the procedure described in Smith et al. (2015).

Figure 1. Graphical representation of the CGE model including economic agents (grey), regions (blue), interactions (arrows), the Greenhouse Gas (GHG) market (green) affecting polluting industries, and the resulting increase in commodity prices due to the addition of a carbon price.

The essential mechanism of the CGE model is to contrast the likely evolution of both the Waikato region and New Zealand economy, based on economic principles and expected technology and policy trends under: 1) a future baseline scenario driven by current technology uptake trends and policies, and 2) two future policy scenarios representing different uptake rates of low-emitting renewable technologies, namely an optimistic and a pessimistic scenario.

CGE models typically assume that an economy is initially at equilibrium (i.e., providing a benchmark) and converges to a new equilibrium in response to an exogenous 'shock' (i.e., a counterfactual scenario). These models converge to new equilibria using a set of microeconomic principles and macroeconomic accounting relationships. From a microeconomic perspective, CGEs rely on a couple of first-order conditions that guarantee the convergence to an optimal equilibrium: 1) profit maximization subject to a zero-profit condition to identify optimal production levels by various sectors, and 2) utility maximisation subject to a full-budget allocation to identify optimal consumption levels by households. An agent's consumption and production behaviour are dependent on the equilibrium prices of commodities and factors of production that satisfy various (Walrasian) market-clearing conditions (i.e., supply must equal demand). From a macroeconomic perspective, a set of closure rules and institutional accounting identities (e.g., savings and investment) ensure that the model behaves well and is tractable.

Our model is specified as a Mixed Complementarity Program (MCP) in the Mathematical Programming System for General Equilibrium

⁵ <https://www.ems.co.nz/em6-carbon-methodology/>

(MPSGE) package (Rutherford, 1999a) as a sub-system of the General Algebraic System (GAMS) (Brooke et al., 1998). An Agile Software Development approach was followed in developing the model, with different versions of the GAMS code tracked using Git processes using cloud-based repositories at Gitlab.com.

A.4 Production

Commodity production follows a nested Constant Elasticity of Substitution (CES) production function, where the inputs are intermediate inputs (commodities), energy and the factors of production as shown in Figure 2 through a generic “nest” diagram representing most sectors included in the model. Although the inputs are nested, using a CES functional form, different substitution patterns exist within the various sub-nests and represented by a substitution elasticity parameter (σ) with different subscripts. Among the substitution patterns, the Leontief ($\sigma = 0$) and Cobb-Douglas ($\sigma = 1$) substitution patterns are exceptional cases. For example, the intermediate inputs’ nest follows a Leontief structure where commodities are non-substitutable with the proportion of commodities required to produce a unit of commodity output remaining constant as represented by the perpendicular lines in Figure 2. The rest of the nests follow different substitution patterns and are differentiated by their respective subscripts.

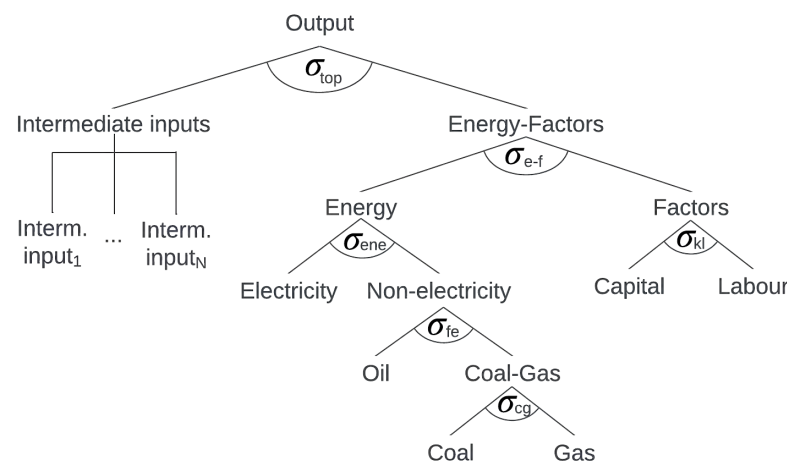


Figure 2. Generic production nest representing most of the industries considered. Perpendicular lines represent a Leontief production structure with an elasticity of substitution (σ) of zero. Subscripts represent different substitution levels: top between intermediate inputs and the energy-factors composite; e-f between the energy and factors composite; ene between electricity and non-electricity; kl between capital and labour nest; fe between oil, coal and gas energy, and cg between coal and gas.

Although the nesting structure in Figure 2 is very similar to the rest of the industries, specific sectors such as the electricity generation sectors (e.g., coal, gas, hydro, etc.) follow a slightly different structure as depicted in Figure 3. The structure that forms the energy-factor aggregate is similar for all sectors and fully presented in Figure 2. The main difference across sectors is in the use of additional branches (most in the top nest) to accommodate the inclusion of additional resource endowments such as Technology Specific Factors (TSF). These additional resources exogenously control the output from certain industries over time. For example, as show in Figure 3 for the electricity sectors, TSFs were used to follow exogenous electricity projections developed through the ENZ for the three scenarios modelled.

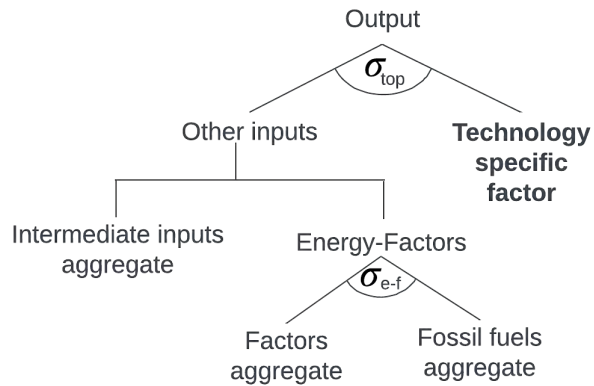


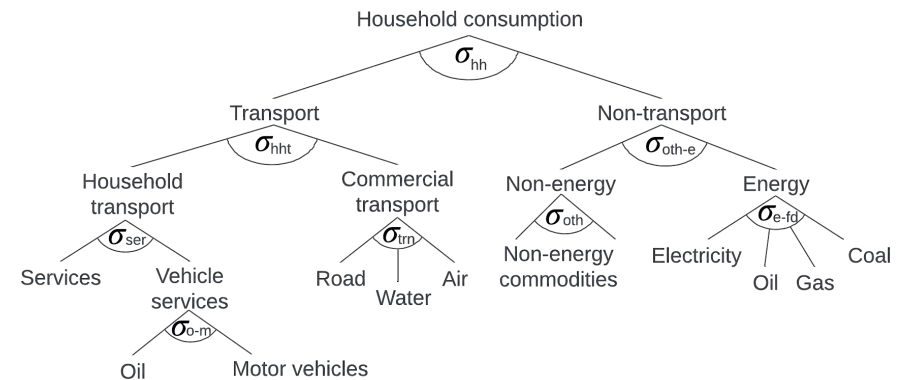
Figure 3. Production nest for electricity technologies with a technology-specific factor (in bold font).

A.5 Consumption

Households and government maximise their respective utilities by adjusting the consumption of commodities subject to budget constraints. Figure 4 shows the nesting structure used to represent consumption patterns of representative households in both the Waikato region and the rest of New Zealand. Government consumption and investment expenditures are determined using a similar nesting structure but with less sub-nests.

As show in Figure 4, households can choose between commercial (e.g., taxis, buses, and airplanes) and household transport (privately-owned motor vehicles). The latter results from consuming products from services (e.g., vehicle maintenance and insurance) and the “vehicle services” composite, which consists of the consumption of refined oil products and motor vehicles. The substitution elasticity of the “vehicle services” composite (σ_{o-m}) is critical as it governs the substitution behaviour when oil prices rise by spending more on motor vehicles and less on fuel, i.e., price-induced preference for more fuel-efficient vehicles.

Figure 26. Household consumption nest. Subscripts represent different substitution levels (σ): *hh* between transport and non-transport composites, *hht* between household and commercial transport composites, *ser* between service composites, *o-m* between oil and motor vehicle services, *trn* between commercial transport alternatives, *oth-e* between energy and non-energy composites, *oth* between non-energy commodities, and *e-fd* between energy sources.



A.6 Sectoral representation

The 40 representative sectors included in this study are listed in Table 1 with their respective codes. The list is comprehensive enough to represent relevant sectors in both the Waikato region and the rest of New Zealand by including 6 primary industries, 10 manufacturing sectors, 11 energy sectors, 1 representative construction sector, 4 service sectors, and 6 transport sectors (5 commercial alternatives and 1 for households). As part of the scenarios modelled, 2 new sectors were created – namely rail transport and data centres. Besides the inter-sectoral demand of intermediate inputs, the model also includes the final demand of commodities by households, government, and investment.

Table 2. Sectors considered in the CGE model for both Waikato and the Rest of New Zealand.

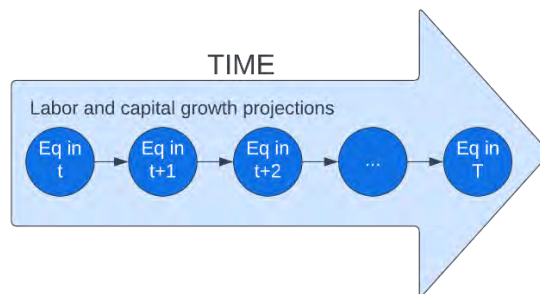
Code	Sectors	Code	Sectors
rmk	dairy farming	bas	beef and sheep farming
oap	other animal products	hor	horticulture
frs	forestry	fish	fishing
col	coal mining	cru	crude oil extraction
gas	gas extraction and distribution	oil	refined oil products
oxt	other mining	ega	gas electricity
eco	coal electricity	ews	wind & solar electricity
ehy	hydro electricity	tnd	electricity trans & distribution
eot	geothermal electricity	nmm	non-metallic minerals
crp	chemical, rubber and plastic	fmp	fabricated metal products
nfm	iron, steel and metals	mtp	meat products
mil	dairy processing	wpp	wood and paper products
ofd	other food products	omf	other manufacturing
mvh	motor vehicle and parts	afs	accomm and food services
cns	construction	dat	online data services
res	residential services	trd	trade services
ser	other services	rai	rail transport
rtp	road transport	hht	household transport
wtp	domestic water transport	wtpi	international water transport
atp	air transport	atpi	international air transport

A.7 Dynamic process

The model is a recursive-dynamic CGE model that generates an equilibrium in each time step, which consists of commodity and factor prices and depends on exogenous growth parameters that change through time. Each equilibrium is dependent on the equilibrium in the previous time step (i.e., myopic foresight by the agents). The set of parameters that drive growth in the model are capital and labour. The labour endowment gets updated in every period using an exogenously determined growth rate, and it is perfectly mobile across sectors and regions. The model considers a putty-clay

specification for capital separating mobile and sector-specific fixed capital to avoid the potential instantaneous movement of capital into impacted sectors (Winchester and White, 2022). New mobile capital every year is a function of solution investment levels, which then gets allocated across sectors, depreciated, and added to the current year's fixed capital to form next year's endowment of fixed capital to be used by different sectors. Capital productivity is specified as a multiplier for each period, adjusted to target external regional GDP growth projections in the baseline scenario, and used exogenously under counterfactual scenarios.

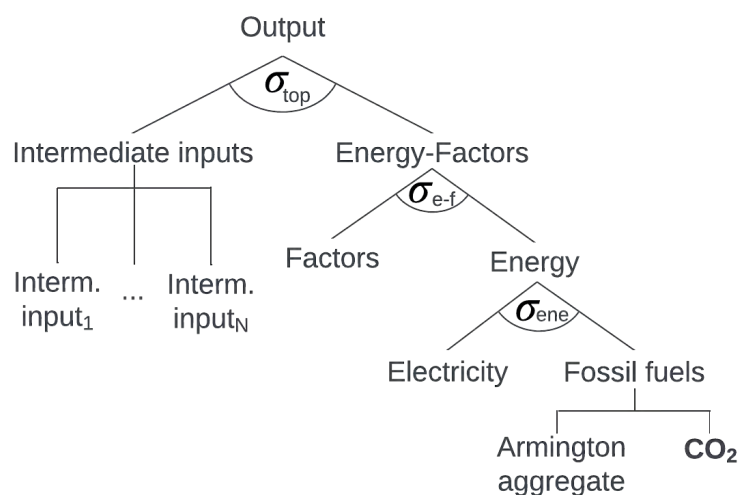
Figure 5. Graphical representation of the recursive dynamic structure with an equilibrium in each time step using projections for labour and capital growth.



A.8 Closure

As a modelling convention in the CGE literature, several micro and macroeconomic relationships must be specified to 'close' the model (Lofgren et al., 2002). Regarding the equilibrium prices of factors of production, following the "neoclassical" assumption of full employment, the national wage adjusts to clear labour markets. The updated supply of each capital type is used as an exogenous shock in the dynamic recursive model and the capital rental rates are endogenously determined in each period. Following Monge and McDonald (2023), in every solution period, the current account balance is fixed to benchmark values. Government spending is endogenously determined as a function of endogenous tax revenues net of transfers. According to Lofgren et al. (2002), the model follows a savings-driven closure where investment spending is endogenously determined as a function of fixed households and government savings net of the current account balance.

Figure 6. Generic production nest with combustion (CO₂) and non-combustion (non-CO₂) GHG emissions.



A.9 GHG markets

As shown in Figure 6, GHG emissions in the model are generated by the combustion of fossil fuels (i.e., CO₂ from coal, gas, and refined oil). As shown on the lower right-hand corner of Figure 6, the rate at which CO₂ emissions are generated from the consumption of each type of fossil fuel is constant (i.e., perpendicular lines representing a Leontief structure). Hence, producing sectors can reduce GHG emissions by substituting fossil fuels for less carbon intensive sources of energy (i.e., renewable electricity and dictated by σ_{ene}) and/or more capital-labour inputs (i.e., energy-efficient technologies and dictated by σ_{e-f}).

The model also integrates emission reductions in the optimistic counterfactual scenario for coal electricity to simulate the future use of biomass at the Huntly Power Station, i.e., phasing out coal for biomass reduces the carbon footprint of the power station.

The model follows three exogenously pre-determined emissions price pathways, one for each scenario. The emissions price pathways were estimated with the ENZ model.

Sector emissions were estimated using public information from Stats NZ (2025). These were disaggregated into fuel types using profiles from the Energy End Use Database (Energy Efficiency and Conservation Authority, 2025). To convert this energy use into Coal, Gas, and Oil, emissions factors from New Zealand's Greenhouse Gas Inventory (Ministry for the Environment, 2025) were applied. This process involved mapping EECA energy profiles (based on ANSIC codes) to Stats NZ industry codes (NZSIOC) and separating combustion from process emissions (such as agriculture) using CO₂ emissions totals. Finally, those emissions were mapped to sectors, and manual adjustments were made to align transport, electricity, gas supply, and household sector emissions and fuel splits with the original C-PLAN approach (Winchester & White, 2022).

Air and water transport were split into their domestic and international components as the ETS does not cover international air and water transport. Based on the original C-PLAN study, it was assumed that the international share of air and water transport is 75% for the rest of New Zealand while it is 0% for the Waikato region.

A.10 Advanced and emergent industries

Advanced technologies are considered in the model as low-emission alternatives to conventional technologies that will be highly impacted by carbon prices. Emergent industries such as data centres are also considered in the future pathways. The technologies considered are: 1) electric vehicles (EV) for the road and household transport sectors, 2) electric rail and air transport, 3) data centres, and 4) bioheat for sectors that heavily depend on industrial heating with coal and gas.

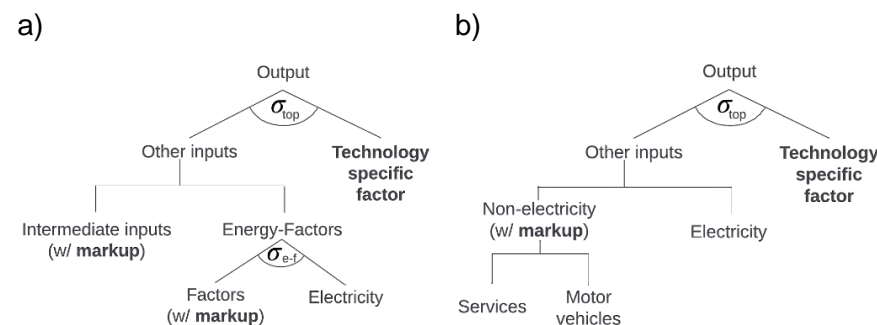
When operational, the output from advanced technologies replaces the existing output from conventional technologies (e.g., electric fleets replacing internal-combustion fleets in the road transport

sector) or inputs used by conventional technologies (e.g., biomass heat replacing the coal-gas aggregate used to dry milk into powder in the dairy processing sector). The operation and deployment of advanced technologies is a function of cost markups and future uptake curves implemented using the TSFs as shown in the nesting structures in Figure 7. Cost markups represent the currently higher costs of the advanced technologies compared to the conventional ones. As the cost of the conventional technologies increase, due to increasing carbon prices, advanced technologies with their lower GHG footprint become more affordable. As previously mentioned, TSFs control the deployment and/or market penetration of the advanced technologies. The deployment or market penetration rate is exogenously predetermined with the ENZ model.

The nesting structure for the production of electric commercial road, rail and air transport, and private household road transport are shown in Figure 7a and Figure 7b, respectively. The top-level nests include TSFs, which follow exogenous EV deployment projections from the ENZ model (Concept Consulting, 2021). Benchmark TSFs are estimated as a share (5%) of total costs on a per unit basis for all electric technologies. A positive substitution elasticity in the top nest ($\sigma_{top} > 0$) implies that output from this technology can increase beyond what is allowed by the TSF endowment but at a higher marginal cost. Electricity is the only source of energy for both production functions. Factors of production and intermediate inputs are needed for commercial road, rail and air transport whereas only services and motor vehicles are required for household transport (as per internal combustion engines on the lower left-hand corner of Figure 4). Factors and non-energy inputs have a cost markup. Electricity costs are assigned based on estimates of electricity requirements per vehicle travel kilometres [JM1.1] from the ENZ model. The ratio of the value of electricity-to-oil purchases (considering a constant output from both EVs and internal combustion engines) is used to estimate required electricity costs.

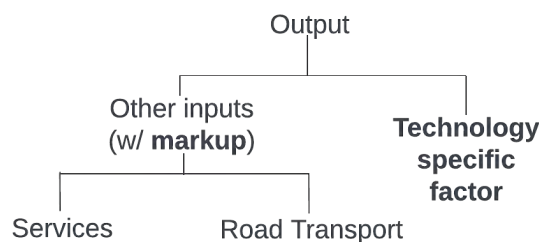
a) b)

Figure 7. Production nests for electric transport in the: a) commercial road, air and rail transport and b) household road transport sectors. Inputs with a cost markup and the technology-specific factor in bold font.



Biomass heat is a perfect substitute for the coal-gas aggregate used as an energy input going into the dairy processing, meat products, other food products, wood and paper products, accommodation and food services, residential services, construction, and other services sectors. The bioheat technology's main input is biomass and its supply is exogenously predetermined from the ENZ model for the three scenarios and controlled through a TSF endowment as depicted in Figure 10. Bioheat also uses services and transport inputs (with a cost markup) to collect and process the biomass. The Leontief structure between the TSF and other inputs limit the output of bioheat to the supply biomass.

Figure 8. Production nest for the supply of biomass heat. Inputs with a cost markup and the technology-specific factor in bold font.



Data centres were introduced in the model through the existing “Internet service providers, web search portals and data processing services” sector included in the StatsNZ 2020 supply-use tables. Electricity is among the main inputs used by this existing sector. Hence, like the previous emergent technologies, the output from this sector was controlled with exogenous growth rates using the sectors TSF. The growth for this sector was not directly obtained from the ENZ as the sector’s current size precluded the model from following the ENZ’s ambitious growth projections. Hence, the following conservative annual growth rates were used to differentiate the sector’s growth across scenarios: 1) for the reference and pessimistic scenarios – 1.1% and 2) for the optimistic scenario – 2.5%.

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