Emissions in New Zealand (ENZ) Model Technical Manual

He Pou a Rangi – Climate Change Commission 2021

Contents

About this document

This manual accompanies the public release of the 'Emissions in New Zealand (ENZ)' model by the Climate Change Commission. It provides a guide for using the model and a summary of some of the core functionality and architecture.

This document is the first version of the ENZ Manual and was prepared in July 2021.

About the ENZ model

The ENZ model has been developed over the years by Concept Consulting, and a version has been purchased by the Climate Change Commission for the purposes of assisting the Commission in setting the carbon budgets. Having purchased the rights to use the model for this purpose, Commission staff have also contributed to developing its functionality in a number of areas.

Software required

The ENZ model has been developed and tested to work on the latest version of Microsoft Office on a Windows 10 Enterprise device. Visual basic macros will have to be enabled in Excel in order for the model to run. Performance may be reduced, or the model may not function on legacy versions of Excel or under alternative operating systems.

Installation

The ENZ model is provided as a zipped file for download and the file contents will have to be extracted into a local directory. By default, Excel opens spreadsheets with macros disabled and the 'Enable Content' prompt will have to be accepted in order for the model to run. If asked to make the file a trusted document, select yes.

Model structure

ENZ is an Excel based model with functionality distributed across multiple linked workbooks. The workbooks disaggregate the core emitting sectors of the economy into heat, industry and power (HIP.xlsx), transport (Tpt.xlsx), land use (Lnd.xlsx) and waste (Wst.xlsx). The structure of the workbooks and key interactions is depicted in the figure below.

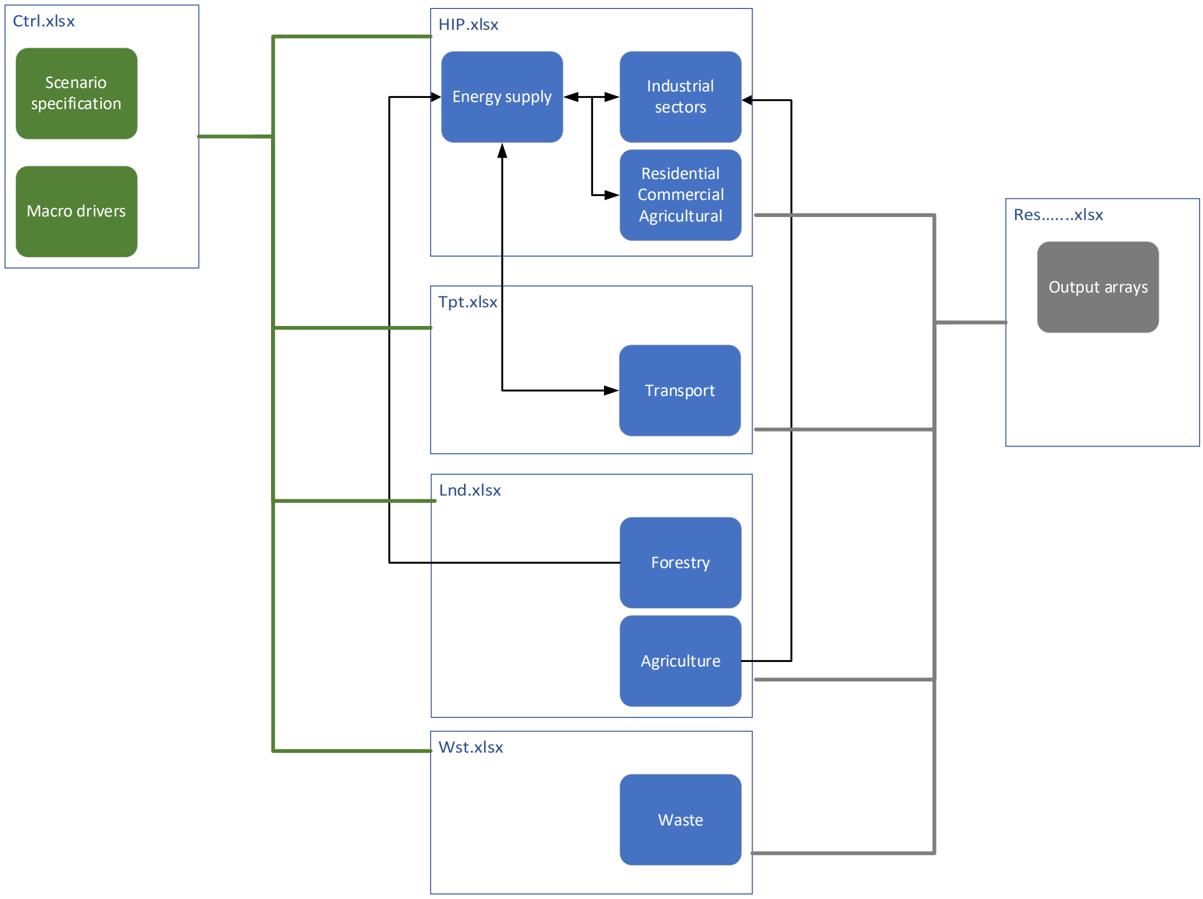

Figure 1 The structure and linkage between workbooks of the ENZ model

The **control** workbook (Ctrl.xlsx) is the control panel for the model and is used to set the main model scenario parameters and to initiate a model run. The **Ctrl** workbook has a number of underlying Visual basic routines which pass settings to the other workbooks, drive some of the workbook interactions and copy back specified output arrays into a results file.

The **HIP** workbook contains the underlying data and projection functionality for energy use and emissions from industrial, residential, commercial and agriculture sectors. The workbook includes detailed models of electricity supply and fossil gas production and has significant interactions with the **transport** workbook. A number of summary emissions arrays which include emissions from the other workbooks are built up in the **HIP** workbook.

The **transport** workbook (Tpt.xlsx) contains the underlying data and projection functionality for transport activity and emissions. This workbook interacts heavily with the **HIP** workbook by setting the requirement for refined fossil fuels, biofuels and electricity demand from electrification of transport. Transport outcomes are driven by the price of electricity which is calculated endogenously and passed from the **HIP** workbook.

The **land** workbook (Lnd.xlsx) contains the underlying data and projection functionality for activity and emissions source or removals in the agricultural and forestry sectors (note that emissions from energy use in the agricultural sector are included under the **HIP** workbook and the **land** workbook includes emissions from livestock). Forestry and agricultural production projected in the **land** workbook provides an input to the **HIP** workbook where it sets the requirement for food processing and the availability of biomass as an energy resource.

The **Waste** workbook (Wst.xlsx) contains the underlying data and projection functionality for activity and emissions in the waste sector. This part of the model is controlled by the **control** workbook and passes emissions data to the **HIP** workbook for summary emissions reporting.

When a model run is completed the output arrays which have been selected are saved into a unique **results** file which is identified with a timestamp.

Note that:

- All workbooks pass summary data back to the **HIP** workbook for aggregated emissions reporting.
- The data passed from the **land** and **waste** workbooks to HIP are not by live links. During a model run, calculations are first completed in the land and waste books and saved to intermediatory output files (LOut_01.xlsx and WOut_01.xls). The run routine then copies and pastes the relevant output arrays into the **HIP** workbook as hardcoded values.

Model use

The model allows a scenario-based approach for projecting future emissions and other outcomes of interest. A scenario is a set of coherent assumptions about how the world might develop. A scenario-based approach allows the user to examine alternative ways that future emissions could evolve and the impact of some of the key uncertainties around assumptions.

The ENZ model is controlled from the **Scn** worksheet of the **control** workbook. This sheet is referred to as the 'control panel' from here on in.

Defining a scenario

Scenarios are defined by a set of scenario parameters which drive outcomes in one or multiple dependent workbooks. Parameters can either specify a key input – such as the oil price – or set an alternative modelling dynamic which is to operate. The scenario parameters are broken down under the categories of Emissions values, Economic drivers, HIP factors, Transport factors, Land factors and Waste factors.

Scenarios are defined in the columns across the control panel, starting from column H. The entries in column H of the **Ctrl** workbook define the current policy reference (CPR) scenario. Scenarios can be defined with reference to another scenario. Where a parameter is left undefined, the scenario inherits the parameter of the reference scenario. In this way it is possible to specify only the parameters which are different.

When completing a model run, a scenario will be run if an 'x' is set in the run column (row 2).

The **Ctrl** workbook comes prepopulated with the scenario definitions which were used in *Ināia tonu nei – a low emissions future for Aotearoa*. New scenarios can be added as new columns.

Common scenario parameters

The emission pricing and economic driver projections are used in a number of the model workbooks. The projections of these are built up in the **Assumptions** worksheet of the **control** workbook. The functionality on this **Assumptions** worksheet is largely the selection of projections in predefined arrays based on the scenario parameter settings which are then linked to the model workbooks. There are options for defining new emission value paths and it is simple to adjust settings for the other arrays.

Running the model

The *run* button on the control panel is pressed to run the model. This launches a routine which steps through all the selected scenarios, performs the model calculations and saves the specified output arrays into a results file.

When this routine runs it will check if the land and waste output files (LOut and WOut) already contain results arrays with the relevant scenario parameters. If they already do then it will not update these files. If they don't, then it will run the Land and/or Waste models and save the relevant results arrays in the land and waste output files. This functionality speeds up run times by not having to constantly re-run the Land or Waste models for each scenario. (Noting that there is no feedback of energy prices from the Transport or HIP models to the Land or Waste models, but the output from the Land and Waste models does feed into the Transport and HIP workbooks).

Because of this, if the land and waste models are altered in terms of their functionality (i.e. as distinct to selecting different scenario parameters in the **Ctrl** workbook) then all the saved results arrays in the output files should be manually cleared in order for them to correctly update. This is not something that a user who merely wishes to explore the implications of different scenario parameters will need to do.

Specifying output arrays

Key results are condensed into arrays within the model workbooks which are identified as named ranges. In order for these outputs to be saved into the results file they need to be selected under the outputs section at the bottom of the control panel. Note that the number of output arrays has a big impact on the time it takes for the model to run. It is generally recommended that only the output arrays which are of interest are selected for inclusion in the results file.

The results file

When the model runs it copies the selected output arrays for the specified scenarios into a results file. The filename begins with 'Res_' and is appended with a datetime string e.g. the file 'Res_202107161620' is a record of a model run completed on the 16th of July 2021 at 4.20pm. The results files are saved into the Results directory in the directory where the model runs.

The 'RunParams' worksheet of the results file is an exact copy of the control panel and so records the particular settings for each model run. The 'Runs' worksheet maps the scenario runs onto the results worksheet names which have the convention 'R_X' where X is the scenario number. The results worksheets have a full record of the saved output arrays for each scenario run.

Live viewing a scenario

A scenario can be selected for live viewing by setting cell D2 of the Ctrl workbook to the desired scenario number (e.g., the demonstration path is scenario number 6). This sets the scenario parameters in all of the dependent workbooks (HIP.xslx, Tpt.xlslx, Lnd.xlsx, Wst.xlsx) to the values defined in the **control** workbook and so enables one to inspect in detail the model calculations.

The **waste** and **land** workbooks take inputs only from the **control** workbook and so they can be opened and inspected without complications. However, because of the interactions between the HIP, transport and other workbooks, and the use of hardcoded values, the following steps should be taken to ensure they are correctly live viewed:

- The **transport** and **HIP** workbooks use live links and should be opened together using the *load HIP & Tpt* button on the control panel. This routine pastes in hardcoded values from the land and waste output files for the selected scenario. Cell A1 in the HIP worksheet of the **HIP** workbook confirms if the correct land use and waste scenarios have been loaded. If the cell includes 'Calc: OK Scen: OK' then the land and waste data has been correctly loaded. If not, press the *load HIP & Tpt* button.

- The *Iterate Prices* button may also need to be run. Several electricity pricing arrays in the **HIP** workbook are calculated dynamically based on various factors including demand. Demand outcomes are, in turn, driven by energy prices as they determine fuel choice decisions. To resolve this circularity the routine copies the output arrays of prices and pastes them as fixed values to feed in as inputs to various formulae which, amongst other things, determine fuel choices and consequently demand, which in turn affects prices. Repeating this process of copying output prices and pasting them as values for inputs several times allows the routine to iterate to a solution, while keeping the spreadsheets numerically stable. The message in cell A1 will confirm if the correct prices are set – if the message includes 'Prices: OK' then they have been correctly set. If the message reads 'Prices: INCORRECT!' then the iterate prices routine needs to be run.

The HIP workbook (HIP.xlsx)

Overview

The **HIP** workbook includes a breakdown of all non-transport energy consuming sectors and makes projections of future levels of activity, energy consumption and emissions. The model represents a diverse range of emitting activities and varied opportunities to mitigate. Some industries operate at a single site and there is considerable uncertainty around their future operation, whereas other sectors consist of many agents. A varied approach to modelling is applied.

The workbook also includes modules representing energy supply which interact with the consuming sectors through prices and also contribute system emissions. Electricity generation and fossil gas production are represented at a high level of detail within ENZ with endogenous supply modules representing generation/production and transmission/distribution to consumers. Biofuels, oil and coal are also modelled in ENZ, but at a more basic level.

Figure 2 below illustrates the core functions and interactions within the **HIP** workbook and with the **transport** and **land** workbooks in ENZ.

Description of the HIP worksheets

There are three worksheets within the **HIP** workbook. The **Assumptions** worksheet summarises the key constants and assumptions that drive the model. The relevant macro driver assumptions which flow through from the control workbook are staged here, and the HIP relevant scenario parameters are applied to select assumption values applied in each scenario. Note that there are many other assumptions which are selected and applied in other parts of the workbook. The worksheet also summarises the key equipment costs which are considered in the fuel switching calculations and economic output.

The **HIP** worksheet contains most of the sector detail and the functionality depicted in Figure 2. The worksheet is structured with the calculations of energy prices at the top of the worksheet. Similar dynamics and mitigations exist for the residential, commercial and agriculture sectors and so these are grouped below, followed by the industrial sectors. Fossil gas and electricity demand from all sectors is collated at the bottom of the worksheet and produced or generated based on the demand above. The fossil gas production and electricity generation modules calculate the wholesale price which is an input to the energy prices calculation at the top of the worksheet.

The **Output** worksheet collates the fuel consumption of all sectors and summarises emissions in accordance with the National Greenhouse Gas Inventory (the Inventory) and CCC conventions. A disaggregation by greenhouse gas type is also applied in order to give summary reporting by CO_2, N_2O, CH_4 and F-gases. The **Output** worksheet also includes the calculation of renewable energy shares from the energy consumption totals.

Summary economic reporting of systems costs and consumer and household bill impacts is also included in the **Output** worksheet. These costs are built up from the energy cost calculations in the **HIP** worksheet and assumptions about capital and operating costs for equipment.

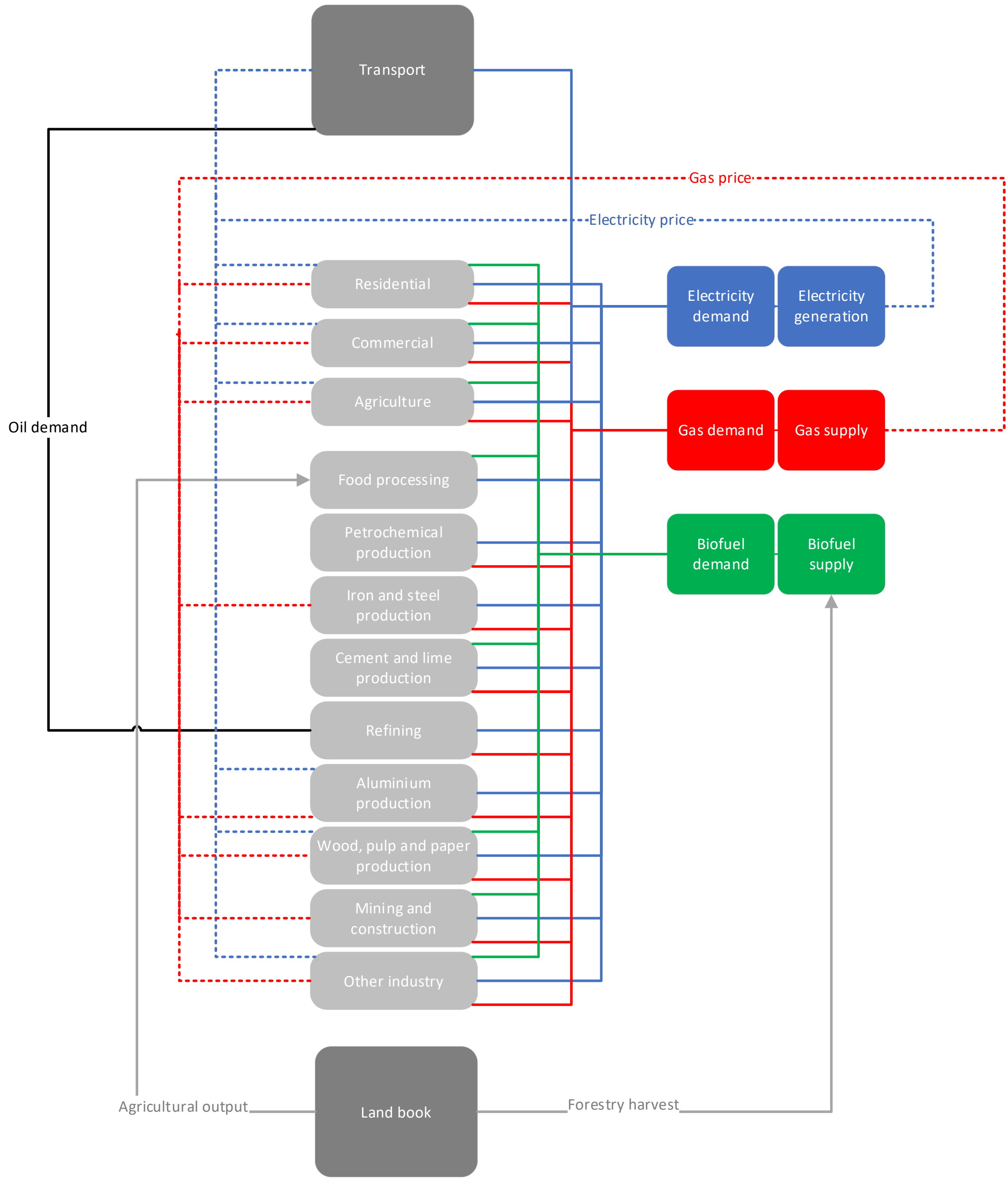

Figure 2 The HIP workbook and linkages with land and transport, showing energy consuming and emitting sectors and their interaction with dynamic supply and demand modules. Note that this is a simplification of the model and not all linkages are shown.

Input data

The Greenhouse Gas Inventory (the 'Inventory') provides a record of annual emissions in Aotearoa from 1990 to 2019. This data source follows a recognised system of emissions classification based on an established reporting framework. The Inventory is the highest tier data source for ENZ and provides the reference from which emissions are projected.

The Inventory includes a detailed disaggregation of emissions into sectors, activities and types. Emissions have been reclassified in ENZ into sectors which are considered better suited for modelling and summary reporting. The mapping between the Inventory and ENZ classifications is given in the table below.

ENZ classification	Inventory match
Residential	1.A.4.b Residential
Commercial	1.A.4.a Commercial/Institutional
Agriculture, forestry & fishing	1.A.4.c Agriculture/Forestry/Fishing
Food processing	1.A.2.e Food Processing, Beverages and Tobacco
Petrochemical production	Gaseous fuels from 1.A.2.c Chemicals 2.B.1 Ammonia Production 2.B.8.a Methanol
Iron & steel production	1.A.2.a Iron and Steel 2.C.1 Iron and Steel Production
Cement & lime production	1.A.2.f Non-metallic Minerals 2.A.1 Cement Production 2.A.2 Lime Production 2.A.4 Other Process Uses of Carbonates
Refining	1.A.1.b Petroleum Refining 2.B.10 Hydrogen Production
Aluminium production	2.C.3 Aluminium Production
Wood, pulp & paper production	1.A.2.d Pulp, Paper and Print
Mining & construction	1.A.2.g.iii Mining (excluding fuels) and quarrying
Other industry	Non-gaseous fuels from 1.A.2.c Chemicals 1.A.2.b Non-ferrous metals 1.A.2.g.i Manufacturing of machinery 1.A.2.g.vi Textile and leather 1.A.2.g.viii Other
Electricity generation	1.A.1.a Public Electricity and Heat Production 1.B.2.d Other (Geothermal)
Other fossil fuel production	1.A.1.c Manufacture of Solid Fuels and Other Energy Industries 1.B.1 Fugitive emissions from solid fuels 1.B.2 Fugitive emissions from oil and natural gas

Fossil fuel consumption has been calculated from Inventory fuel combustion emissions by assuming constant emission factors for each fuel. The Energy Balance tables published by MBIE have been used to enrich the model of energy use as it provides non-energy use of fuels and statistics for renewable energy and electricity. There is imperfect matching between fuel consumption values derived from Inventory emissions and the Energy Balance tables due to a difference in methodology. Where conflicts exist, fuel totals derived from the Inventory are used.

Residential, commercial and agriculture sectors

Energy use in the residential, commercial and agriculture sectors (RCA) is disaggregated by fuel and end use. EECA's energy end use database (EEUD) is used as a base year representation of how energy is used in terms of space heating, water heating, process heat, lighting, and other electrical and motive power.

Most of the energy use in residential and commercial sectors is through space and water heating in buildings. Using a building stock model, the demand for useful heat for these applications is projected. A number of dynamics are represented in this model including the construction of new buildings, the retrofit of existing buildings, and the demolition of old buildings. Improvements in energy efficiency which reduce the demand for useful heat are applied by assumption for new buildings and retrofits – this is adjusted by the scenario parameter *Building thermal efficiency and appliance efficiency improvements*. The assumed population growth inputs to the model through the total number of ICPs (individual connection points).

The model projects how the current EEUD-derived mix of fuels and technologies for space and water heating will change in the future based on the relative costs of the two systems – the selection considers the combined appliance and delivered energy costs over the lifetime of each appliance, and distinguishes between fuel choices for property new-build situations and potential fuel-switching for existing properties. The appliance component of these costs is built up from the *Residential and commercial heating appliance costs* detail in the **Assumptions** worksheet and the energy costs are endogenous within HIP.

There is a functionality to override this consumer choice functionality with exogenous phaseout profiles of fossil gas, liquid and coal heating. These profiles are defined in the *Residential, commercial and agriculture fuel switching settings* section of the **Assumptions** worksheet and selected with the *Building heating and cooking fossil fuel phaseout* scenario parameter.

A large share of the energy use in agriculture is for off-road vehicles and machinery. Although there are a diverse range of activities that this term will encompass, it is assumed that electrification of these vehicle types will become increasingly feasible and economic in the future. The model uses the electrification of the heavy truck vehicle class in the **transport** workbook as a proxy for projecting the electrification of off-road vehicles and machinery in the **HIP** workbook. A basic fleet model is set out in the motive power section of the RCA model which applies the heavy truck fleet entry projection to independent assumptions around stock turn over. Note that this dynamic is also applied for motive power use in the industrial sectors.

The use of biofuel as a substitute for liquid fossil fuels for motive power is also applied in these sectors. This is set by the transport scenario parameter *Liquid bio-fuel supply setting* and the methodology is documented under the transport section of this manual.

Energy supply modules

ENZ includes detailed supply modules for electricity and fossil gas and basic modules for oil and coal. The demand for the fuel is built up from the projected consumption from the industrial, residential, commercial, agriculture and transport sectors. Energy losses through fuel delivery are applied on top of this, which then sets the requirement for electricity generation and fossil gas production. These modules meet supply with allocated resources (potential renewable projects for electricity generation and estimates of field potential for fossil gas).

The cost of fuels is built up from the wholesale price of production, the carbon cost from the modelled emissions value, the cost allocation from supply infrastructure, and a retail charge. These prices become inputs into the modelled fuel switching dynamic for the consuming sectors.

There is considerable complexity in the energy supply modules in ENZ. Their functionality is documented in the supporting technical note to this manual, *Modelling energy cost and prices – A technical note supporting Ināia tonu nei.*

Industrial sectors

For each industry a projection of activity is made which sets a demand for useful energy. Improvements in energy efficiency are applied which reduce this demand for useful energy and fuel switching transforms the energy supply to lower emissions fuels. The resultant fossil fuel combustion sets direct emissions for the sector and the demand for fossil gas, oil and electricity feed into respective energy supply modules.

The fuel switching dynamics are generally price driven – the model considers the relative costs of continuing to operate fossil fuel assets versus converting to electricity or in some cases biomass. The use of fossil fuels in industry is generally separable into providing process heat or motive power. Industrial sector fuel use in ENZ is disaggregated on this basis as these applications have different fuel switching options.

Food processing

This module first projects the demand for useful heat at a regional level based on the outputs of the agricultural module of the **land** workbook and using a base year map of process heat demand published by MBIE. This demand is disaggregated into useful heat from coal, fossil gas and diesel for the subsectors of dairy, meat and other food processing based on the EECA energy end use database.

Energy efficiency improvements are applied based on scenario parameters to reduce the demand for boiler heat based on scenario settings. The efficiency improvements cause an increase in electricity demand as it is assumed that some of these measures involve the integration of heat pumps.

The residual heat from coal, fossil gas or diesel boilers can then be converted to biomass or electricity. The module considers the availability of forestry residue and pulp logs which can be used as boiler fuel for each region and projects the costs of delivered fuels. The fuel switching considers the relative cost of continuing to operate fossil fuel assets (based on fuel costs and carbon costs, and non-fuel operating costs) versus investment to replace boilers or cofiring and paying for an alternative fuel. Fuel switching options are ranked based on the costs of abatement and taken up at the point they become cost effective. This is subject to fuel availability constraints and conversion rate constraints. The modelled emissions value drives much of the fuel switching.

The main scenario parameters which influence this sector are the *Food processing energy efficiency scenario, Biomass fuel availability, Forest residue price* and *Pulp log price.*

Petrochemical production

This module includes methanol, urea and historical synthetic petrol production. The future level of activity of this sector is projected based on exogenous assumptions around the timing of plant closure. The three methanol producing trains and the urea plant in Taranaki are modelled explicitly and it is assumed they operate at a constant rate. The sequencing of plant closure, or their continued operation, is defined in the *Petrochemical production scenarios* section of the **Assumptions** worksheet and selected using the *Petrochemical exit scenario parameter* on the control panel.

Iron and steel production

This module projects a constant level of future steel making activity with the ability to convert the Glenbrook operation to a zero-emission process. This conversion date is exogenously specified on a scenario basis using the parameter *Convert steel mill to zero carbon-process* on the control panel – it is not cost driven. The plant is modelled to convert to a hydrogen-based process which removes the demand for fossil gas and coal and increases the demand for electricity. This conversion also switches off the self-cogeneration which currently operates at the Glenbrook steel mill and so further increases the demand from the grid.

Cement and lime production

This module projects a constant level of future activity for domestic cement, lime and glass production. Substitution of coal with tyre-derived-fuel (TDF) and biomass is applied and reduces the emissions from process heat. The biomass uptake is price driven and regionally constrained (most of the sector coal use is for cement production in Northland) while the TDF substitution is exogenously specified.

The emissions from the combustion of fossil gas and diesel are fixed as these are considered high-temperature applications which are difficult to substitute. Industrial processes and product use (IPPU) emissions which result from the calcination reaction are also constant.

Refining

Domestic demand for refined oil is projected based on the demand from the transport, industrial, residential, commercial and agriculture sectors. The refinery operates at its current capacity until the time when this exceeds domestic demand – i.e. it is assumed that imported oil is displaced before domestic product. Fuel use and electricity demand is proportional to total production. The supply of biofuel does not involve the modelled refinery.

It is possible to exogenously close the refinery via a scenario parameter in the control panel (i.e. New Zealand moves to importing all its refined fuel). This will subsequently halt all emissions associated with fuel refining.

Aluminium production

The future activity of the aluminium smelter is projected based on exogenous assumptions around closure or continued operation. These scenarios are defined in the *Tiwai exit scenarios* of the **Assumptions** worksheet and are selected using the *Tiwai smelter exit scenario* parameter on the control panel. The control panel also includes an option to convert the smelter to a zero-emission process (i.e completely removing IPPU emissions) – this setting was not used for the Commission's modelling.

The timing of the closure of the smelter has flow on impacts for electricity generation and pricing in the model. The parameters outlined in the *Tiwai exit scenarios* section of the **Assumptions** worksheet define this impact.

Wood, pulp and paper production

This sector is disaggregated within the model into pulp and paper production and wood processing. It is assumed that these subsectors maintain a constant level of activity and demand for useful energy into the future.

Fuel switching from fossil gas and coal to biomass for process heat is price driven within the model. A cost of abatement for fuel switching is calculated based on the relative delivered energy prices. As the emissions value approaches this cost of abatement for fossil gas and coal conversion, the share of biomass increases. Rate constraints set the maximum speed at which the fuel share can change and is assumed that some proportion of fossil gas will always be required for high temperature process heat applications. A large proportion of pulp sector fossil gas use is consumed at the Kinleith plant and its conversion to a high efficiency recovery boiler is exogenously specified and varied between scenarios using the scenario parameter *Kinleith plant conversion*.

The wood processing sector also consumes significant amounts of diesel for motive power applications. These applications become electrified within the model using the off-road vehicles and machinery fuel switching dynamic described in the Residential, Commercial and Agriculture section of this manual. The use of biofuel as a substitute for liquid fossil fuels for motive power is also applied in this sector. This is set by the transport scenario parameter *Liquid bio-fuel supply setting* and the methodology is documented under the transport section of this manual.

Mining and construction

A growth in demand for useful energy is projected for the mining and construction sector. Most of this energy demand is for motive power and ENZ models the conversion of diesel motors to electric motors by applying the off-road vehicles and machinery fuel switching dynamic described in the Residential, Commercial and Agriculture section of this manual. The use of biofuel as a substitute for liquid fossil fuels for motive power is also applied in this sector. This is set by the transport scenario parameter *Liquid bio-fuel supply setting* and the methodology is documented under the transport section of this manual.

Process heat makes up a small proportion of sector fuel usage and the modelled boiler conversion in the food processing sector is used as a proxy for fuel switching in mining and construction.

Other industry

This industry collates the residual energy use and IPPU emissions which are not represented in the previous sectors. A growth in demand for energy in this sector is projected which is based on the historical relationship with GDP. The growth projected in this sector therefore depends on the exogenous GDP projection used a macro driver for this modelling.

Fuel switching energy use in other industry is based on detailed dynamics represented in other parts of the model. For process heat, the boiler fuel switching dynamic in the food processing sector is used as a proxy for the conversion from fossil fuels in other industry. For motive power applications the off-road vehicles and machinery fuel switching dynamic described in the Residential, Commercial and Agriculture section of this manual is applied.

Fossil fuel production

Although not outlined explicitly in the **HIP** worksheet, fugitive emissions from the production and distribution of fossil gas are accounted for in ENZ. It is assumed that these emissions remain proportional to relevant proportions of fossil gas volumes. For example, fugitive emissions from the distribution of fossil gas are proportional to total distribution pipeline volumes. These emissions projections are built up under the *1.B Fugitive emissions (ktCO2e)* section of the **Output** worksheet.

Key linkages

The **HIP** workbook provides outputs and accepts inputs from all the other model workbooks. By including these key linkages ENZ can build up a systems perspective of emissions. The main links are depicted in Figure 2 and are summarised as follows:

- Regional agricultural production of milk solids and meat is an input from the **land** workbook. This sets the requirement for process heat from the food processing sector which is modelled in HIP.

- Regional harvest of pulp logs and the availability of forestry residue is an input from the **land** workbook. These sources of biomass are utilised as boiler and kiln fuel for industrial process heat and for the production of liquid biofuels.
- The demand for refined oil (diesel and petrol) for transportation is an input from the **transport** workbook. The total demand for refined oil sets the maximum operation of the refinery which is modelled in HIP.
- The demand for electricity for the electrification of transport is an input from the **transport** workbook. This sets the requirement for electricity generation which is modelled in the **HIP** workbook. The **HIP** workbook calculates the price of electricity which feeds back through into **transport** workbook and influences electrification of transport.

The Transport (Tpt.xlsx) workbook

Overview

ENZ includes road transport, rail, shipping and aviation, with the latter two split into domestic and international. Road vehicles are divided into light passenger vehicles (cars and SUVs), light commercial vehicles (vans and utes), motorcycles, buses, medium trucks (defined as less than 30 tonnes gross vehicle mass (GVM)) and heavy trucks (over 30 tonnes GVM). ENZ models the dynamics of the transport fleet, such as vehicle scrappage and the pattern of usage over a vehicle's life, based on fleet statistics published by the Ministry of Transport. The model also includes different fuel types: fossil fuels, electricity, hydrogen, and biofuels.

ENZ models the main levers which influence emissions, including transport demand and the size and makeup of the vehicle fleet, based on factors driving them, such as population. It also accounts for projected improvements in vehicle efficiencies.

ENZ takes account of behavioural change, including mode shift for passenger (e.g. between cars and public transport) and freight (e.g. between trucks and rail) transport, and reduced demand for travel. These behavioural changes are input as scenario assumptions; ENZ does not model changes in travel behaviour in response to factors such as changes in fuel prices. ENZ draws on underlying regional travel data and projections from the Ministry of Transport and aggregates these into five broad regions: Auckland, Waikato, Wellington, Canterbury, and the rest of Aotearoa.

Travel and freight demand

The Transport workbook uses the Ministry of Transport's Transport Outlook base case, updated in 2020 for baseline travel demand projections. This outlook gives the demand for household travel, commercial travel, freight, and domestic aviation by region in 5-year intervals. The outlook data is located in the **Travel demand & mode** worksheet of the **transport** workbook where it is converted into an annual timeseries (shown on far right of the worksheet) and passenger travel is aggregated into 5 regions (Auckland, Waikato, Wellington, Canterbury, Rest of NZ). Freight and commercial travel are aggregated at a national level.

ENZ makes adjustments to MoT baseline to account for differences in the population and GDP assumptions selected for the ENZ scenario run, and those used by MoT for producing its baseline projections. The *Population & GDP impact on travel demand* control panel parameter determines the extent to which different components of travel demand are driven by population and GDP. The settings for this parameter are defined in the **Travel demand and mode** worksheet.

Reductions to the baseline travel demand can be applied in ENZ on a scenario basis using the control panel parameter *Travel demand reduction.* This setting applies percentage reductions to the baseline as defined in the *Scenario build step 2* section of the **Travel demand and mode** worksheet. Reductions can be specified by region or as a national average for different transport types. The CCC's scenarios considered only reductions in household travel demand applied evenly across all regions.

A reduction in demand for travel and freight due to the covid-19 pandemic is applied to this projection. The settings in the model apply a varying impact across different travel modes across the calendar years 2020, 2021 and 2022. It is possible to select between different impact scenarios for the pandemic in the model using the *Covid factor* scenario parameter – however, note that there is only a single set of impact parameters defined in this version of the model.

Mode shift

ENZ includes the functionality to change the share of modes which satisfy the demand for travel. The *Passenger mode shift* scenario parameter selects between the mode shift scenarios defined in line in the *Scenario build step 3* section of the **Travel demand & mode workbook**. Mode shifts are defined at a regional level for passenger person-kilometre-travel across the categories of pedestrian, cyclist, micro-mobility, local train, local bus, local ferry, motorcycle and taxi/vehicle share. Light vehicle travel makes the up the residual travel demand. For national freight, travel can shift from road to rail and costal shipping based on the *Freight mode shift* scenario parameter. Note that mode shares changes are specified as relative to the MoT baseline mode share projections at 5-year intervals.

Road transport

ENZ includes representations of the following vehicle classes:

Vehicle class	ENZ abbreviation
Light passenger vehicle (car, SUV)	LPV
Light commercial vehicle (van, ute)	LCV
Medium trucks	MT
Heavy trucks	HT
Bus (includes public transport buses and coaches/other)	Bus
Motorcycles	MC

The travel demand projections are translated into vehicle-kilometres travelled (VKT) for these vehicle classes in the *Resultant scenario projections of travel* section of the **Travel demand & mode** workbook. This translation applies assumptions and changes to the split between LPV and LCV use for passenger and commercial travel (this accounts for the use of utes for household travel). The *Passenger mode shift* scenario parameter is used to drive these changes.

For road freight, an operational/system efficiency factor is applied which reduces truck VKT per tonne-km of freight. This is selected using the *Road freight operational efficiency* scenario parameter and applied in the *Scenario build step 2* section of the **Travel demand & mode** worksheet. The VKT projections at 5-year intervals are converted into a yearly timeseries on the far right of the worksheet.

A vehicle stock model which accounts for turnover of the vehicle fleet is set out in the **Road** worksheet. The number of vehicles for each vehicle class is calculated based on the total projected VKT divided by the VKT/vehicle. The VKT/vehicle projection used in the model is based on the MoT base case. Note that it demonstrates an increase in the VKT/vehicle (i.e a greater utilisation of vehicles) due to the increasing proportion of PKT met by rideshare and other means. A short run adjustment factor is added to give a lag between reductions in VKT and reductions in the size of the vehicle fleet in scenarios with significant VKT reductions.

The annual rate of vehicle scrappage which applies to the stock model is specified as a percentage of fleet size for each vehicle type. The scrappage factors are set out in the **Road assumptions** worksheet. The annual number of vehicles entering the fleet is calculated as the difference between the total vehicles and the number scrapped.

New vehicles entering the fleet can be either:

- petrol internal combustion engine (*petrol)*
- diesel internal combustion engine (*diesel)*
- battery electric (*BEV*)
- plug-in hybrid electric vehicle (*PHEV*)

The selection of vehicles entering the fleet in ENZ can be based on their relative total cost of ownership (TCO). For each vehicle class the TCO is projected for all vehicle types in the *Project costs and performance of vehicles entering the fleet each year* section. This builds up capital, fuel and carbon costs, road user charges, maintenance and other costs.

Vehicle purchase costs

Average internal combustion engine (ICE) vehicle purchase costs have been derived by combining Stats NZ import value data and MoT fleet statistics. This is set out in the **Road assumptions** worksheet. Electric vehicle (EV) costs are built up from battery and other costs. Future battery costs in $/kWh are projected in the *Vehicle cost assumptions* section of **Road assumptions** and the scenario parameter *Global EV cost improvement* can be used to scale the rate at which costs reduce. Non-battery EV costs are also projected to decrease and fall below the relative price of an ICE. A cost penalty is applied to the EV purchase price to reflect NZ specific cost factors – the initial penalty is constant across scenarios and reduces linearly over time. The parameter *NZ-specific EV cost improvement* selects the date at which is ceases to apply.

Fuel and carbon costs

The model projects the fuel and electrical efficiency of electric and ICE vehicles and uses the MoT projections as a baseline. Further improvements in vehicle efficiency are applied using the *Road vehicle efficiency improvement* scenario parameter. Note that these projections include the effect of conventional hybrid vehicles on the average ICE fleet efficiency.

Petrol and diesel costs are calculated using the fuel prices projected in the *Modelled projections of fuel prices based on exogenous inputs* section of the workbook. These prices include the commodity price (which is tied to the exogenous oil price assumption) and fuel distribution price. The methodology behind these projections is described in *Modelling energy cost and prices – A technical note supporting Ināia tonu nei.* The carbon cost is calculated based on the modelled emissions value.

Electricity prices for charging electric vehicles, for each vehicle class are brought through from the **HIP** workbook. These prices are endogenous in the model. The methodology by which electricity prices have been calculated is described in *Modelling energy cost and prices – A technical note supporting Ināia tonu nei.* A charger cost is applied on top of the energy price, and a weighted average electricity cost is calculated based on assumptions around the proportion of charging at base and away from base (these locations see difference electricity prices and charger costs).

Other costs

The contributing costs are from road user charges and petrol excise duty, maintenance and other vehicle costs are projected based on the parameters in *Vehicle running cost assumptions* section of the **Road assumptions** worksheet.

Total cost of ownership

The vehicle cost components are built up into a total cost of ownership (TCO) over a specified ownership period and discounted back to a present value. The parameters used for the TCO calculation are specified in the **Road assumptions** worksheet and are selected using the *TCO-based uptake params* scenario parameters.

Vehicle capital costs are depreciated based on rates specified in line with the calculations. A fixed depreciation rate is applied for ICE vehicles. The initial EV depreciation rate is higher but it reduces to the ICE rate over time.

Note that an assumption is applied around the distribution of VKT over a vehicle's lifetime where it is assumed that annual VKT reduces with vehicle age. These assumptions were derived from MoT fleet statistics and are specified in the *Scrappage and travel patterns by vehicle age* section.

Fleet dynamics

In ENZ the type of vehicles entering the fleet can be selected based on TCO or be exogenously specified. The *EV uptake approach* scenario parameter sets the method. For TCO based vehicle selection, a purchaser choice function determines the EV market share of vehicles entering the fleet in each year as a function of the relative difference in TCO between an EV and ICE vehicle. The function used is a dynamically evolving logit curve, which shifts as the EV market share grows. There is a specified initial bias against EVs. The bias reduces as the EV market share grows, until it is eliminated when market share reaches a specified level. The parameters in the **Road assumptions** worksheet dictate the size of the bias and the width of the curve.

The model applies growth rate constraints on top of this economic selection to limit the rate at which EVs can penetrate the fleet. Rate constraint settings are defined in terms of a short-run and long-run limit. The settings are specified in the *EV uptake assumptions and scenarios* section of the **Road assumptions** worksheet and selected between using the *TCO-based EV growth constraints* scenario parameter.

There is also an option to phaseout the importation of ICE vehicles (i.e. simulating the implementation of an 'ICE ban' policy) which forces the model to select EVs. This phaseout is specified as a date by which the entry of ICE vehicles is prevented and a number of years to transition to this. The ICE phaseout parameters are set out in the *ICE import phaseout scenarios* of the **Road assumptions worksheet** and selected using the *ICE import phaseout scenario* parameter.

The fleet model is combined with the VKT projections into a projection of VKT by vehicle type. Note that a travel decay function is applied in generating this which reduces the share of travel undertaken by older vehicles. The function combines the scrappage curve and declining use over the vehicle life curve and has been derived from real world data and MoT reported vehicle statistics. The fleet model and projections of VKT are used to project fleet-wide fuel consumption, demand for electricity and direct emissions. These statistics are reported in summary arrays in the **Out** worksheet with relevant datasets linked through to the **HIP** workbook.

Note that it is possible to substitute liquid biofuels in these transport modes – see the section on liquid biofuels below for detail.

Rail, Shipping and Aviation

Projections of service and fuel demand, and the extent of electrification for rail, shipping and aviation are built up as indexes in the **Non-road** worksheet of the **Transport** workbook. The non-road transport sector is disaggregated into rail, local ferry, coastal shipping, domestic air, international air and international marine.

The model applies an annual rate of improvement in fuel efficiency based on the scenario parameter *Non-road vehicle efficiency improvement*. The demand for the transportation service flows from the MoT baseline projections, demand reduction and mode shift assumptions described earlier in this document. The energy demand index is the product of the fuel efficiency index and this service demand index.

Non-road transport services can electrify in ENZ based either on an exogenously specified profile, or by using a road vehicle class as a proxy. The approaches to electrification are set out in the *assumption* section of the N**on-road** sheet and selected based on the scenario parameter *Non-road transport electrification scen* setting. Note that the extent of electrification for rail cannot fall behind that for the heavy truck fleet as it is assumed these transport modes are interchangeable.

The resultant fuel demand and emissions for non-road transport flows through to the **Out** sheet. Note that it is possible to substitute liquid biofuels in these transport modes – see the section on liquid biofuels below for detail.

Liquid biofuels

The model includes the option to displace liquid fossil fuel with biofuel – this is enabled using the *Liquid bio-fuel supply* scenario parameter. This setting selects between the different uptake profiles of biofuels specified in the *Assumptions* section of the **Non-Road** worksheet of the **Transport** workbook. Profiles are specified in terms of a total volume which is ramped to between two specified dates.

The biofuel use is distributed in proportion to total liquid fuel consumption across specified sectors. In the CCC scenarios the biofuel is distributed amongst domestic land, air and marine transport and motive power applications in the industrial, residential, commercial and agriculture sectors. The fuel is applied in the **Output** sheets of the **Transport** and **HIP** workbook.

The Land workbook (Lnd.xlsx)

The **Land** workbook includes:

- Land used for agriculture and forestry
- Emissions from agriculture, with detailed representation of the dairy and sheep and beef sectors
- Emissions and removals by forests
- Production metrics for agriculture and forestry
- Available biomass supply by region

A range of mitigation measures are modelled in the categories of land use change, farm practice changes, and low-emissions technologies.

Description of the Land worksheets

- **Inputs** contains key input data arrays sourced from the Ministry for Primary Industries (MPI), including breakdowns of historic and projected emissions and underlying activity data.
- **Land use** contains assumptions for the land use change parameters in the control panel and calculates land areas for the chosen scenario.
- **Ag assumptions** contains assumptions for all other agriculture parameters, along with other fixed assumptions and data inputs.
- **Forestry assumptions** contains other fixed assumptions and data inputs related to forestry.
- **Agriculture** calculates emissions and other outcomes of interest for the dairy and sheep and beef sectors for the chosen scenario.
- **Forestry** calculates emissions and removals from forests and regional wood harvest volumes for the chosen scenario.
- **Out** brings together total agriculture emissions, including calculating emissions from fertiliser use, and calculates available biomass supply.

Land use

The module starts from a baseline scenario of future land use. This is based on the Ministry for Primary Industries' latest available emissions projections under current policy settings (the Government's 'With Existing Measures' scenario or 'Base case'). For these projections, MPI uses its Pastoral Supply Response Model, forestry projections model, and other information to project changes in agriculture and forestry activity. MPI then uses the Agricultural Greenhouse Gas Inventory model to project emissions. The input data from MPI are found in the **Inputs** worksheet.

Land use scenarios in ENZ are exogenously specified. In the control panel, the user selects settings for the following individual land use parameters:

- Exotic afforestation
- Native afforestation
- Deforestation (both exotic and native forest)
- Land use change to horticulture
- Land retirement (conversion of agriculture and forest land to other purposes, e.g. urban)

The assumptions tied to these parameter settings are specified in the **Land use** worksheet. The model calculates changes relative to the baseline scenario (MPI's 'Base case') and makes area adjustments to the different land use categories using specified area balancing assumptions.

Agriculture

The agriculture sector is split into dairy, sheep and beef, and other agriculture (which includes other livestock, horticulture and cropping). The first two are explicitly modelled in ENZ with a range of mitigation options. Sheep and beef farming as modelled as a single sector, using a weighted population metric to aggregate sheep and cattle numbers. Other agriculture is largely fixed as in the baseline scenario with adjustments for changes in land area only.

Livestock population

Baseline livestock population numbers out to 2050 are taken from the MPI emissions projections. Data from the New Zealand Dairy Statistics 2019/2020 are also used to project milking cow population from total dairy cattle. National average stocking rates are calculated based on total population and land area.

In the control panel, the user can select a different trajectory for average stocking rates with the *Stocking rate scenario* parameter. The assumptions for each parameter setting are specified in the **Ag assumptions** worksheet (section titled 'Future stocking rate scenarios').

Milk and meat production

Baseline milk and meat production are projected based on the MPI emissions projections and used as an input in the **Ag assumptions** worksheet. For milk, MPI provides total liquid milk production in litres. This is converted to total production of milk solids by linear extrapolation of the historic trend in milk solids per litre of milk. The Commission has estimated baseline meat production using historic and projected carcass weights provided by MPI along with livestock slaughter statistics. The model uses and reports estimated meat production from sheep and beef farming only – as a measure of output for the sector – excluding meat from dairy cattle and other livestock types such as deer.

In the model, production per animal (referred to as 'productivity') is first calculated based on two scenario parameters selected in the **Ag assumptions** worksheet:

- *Baseline productivity*. This defines an exogenous rate of improvement in production per animal which can decline over time. The standard setting used has been manually calibrated to match the total baseline production inputs described above.[1]
- *Stocking rate-production relationship*. This defines a parameter for an equation relating changes in average stocking rate to changes in productivity. This assumes production per animal can increase up a curve towards a maximum value as stocking rate is reduced. The scenario parameter defines the starting point on the curve, which determines the extent to which production per animal can be increased relative to the starting value.

This calculation takes place in the **Agriculture** worksheet. Total production is then calculated by multiplying production per animal by total population.

Production by region is estimated for use as an input into the food processing energy module. This is based on a mapping of regional production data from the New Zealand Dairy Statistics 2019/2020 and Beef & Lamb New Zealand Benchmarking Data 2018/2019. The calculation assumes regional shares of total production remain constant in the future.

Modelling livestock emissions, before impact of technologies

Emissions from livestock are first estimated in the absence of any low-emissions technologies that change how feed consumption and livestock numbers drive emissions. The effects of such technologies are then superimposed as described in the next section. This takes place in the **Agriculture** worksheet.

ENZ uses a simplified modelling approach which aims to emulate the emissions outcomes of MPI's more detailed Agricultural Greenhouse Gas Inventory model. The approach assumes a quadratic relationship between total CO_2-e emissions per head (E_h) and production per head (P_h):

$$E_h = aP_h{}^2 + bP_h + c$$

The model is calibrated by fitting coefficients (a, b, c) to the historic and projected baseline emissions data from MPI using the least squares method. For sheep and beef, there is a control panel parameter, *Meat emissions relationship*, which selects between a quadratic or linear

[1] Hardcoded values for the annual change in production per animal are used for the first 2-3 years of the projected period to match the MPI baseline.

relationship (a=0). The Commission has used the latter as it provides a better fit to the projected emissions.

The total emissions per head determined by the above formula are broken down into contributions from enteric fermentation, manure management and agricultural soils in line with the MPI baseline data.

Technologies to reduce livestock emissions

ENZ includes control panel parameters for the following low-emissions technologies:

- Low-methane breeding
- Methane inhibitors and vaccines (combined impact)[2]
- Nitrification inhibitors
- Urease inhibitor – see the following section on fertiliser use and emissions.

The settings for the first three parameters are specified in the **Ag assumptions** worksheet under the 'Mitigation technology scenarios' heading. The total emissions reduction effect for each technology – accounting for technology effectiveness and adoption rate – is specified in five-year intervals separately for the dairy and sheep and beef sectors. This is expressed as a percentage reduction for the relevant emissions category (enteric fermentation for low-methane breeding and methane inhibitors and vaccines; agricultural soils for nitrification inhibitors[3]).

Fertiliser use and emissions

In ENZ, reductions in fertiliser emissions can occur through the modelled impact of changes in dairy stocking rates and production on fertiliser use, and through increased use of urease inhibitor.

Total use of nitrogen fertilisers in the baseline scenario is derived from the MPI projections data in the **Ag assumptions** worksheet under the 'Fertiliser' heading. Historic shares of fertiliser use for dairy farming, sheep and beef farming, exotic forestry, horticulture and arable cropping reported by Stats NZ are used to estimate the historic fertiliser use per hectare for each land use. An assumed future annual rate of reduction is set to provide a good match with MPI's total projected fertiliser use.

For dairy farming, changes in fertiliser use per hectare are modelled in response to changes in stocking rate and productivity.[4] The model calculates dry matter consumption and estimates the initial feed surplus relative to baseline. Reductions in use of supplement, fertiliser, and grazing off to eliminate the feed surplus are calculated based on specified assumptions. This takes place in the **Agriculture** worksheet.

The share of urea fertiliser coated with urease inhibitor is set using the *Urease inhibitor* parameter in the control panel. Settings for this are specified in the **Ag assumptions** worksheet, in the form of a target usage level and year.

Total fertiliser use and emissions across the different land uses are calculated in the **Out** worksheet. Emissions from liming are assumed constant in line with the MPI projections, with the breakdown by land use type assumed to be the same as for nitrogen fertilisers in 2019.

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[2] Methane inhibitors and vaccines are assumed to be mutually exclusive, so cannot both be applied to the same animal.

[3] Nitrification inhibitors are assumed to only affect nitrous oxide emissions from animal excreta and have no effect on emissions from fertiliser use.

[4] Changes in fertiliser use per hectare for other land uses are not currently modelled in ENZ.

Forestry

As described earlier in the *Land use* section, trajectories for exotic and native afforestation and deforestation are exogenously specified. The chosen scenario settings feed through into the **Forestry** worksheet.

Modelling emissions and removals

Emissions and removals by forests are calculated using a modified activity-based approach, as used in New Zealand's Nationally Determined Contribution under the Paris Agreement. This approach is described in the Commission's 2021 advice to Government, *Ināia tonu nei* (see section 10.3, Accounting for land emissions). It uses "averaging" for harvested forests, where newly afforested land is credited with CO_2 removals up until its long-term average carbon stock (across multiple harvest cycles) is reached.

The calculations use age-based carbon yield tables, soil carbon and biomass carbon stock factors sourced from New Zealand's Greenhouse Gas Inventory 1990-2019. The methodology is consistent with the Inventory, apart from the use of averaging. ENZ precisely replicates results from MPI's forestry projections model.

Regional breakdown of exotic forest area

ENZ estimates exotic forest area across nine regions for the purpose of modelling regional biomass availability.

Historic afforestation is allocated among regions based on reported areas of post-1989 forests by planting year in the National Exotic Forest Description (NEFD). Future afforestation is allocated assuming the same estimated regional distribution as the total exotic forest estate in the first year of the projected period. Deforestation is allocated based on the region's share of the national area of forest at the assumed deforestation age.

Total area of pre-1990 and post-1989 forest by region is built up from a starting area in 1990 and the annual areas afforested and deforested.

Wood harvesting

Historic harvest areas up to 2018 are sourced from the NEFD and the Ministry for the Environment (MfE)'s forestry model. Future annual harvest areas are projected using a simple method to smooth out large interannual fluctuations due to the age profile of New Zealand's exotic forests. First, a rolling 20-year average area available to harvest is calculated. Second, a limit is applied on how much the harvest area can change from year to year. A final harvest area is then calculated which allows for any shortfall to be made up for in subsequent years.

The volume of wood harvested by region is then calculated. This calculation uses a yield table for the total recoverable volume (TRV) for a reference site, with regional multipliers to reflect different average growing conditions. The volume of pulp logs harvested is split out from the TRV for assessing their potential use for bioenergy.

Biomass supply

ENZ calculates the potential regional biomass supply of harvest residues and export pulp logs for use as bioenergy.[5] Potential harvest residue supply is calculated based on an assumed amount

[5] Functionality exists in the model to include wood processing residues, but this is not currently used.

recoverable as a percentage of TRV. For pulp logs, existing domestic pulp log demand is estimated and subtracted from the total volume harvested to estimate the volume of pulp logs that would otherwise be exported. The volume of wood biomass is converted to energy content and fed into the **HIP module**.

The Waste workbook (Wst.xlsx)

The **Waste** workbook calculates greenhouse gas emissions from disposal, biological treatment and burning of solid waste. It uses the same methodology as New Zealand's Greenhouse Gas Inventory 1990-2019 and projections of future waste activity by the Ministry for the Environment. Mitigation measures included are waste reduction, waste recovery/diversion, and increases in the coverage and capture efficiency of landfill gas (LFG) capture systems.

Description of the Waste worksheets

- **Baseline inputs** contains key input data arrays sourced from the Ministry for the Environment, including historic and projected waste placement.
- **Mitigation scenarios** contains the assumptions for the four scenario parameters in the control panel and converts the selected scenario values into annual time series.
- **Assumptions** contains other technical assumptions used in the emissions modelling.
- **Emissions calcs** performs the calculations of emissions from all solid waste categories.
- **Out** compiles the emissions results and other output arrays.

Waste generation

In ENZ, waste is categorised by destination landfill types and waste types as shown in the table below.

Historic and projected baseline waste generation across these categories is sourced from the Ministry for the Environment. This is based on MfE's latest available emissions projections under current policy settings (the Government's 'With Existing Measures' scenario). The exception to this is for non-municipal landfills, where the projected waste generation for organic waste types has been assumed constant at estimated 2019 levels.[6]

The *Waste reduction* parameter in the control panel selects a scenario for reduction in the quantities of waste generated across the different categories. The assumptions for each parameter setting are specified in the **Mitigation scenarios** worksheet. These are expressed as a percentage reduction relative to the baseline waste generation in the year. For this and the other parameters in the waste module, setting to zero gives the baseline scenario.

	Landfill types		
Waste types	Municipal Sub-categories by wet/dry climate, open/closed landfills, and sites without LFG capture	Non-municipal	Farm fills Sub-categories by farm type: Dairy, Other livestock, and Horticulture & arable
Food	x	x	
Garden	x	x	x
Paper	x		x
Wood	x	x	x

[6] The latest MfE emissions projections did not include a projection of non-municipal waste generation as the projection was instead based on extrapolation of the emissions trend. Future waste generation levels were assumed constant given difficulties projection forward from noisy and unreliable historic data.

Textile	x		x
Nappies	x		
Sludge/biological	x	x	
Inert	x	x	x
C&D[7]		x	
Bulk/miscellaneous		x	x
Industrial		x	x

Waste recovery/diversion

ENZ includes four options for waste recovery: recycling, compost, anaerobic digestion, and use for boiler fuel. The *Waste diversion* parameter in the control panel selects a scenario for the proportion of waste recovered across the different categories. The assumptions for each parameter setting are specified in the **Mitigation scenarios** worksheet. These are expressed as a percentage reduction of the residual waste that would be sent to landfill, after accounting for reduced waste generation.

Landfill gas capture

Improvements in LFG capture are represented through two control panel parameters, *LFG capture coverage* and *LFG capture rate*. The first determines the proportion of methane generated that is subject to an LFG system, while the second determines the proportion that is captured by the system. The assumptions for each parameter setting are specified for each landfill category in the **Mitigation scenarios** worksheet.

Modelling waste emissions

The calculations of emissions take place in the **Emissions calcs** worksheet.

Emissions from solid waste disposal to landfills are calculated using a First Order Decay model. This is the same approach used in New Zealand’s Greenhouse Gas Inventory based on Intergovernmental Panel on Climate Change (IPCC) guidance. Values for all parameters used in the model, such as degradable decomposable organic carbon content and decay constants, are sourced from the Inventory and contained in the **Assumptions** worksheet.

Emissions from composting, anaerobic digestion, and open burning of farm waste are calculated using simple emissions factors. The emissions factor for open burning of farm waste is a weighted average based on the assumed composition of waste burned.

Emissions from uncategorised landfills, incineration, and wastewater treatment and discharge are not explicitly modelled, and are assumed unchanged from the baseline scenario. These are relatively small sources of emissions and no mitigation options are currently included in ENZ.

[7] Construction and demolition waste