Future Energy Development

NERA ECONOMIC CONSULTING

LONG-DISTANCE HEAVY FREIGHT
TOTAL COST OF OWNERSHIP COMPARISON TOOL USER GUIDE

NOVEMBER 2021

VERSION 2.0

Comparison tool qualifications, assumptions and limited conditions

Ara Ake owns, or has a licence to use, all the intellectual property included in this long-distance heavy freight total cost of ownership comparison tool. The comparison tool is not to be used, reproduced, or distributed for any purpose other than those permitted by the terms of the Creative Commons – Attribution ShareAlike 4.0 International (CC BY-SA 4.0) license.

Ara Ake believes that the information provided by others which is incorporated or reflected in the comparison tool is reliable, but this has not been verified. No warranty is given as to the accuracy of that information.

The results produced by the comparison tool are solely for illustrative purposes and should not be used to forecast or predict actual results. Neither Ara Ake nor NERA accept any responsibility for any results produced by using the comparison tool. No obligation is assumed to revise the comparison tool to reflect changes, events or conditions which occur subsequent to the date on which the comparison tool was first made available on the Ara Ake website. Neither Ara Ake nor NERA have any responsibility for any modifications to, or derivative works based upon, the comparison tool made by any person.

The comparison tool is provided for use by businesses within New Zealand. Neither Ara Ake nor NERA have any liability for any use of the comparison tool for non-business purposes or outside of New Zealand. All decisions in connection with the use of the comparison tool or any results produced by the comparison tool are the sole responsibility of the user.

The comparison tool is provided "as is", without any warranties or representations, express or implied, about its accuracy or completeness. To the maximum extent permitted by law, neither Ara Ake (including its affiliates) nor NERA have any liability to any user of the comparison tool in respect of the information set out in the comparison tool or any actions taken or refrained from or decisions made as a consequence of that information or for any consequential, special or similar losses or damages, even if you advise Ara Ake of the possibility of those losses or damages.

Neither Ara Ake nor NERA accept any liability for (i) any third party software (ii) any liability that may arise as a result of delay or the user's failure to install any software updates, upgrades, modifications, bug fixes, enhancements or versions; (iii) the user's use of the comparison tool, whether or not this use is in the manner described in the comparison tool user guide; (iv) any viruses, worms, disabling, programming codes or other items that may be introduced to the user's system, network or hardware as a result of installation and/or operation of any third party software; or (v) any failure of the user's network and/or their IT system to comply with any requirements necessary to operate any third party software on which operation of the comparison tool is reliant and all other losses or damages arising from or relating to the user's network and/or IT system functionality impairments or failures, network connections and/or telecommunications links.

If Ara Ake and/or NERA are found to have any liability to any user of the comparison tool (or any other person), that liability is limited to $10.

The rights and obligations relating to the use of the comparison tool are governed in accordance with the laws of New Zealand and all money is in New Zealand currency.

Contents

1 Background and Purpose

Background

Our 17 December 2020 Stage 1 report, available here, summarised recent quantitative studies of using green hydrogen (H_2) for long distance heavy freight (LDHF) in New Zealand.

We concluded that no single existing work considered the broad set of options that could be used to decarbonise LDHF in New Zealand, and therefore comparison across studies regarding each potential option is presently difficult. Moreover, each largely focused on the “end point” (e.g., net zero by 2050) and did not adequately consider transitory options on the “path” to that end point.

We have therefore constructed a tool which allows the user to calculate the total cost of ownership (TCO) for a wider variety of fuel and vehicle combinations that could be used to decarbonise LDHF, both now and in the future, using the user’s own inputs to allow for flexibility and experimentation.

Purpose

The purpose of the comparison tool is to estimate the *relative* costs of using different vehicle+fuel combinations for a given freight trip. By nature of focusing on the costs of specific trips, some common costs for a trucking operator are not considered, as they do not vary between the different vehicle+fuel combinations.

Moreover, the focus of the comparison tool's TCO output is per tonne-kilometre, rather than kilometre, as this is a more representative measure of the true TCO where vehicles have differing payload capacities.

It is intended to be a flexible tool for interested parties determine **what needs to be true** for a vehicle+fuel combination to be the lowest-cost option for a given freight trip. This is a "comparison tool", rather than a specific forecast of TCO of the different vehicle+fuel combinations.

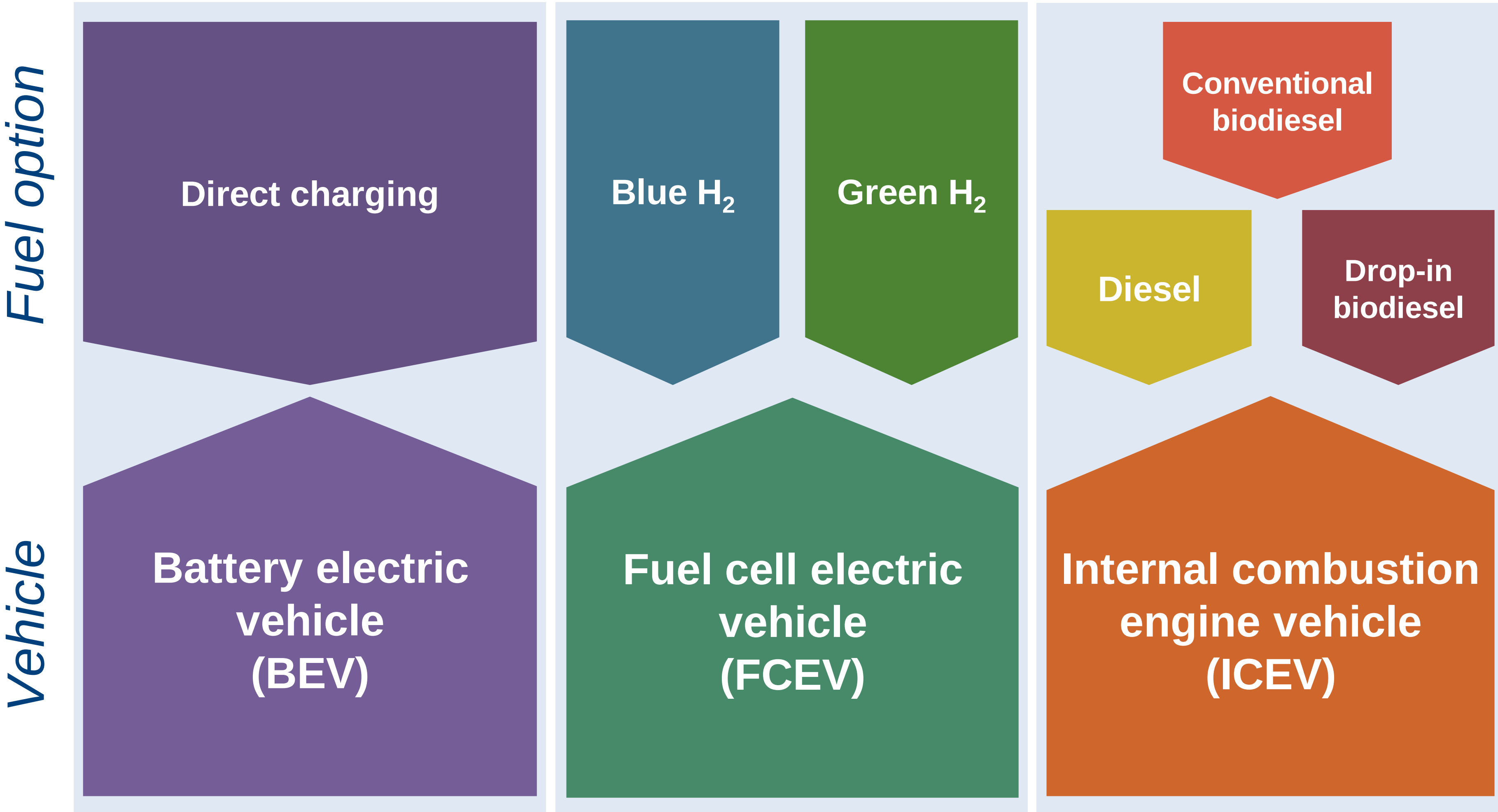
The intent is for users to run their own scenarios; to facilitate this, we have provided the means for users to easily save their scenarios.

We have provided a set of default reference assumptions so the comparison tool is functional "out of the box". While we have endeavoured to provide reliable and referenced sources, in many cases these are not available, already outdated or likely to be quickly outdated given the early stage of adoption of many of the technologies we have included. The default assumptions should therefore be considered illustrative only.

Users are encouraged to examine the provided references and input their own assumptions into the comparison tool.

Scope of TCO comparison tool

Fuel alternatives considered for each vehicle type



Note Different vehicle sizes can be modelled in the tool using inputs regarding vehicle cost, fuel efficiency, payload, road user charges, and (for BEVs) battery capacity. See page 22 for details on default scenarios provided within the tool for various vehicle sizes.

Scope of TCO comparison tool

Vehicle+fuel overview

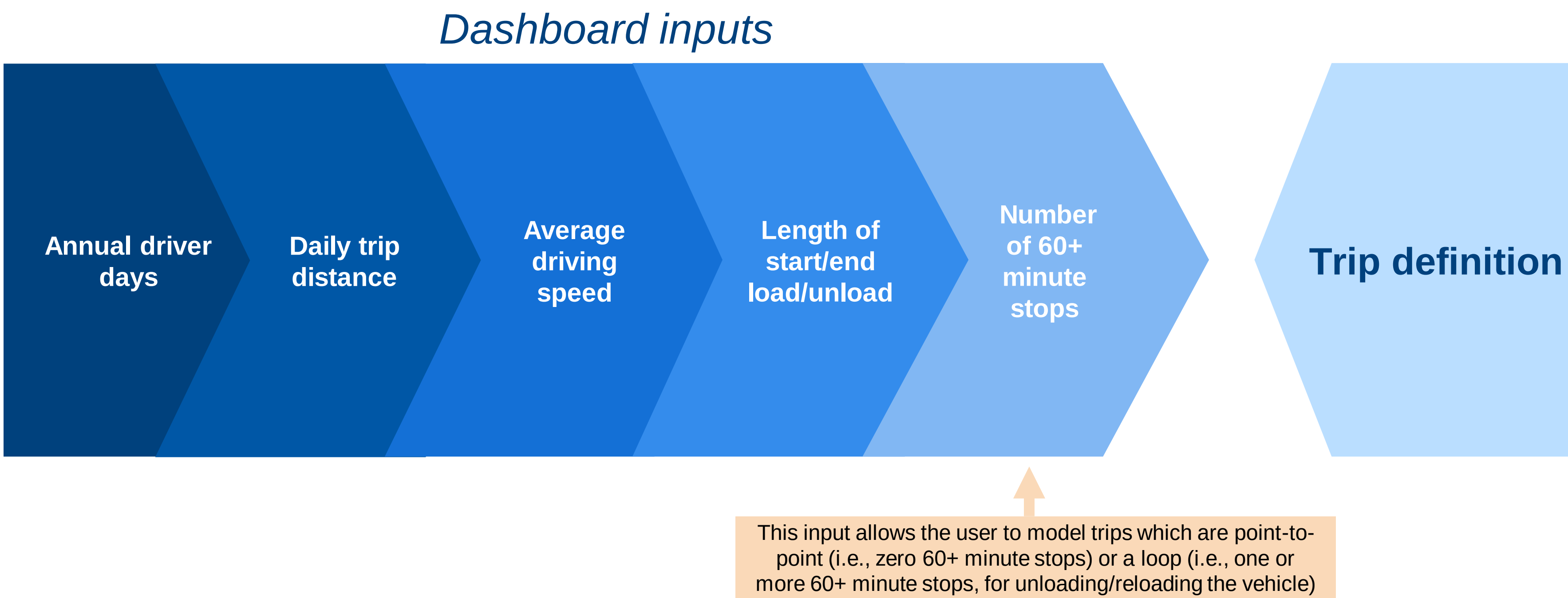
Direct charging	A ***BEV*** uses an electric motor in place of an internal combustion engine. This motor is powered by batteries within the vehicle, which are charged by an external power source. If renewable electricity is used to charge the battery, ***BEVs*** run on zero-emission energy. If the vehicle is plugged into the grid to charge its battery, there are likely to be emissions based on the generation powering the grid.
Blue H_2	A ***FCEV*** also uses an electric motor (with zero tailpipe emissions), but is powered by H_2 fuel, converted into electricity by a fuel cell to power the motor. Blue H_2 fuel is generated by steam methane reformation, which releases carbon. However, the developing technology of carbon capture and storage (CCS) could allow blue H_2 to become a low- to zero-emission fuel depending on the CCS efficiency.
Green H_2	Green H_2 fuel is produced by an electrolyser, which uses electricity to split water in to H_2 and oxygen. Like BEVs, if renewable electricity is used to power the electrolyser, ***FCEVs*** run on zero-emission energy. If grid electricity is used to power the electrolyser, there are likely to be emissions based on the generation powering the grid.
Diesel	The use of diesel in ***ICEVs*** is the status quo. The emissions released from using diesel fuel in an ***ICEV*** are charged a carbon price.
Conventional biodiesel	Conventional biodiesel is a form of diesel produced from plant or animal materials and used in an ***ICEV***. This fuel may be carbon neutral depending on the emissions profile along the supply chain. Conventional biodiesel must be blended at relatively low levels to be compatible within a standard diesel vehicle. To use higher blends or be used neat, a standard diesel vehicle would need modification.
Drop-in biodiesel	Drop-in biodiesel, also called renewable diesel, can be used directly in ***ICEV*** engines without modification as it is chemically identical to fossil diesel. Depending on upstream supply chains, this fuel may also be carbon neutral.

2 Comparison tool methodology

Driving profile and trip definition

TCO is determined using a standardised trip across vehicles

Underlying the TCO calculation for **all vehicle types** are parameters defining a standardised trip, which the vehicle is assumed to make each day the vehicle is driven. This trip definition remains stable across vehicles and (where relevant) through time.



! New Zealand law limits commercial drivers to 13 cumulative hours of work in a 24-hour period. As such, if the user defines a trip in which a single driver could not complete the trip in a single workday, red alerts will appear with the relevant vehicle+fuel. Certain trips may require BEVs to stop for additional time to charge the vehicle, which will add to the labour hours of the trip.

Driving profile and trip definition

Freight task analysis

Within the comparison tool, an analysis of EROAD's aggregated fleet movement data is offered to provide the user context for New Zealand's road freight task on the tab ***Freight task analysis***. The analysis aggregates all daily truck trips collected by EROAD in 2020 into weight bands (as defined below) and 100km-increment distance bands to show the types of road freight trips taken in New Zealand.

Weight bands

3.5t - 7.5t | 7.5t - 10t | 10t - 20t | 20t - 25t | 25t - 30t | 30t+

Following this analysis, statistics on driving behaviour for each distance+weight band trip type are presented in Table 1 of the ***Freight task analysis*** tab. Items in this table can be mapped as direct inputs into the comparison tool to create a trip definition. These items are displayed in **red** below.

Table 1 trip statistics

- Median annual days driving
- *Estimate within chosen distance band*
- Average speed
- Average length of 15+ min stop
- Total length of 15+ min stop time less un/load

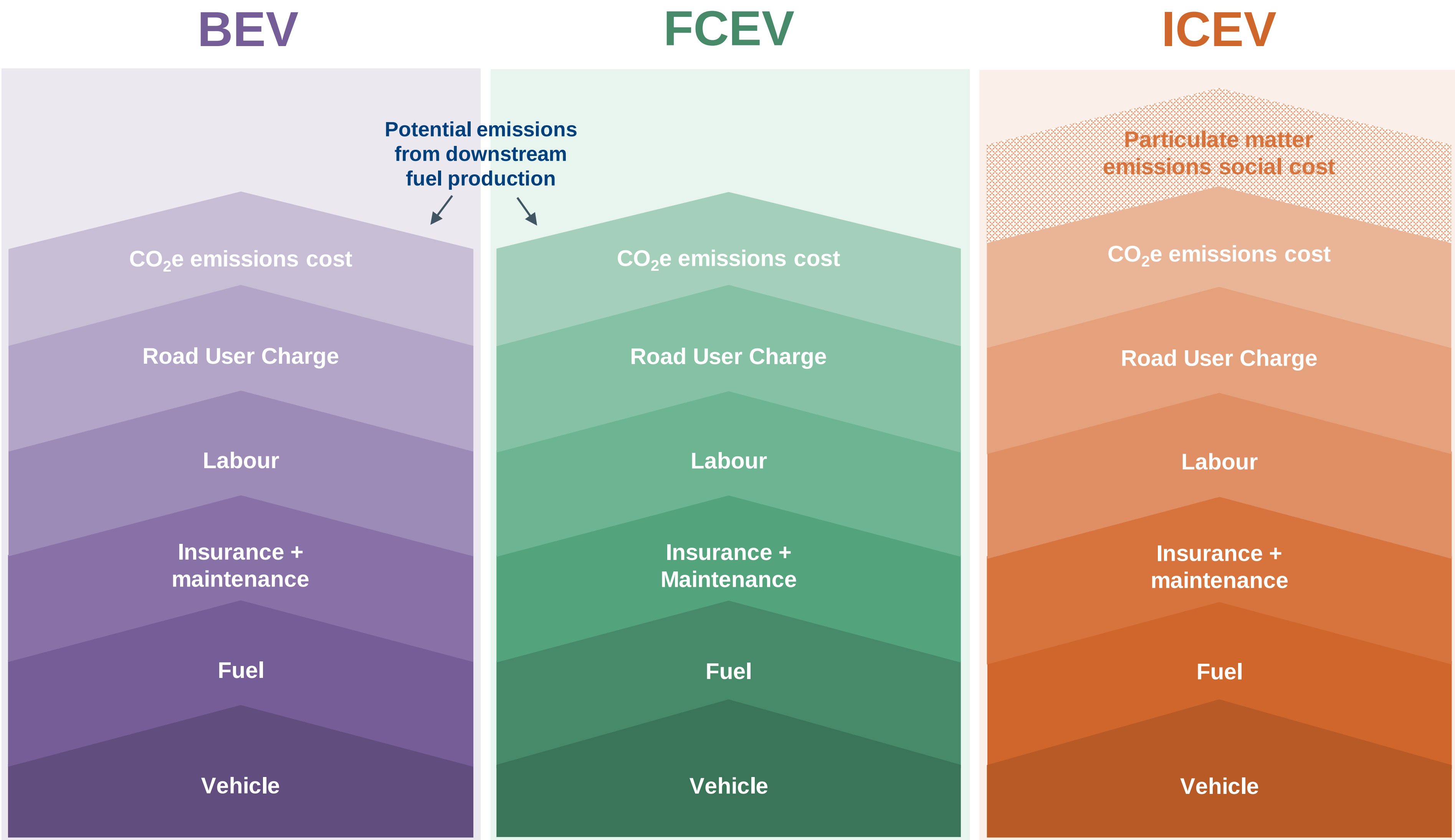
Dashboard inputs

- Annual driver days
- Daily trip distance
- Average driving speed
- Length of start/end load/unload
- Number of 60+ minute stops

Trip definition

Methodology

Cost components considered in TCO build-up



Methodology

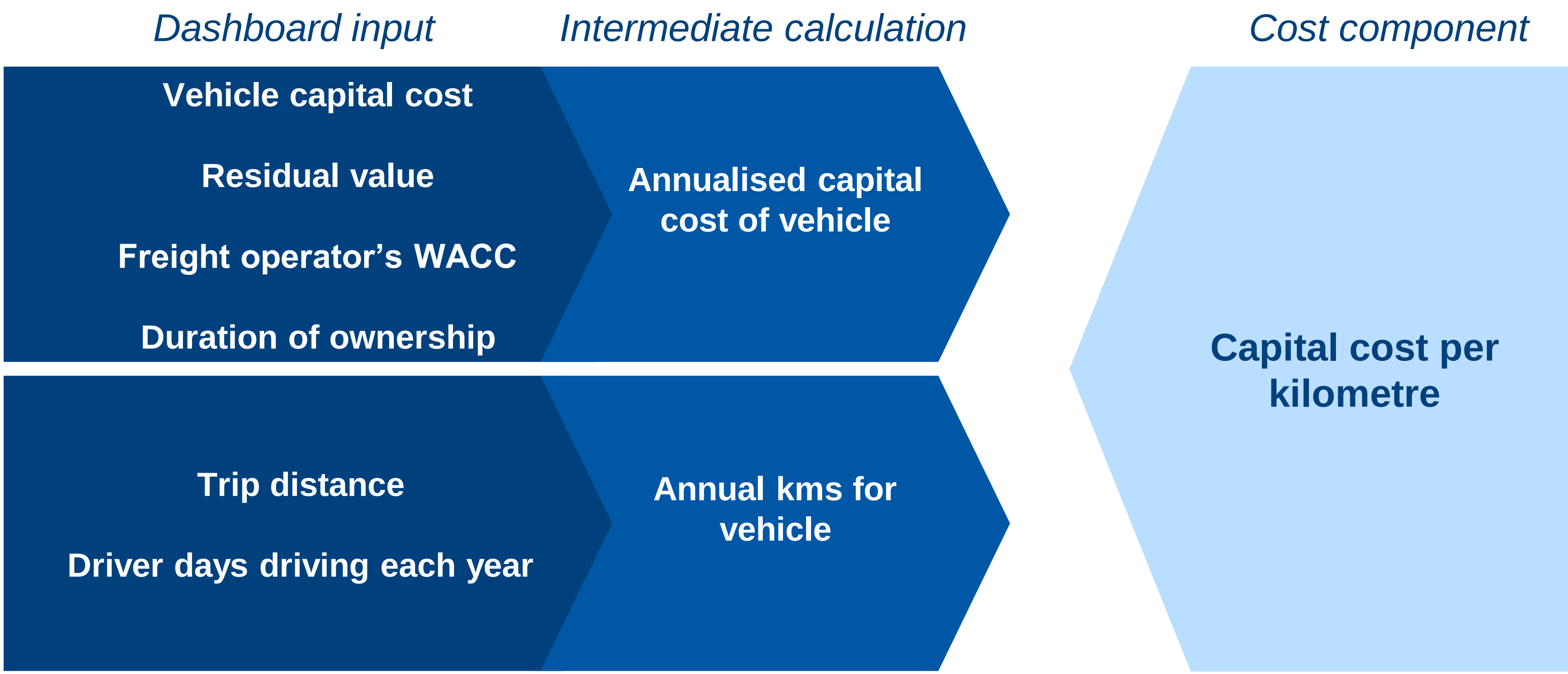
Cost components detail

Vehicle	Vehicle costs are unique to each of ***ICEVs***, ***BEVs*** and ***FCEVs*** and are calculated consistently for any given fuel used in each vehicle. The driving profile of the vehicle factors into the vehicle cost component of TCO. The vehicle can be *purchased* or *leased*. For the *purchase* option, the residual value of the vehicle is also a key component, which a user could use to account for costs of battery replacement, recycling batteries or fuel cells, etc. For the *lease* option, the lease input cost is simply divided by the monthly kilometres driven.
Fuel	Fuel costs are determined differently for each TCO calculation, as the fuel input is unique to each calculation. For each fuel source, well-to-pump costs are intended to be captured by the "delivered cost of fuel" for any given fuel type.
Insurance + maintenance	Insurance cost per km and maintenance cost per km are direct inputs into the dashboard for ***ICEVs***. For each of ***BEVs*** and ***FCEVs***, the dashboard asks the user to define these costs as a percentage of the ICEV cost inputs.
Labour	The trip specifications being calculated are the most significant part of the cost of labour. However, a ***BEV's*** (1) battery size (2) battery density (3) fuel efficiency and (4) access to fast chargers may cause the labour costs for a BEV freight trip to increase if the driver must wait on the clock for the truck to recharge.
Road User Charges (RUC)	RUC apply to all diesel vehicles in New Zealand as a cost to the operator to approximate road damage caused by the vehicle. We default this to always be included in TCO, as fuel use does not impact vehicle road damage. However, exemptions may be allowed for vehicles with lower emissions profiles (although from a societal standpoint, this would be a transfer). RUC is a direct per-kilometre input in the dashboard.
CO_2e emissions cost	This cost applies anywhere carbon (or carbon equivalent) emissions are emitted from well to wheel (excluding vehicle production and disposal). For ***ICEVs***, this is from the use of diesel fuel. For ***BEVs***, this could stem from charging with on-grid electricity, which has an emissions profile. For ***FCEVs***, this could stem from inefficient CCS (for blue H_2) or grid-connected electricity to power an electrolyser (for green H_2).
Particulate matter emissions social cost	This cost applies only to ***ICEVs***. It captures the social cost incurred to New Zealand through the negative health effects or premature death stemming from the particulate matter emitted by ICEVs. There are potentially additional societal costs which apply to all vehicles, such as safety or effects from brake dust, but these are not captured in the comparison tool.

Methodology

Vehicle cost component: Purchase

Annual capital costs are determined for the purchase option by amortising the vehicle capital cost input (purchase price) over the duration of ownership, taking into account the assumed residual value. This annual value is converted into a per-km cost by dividing by the annual kms of the vehicle.

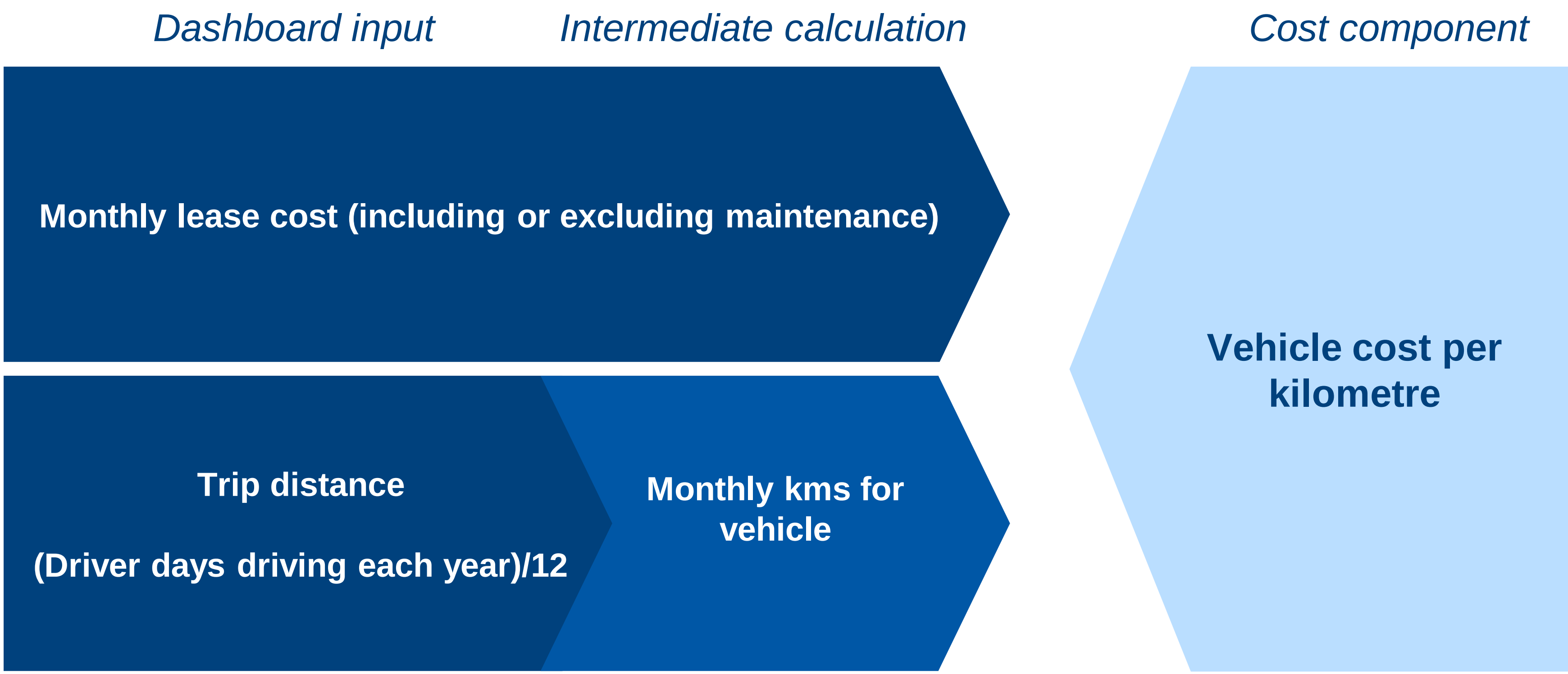


All calculations can be examined in depth within the ***Calculations step-by-step*** tab in the comparison tool. This walk through is to illustrate how some inputs offered in the dashboards fit together to calculate more complex pieces of each TCO component.

Methodology

Vehicle cost component: Lease

Vehicle cost per km, and maintenance costs if the user chooses, are determined for the lease option by taking the monthly lease payment and dividing it by the monthly kms driven depending on the driver days driving and the trip distance inputs.

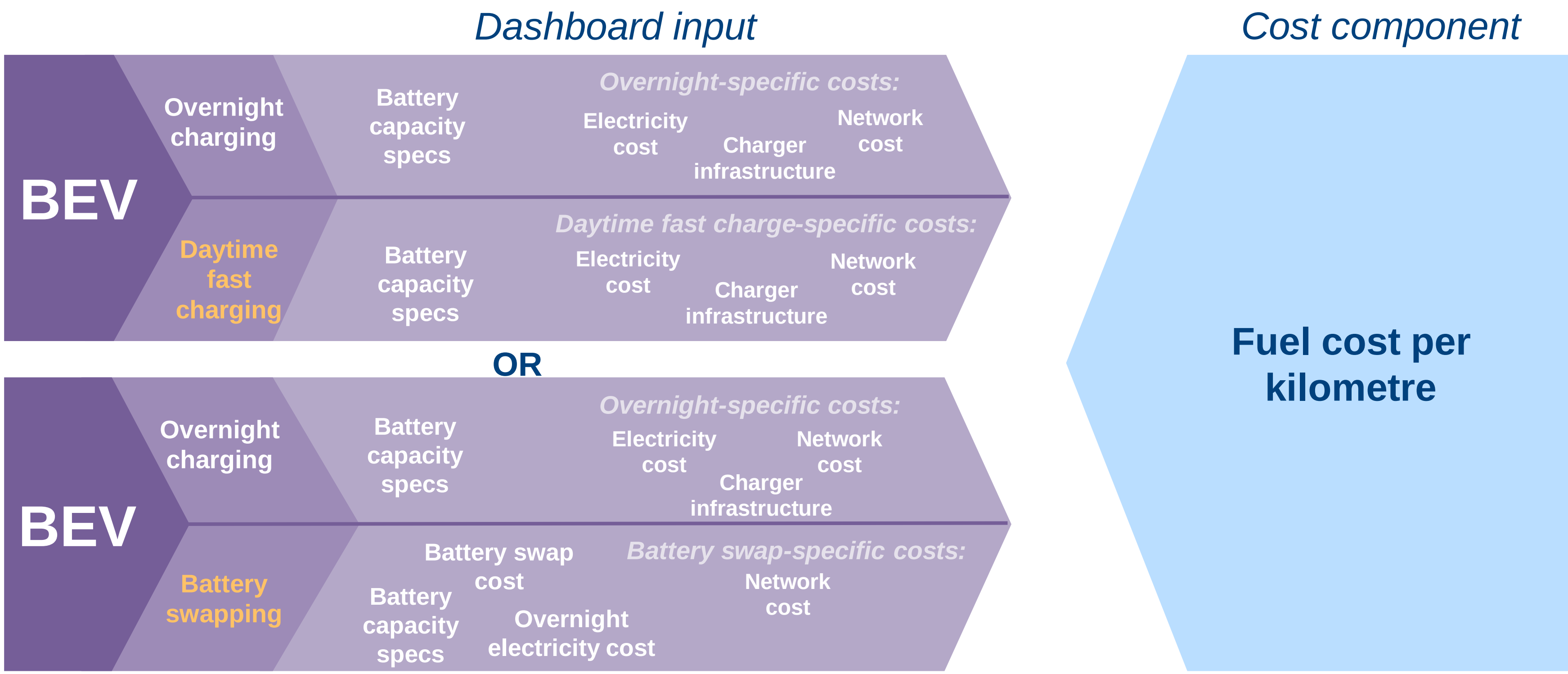


All calculations can be examined in depth within the ***Calculations step-by-step*** tab in the comparison tool. This walk through is to illustrate how some inputs offered in the dashboards fit together to calculate more complex pieces of each TCO component.

Methodology

BEV fuel cost component

BEVs have a more complex methodology to determine fuel costs than ***ICEVs*** and ***FCEVs***. The calculations assumes the ***BEV*** starts a trip fully charged from overnight charging. If more power is needed to complete a trip, the dashboard offers two options to “refuel”: fast charging or battery swapping. Each of these options have different electricity, network and infrastructure costs.

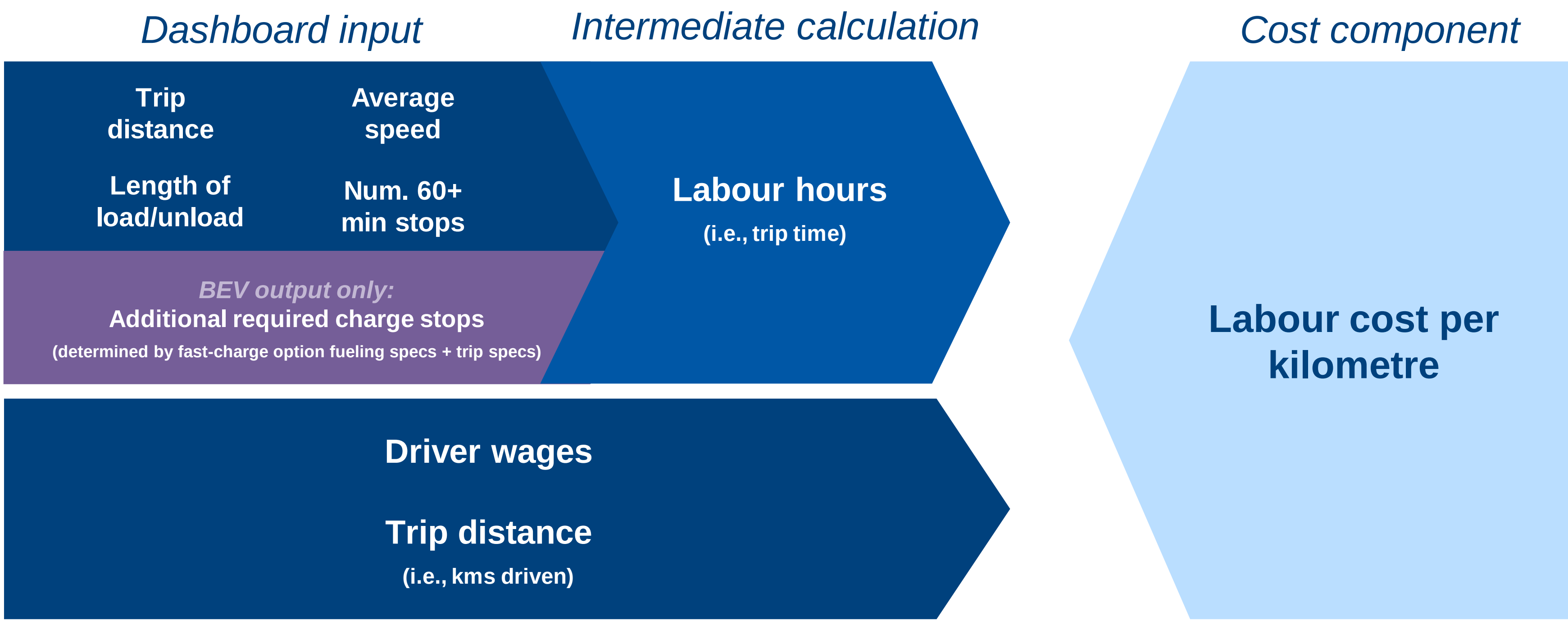


All calculations can be examined in depth within the ***Calculations step-by-step*** tab in the comparison tool. This walk through is to illustrate how some inputs offered in the dashboards fit together to calculate more complex pieces of each TCO component.

Methodology

Labour cost component

Labour costs are driven by the total time to complete the trip. This is driven by the driving time required (a function of trip distance and speed), the time to load and unload the vehicle at the beginning and end of the trip and any mid-trip stops required for unloading/reloading (and for BEVs, any additional charging stops). Commercial drivers in New Zealand may only work 13 cumulative hours in a day – if the trip specifications create conditions where this is exceeded for a single driver, the dashboard will alert the user.

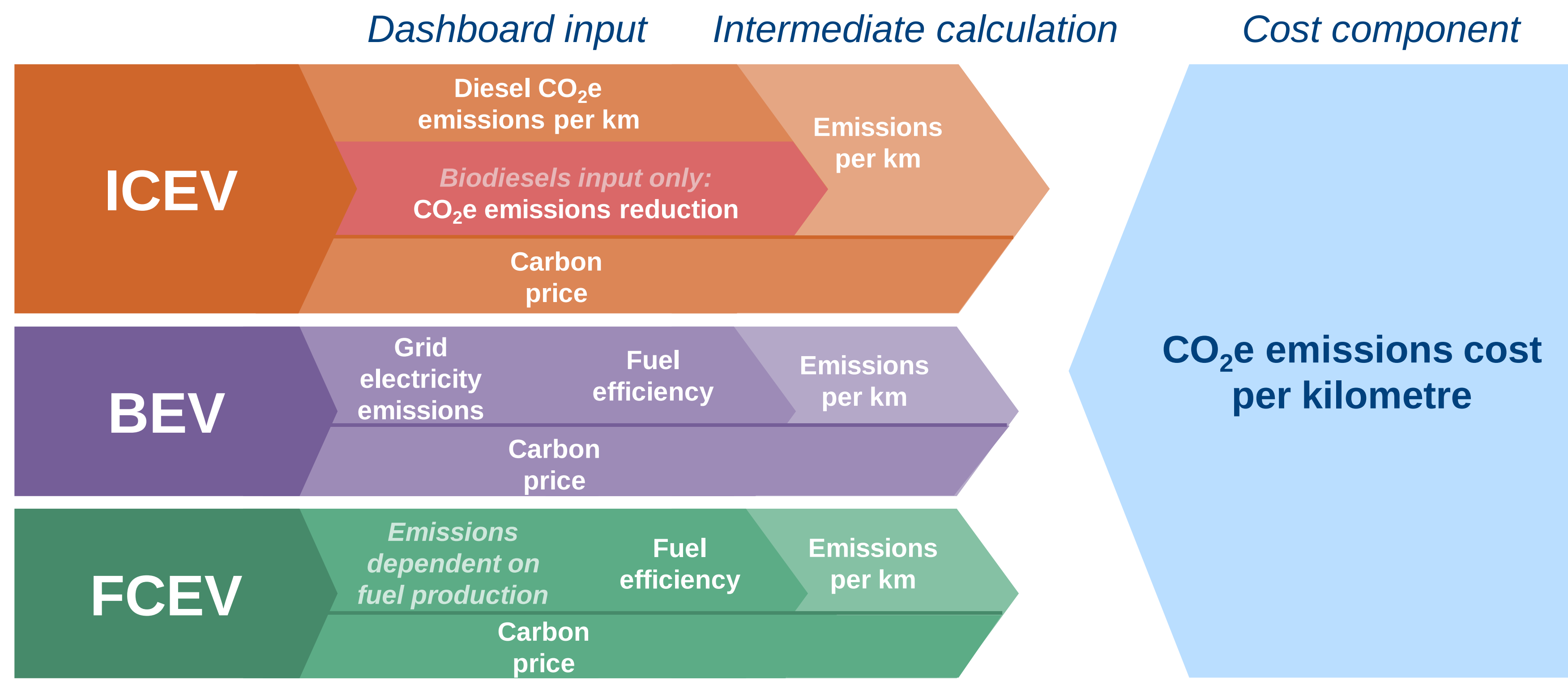


All calculations can be examined in depth within the ***Calculations step-by-step*** tab in the comparison tool. This walk through is to illustrate how some inputs offered in the dashboards fit together to calculate more complex pieces of each TCO component.

Methodology

CO_2e emissions cost component

Carbon and carbon equivalent emissions are calculated differently across most fuel types. These are dependent on **upstream production** for ***BEVs*** (grid electricity emissions) and ***FCEVs***. ***FCEVs***, because there are two quite different methods of producing H_2, may have upstream emissions due to **(1)** carbon capture and storage inefficiencies for blue H_2 or **(2)** grid electricity emissions (if not using captive wind) for green H_2.

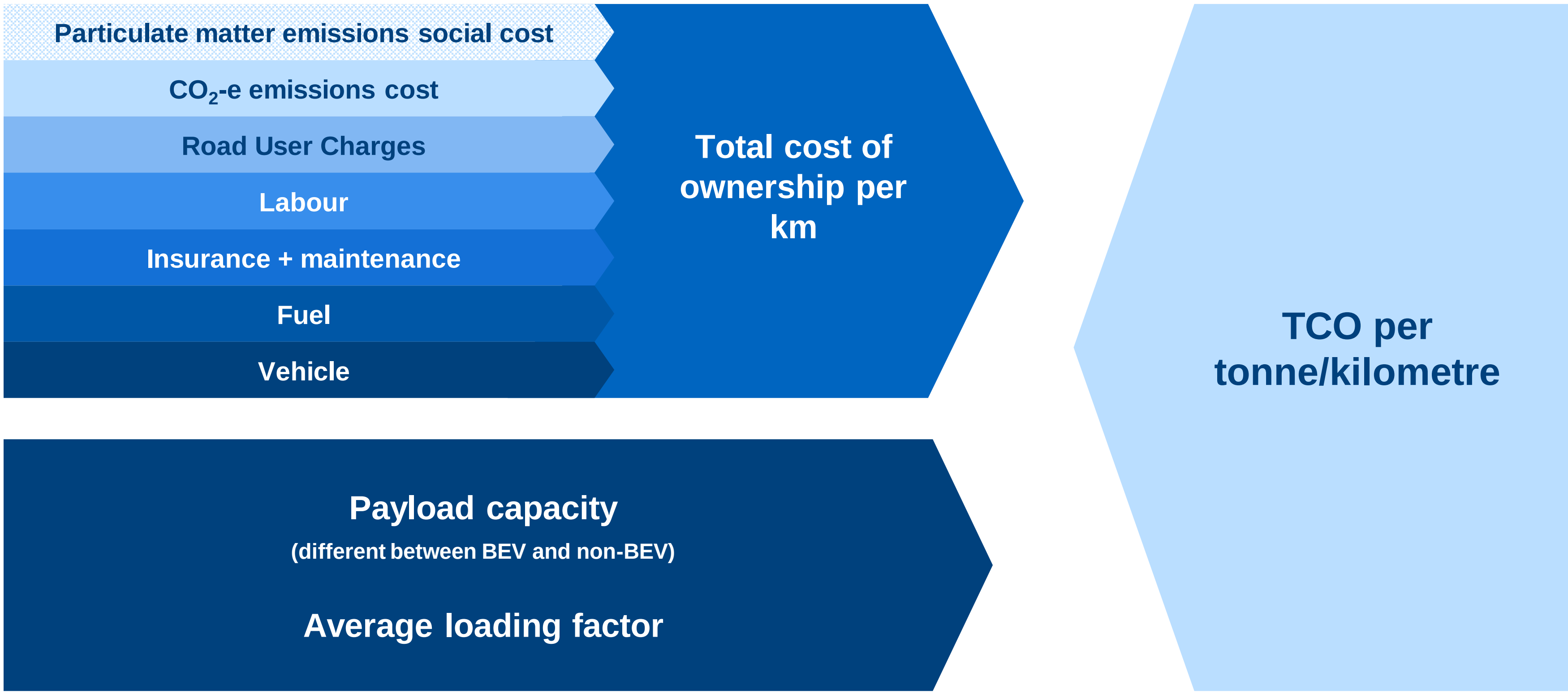


All calculations can be examined in depth within the ***Calculations step-by-step*** tab in the comparison tool (and, for FCEVs, the ***H_2 cost calculator***). This walk through is to illustrate how some inputs offered in the dashboards fit together to calculate more complex pieces of each TCO component.

Methodology

TCO/km vs. TCO/tkm

Once the total cost of ownership per kilometre is established, the **payload capacity** and the **average loading factor** (i.e., how full the vehicle is on average across the entire driving profile) work together to determine the total cost of ownership per tonne-kilometre. As BEVs may not be able to carry as much freight as non-BEVs, this measure gives a better representation of the overall cost of moving freight.



3 Comparison tool overview

Comparison tool overview

Summary of tabs

Freight task analysis	Presents an aggregate analysis of EROAD's fleet movement tracking data for 2020. Charts providing an overview of the composition of the freight task in New Zealand are provided, then a table providing driving behavior statistics for various vehicle weight bands driving 100km increment distances.
Dashboard A	Presents **point-in-time calculations** of total cost of ownership per kilometre (TCO/km) and total cost of ownership per tonne-kilometre (TCO/tkm) for the various vehicle+fuel combinations with user input boxes for assumptions. A bar chart with cost components displayed for each vehicle+fuel combination in TCO/tkm is the main output displayed.
Dashboard B	Presents a **ten-year projection** of TCO with further user inputs to calculate projections. The inputs available for projection on Dashboard B generally reflect those on ***Dashboard A***, although certain inputs which are assumed to remain unchanged over time are not include to simplify presentation. The main output displayed is the TCO/tkm in a line chart and table.
Calculations step-by-step	For informational purposes and transparency. This walks the user through the calculations underlying the overall TCO calculations for each vehicle+fuel combination presented on ***Dashboard A*** (note that the same calculations underlie the output on ***Dashboard B***, using the relevant years' inputs.
H_2 cost calculator	Provides optional user input to develop a built-up cost for delivered green and blue H_2. The purpose of the cost build-up is such that (a) the cost of electricity is transparent so the cost of delivered green H_2 can be developed comparably to BEV charging, and (b) the cost of distributing H_2 fuel can be developed comparably in the delivered costs for blue and green H_2. This output can be overridden on ***Dashboard B***.
BEV payload calculator	Provides optional user input to develop the BEV payload capacity based on the size of battery specified on ***Dashboard A*** and ***Dashboard B***. This output can be overridden on ***Dashboard B***.
Default scenario references	Each of ***Dashboard A***, ***Dashboard B***, ***H_2 cost calculator***, and ***BEV payload calculator*** contain inputs for a default scenario. References and/or explanatory notes for each input are available here for the user to examine.
Saved scenarios	This allows the user to save and store user-defined scenarios for ***Dashboard A***, which can be loaded back into the model or referenced as required. Further instruction is provided **within the comparison tool**.

Comparison tool overview

Default scenarios

Three default scenarios are available to select at the upper centre of Dashboard A. The model opens onto the default for a 50MAX heavy goods vehicle (HGV), with additional options for a 26t 6x2 HGV and a 16t 4x2 HGV. Note that these default scenarios are for guidance, reference and are based on best available information, but are not intended to provide advice or represent NERA or Ara Ake's opinion on any technology.

Large HGV: 50MAX B-train

This is the default scenario the model opens with, for the largest available truck. Best estimates are available for **all fuel and vehicle types**, with a reference trip determined using the EROAD ***Freight task analysis*** results. All relevant inputs are labelled on the ***Default scenario references*** tab.

Medium HGV: 26t 6x2

This additional scenario is for a medium HGV. Currently, vehicle cost estimates for the BEV are very difficult to obtain, and have been determined by scaling down the BEV estimate for the 50MAX scenario using the percentage difference between the BEV and ICEV inputs.

Best estimates are provided for ICEVs and BEV, but FCEVs are not, to our knowledge, currently being developed at this size at the time of publishing. Therefore, FCEV-related output is set to *Unavailable*. Inputs for the heaviest FCEV remain for reference, if a user wishes to experiment with those inputs. The reference trip is determined using the EROAD ***Freight task analysis*** results. All relevant inputs are labelled on the ***Default scenario references*** tab.

Smaller HGV: 16t 4x2

This additional scenario is for a smaller HGV. Currently, vehicle cost estimates for the BEV are very difficult to obtain, and have been determined by scaling down the BEV estimate for the 50MAX scenario using the percentage difference between the BEV and ICEV inputs.

Best estimates are provided for ICEVs and BEV, but FCEVs are not, to our knowledge, currently being developed at this size at the time of publishing. Therefore, FCEV-related output is set to *Unavailable*. Inputs for the heaviest FCEV remain for reference, if a user wishes to experiment with those inputs. The reference trip is determined using the EROAD ***Freight task analysis*** results. All relevant inputs are labelled on the ***Default scenario references*** tab.

Comparison tool overview

Dashboard A

Dashboard A requests general, vehicle-specific, and fuel-specific inputs from the user on the Dashboard interface to develop a TCO/km and a TCO/tkm output, displayed by cost components in the accompanying stacked bar chart.

Inputs		All value inputs are indicated by a white cell with a green border. All calculations rely on user inputs (i.e., no value assumptions are built into the comparison tool).
Availability dropdowns	Available	If the user wishes to exclude a vehicle+fuel combination (for example, if the fuel is not available in New Zealand), they may use the dropdown provided at the header of each vehicle+fuel section of the interface to remove the output by changing the selection to Unavailable. Note this does not affect ***Dashboard B***.
RUC exemptions		Below the general inputs, RUC costs can be excluded from a given vehicle+fuel combination (other than diesel+ICEV) to model TCO accounting for a potential RUC exemption (for example, at the time of publishing BEVs are RUC-exempt until 2025).
BEV day-charging or battery swapping		In the BEV input section, the user can choose between whether the BEV will be using fast-charging mid-trip to refuel or a battery swapping service. Note that the default scenario **does not** provide assumptions for battery swapping, as there is currently little commercial information about these costs. The default scenario instead relies on day-charging.
Labour hour limit alerts	!	If the given vehicle+fuel combination is not physically capable of completing the trip in **13 hours**, this alert will appear above the relevant bar in the chart, while the labour hours output will turn red. Generally, this will apply similarly across all vehicle+fuels but for BEVs which are using fast-charging (given extra labour hours may be required while waiting to charge).
Reset default scenario	*Reset default scenario*	This button resets all values, drop-downs, check boxes, and switches to the selected default scenario across **all tabs**. Before resetting, one may wish to save their ***Dashboard A*** scenario. This is available within the ***Saved scenarios*** tab.

Note that **footnotes** further explaining specific items are provided throughout ***Dashboard A***.

Comparison tool overview

Dashboard B

Dashboard B applies inputs from ***Dashboard A*** as year one in a projection forward ten years. The Dashboard outputs both a line chart and a table (colour-coding for the **lowest** and **highest** TCO in the year) with the TCO/tkm outcomes.

Trend	For all input options, the user may choose the Trend selection to project the given input in Dashboard A forward into the future. This is the default for almost all assumptions (but for those which have a cost build-up – see below). The trend is projected using a linear **annual percentage change** input, while the user may also input a **floor or ceiling** value such that the relevant parameter does not dip below/rise above a certain level. The user could also use this to proxy a non-linear change. ***Note:*** If the floor/ceiling input is higher/lower (respectively) than the input in ***Dashboard A***, the values will remain static at the year one value.
User input	The user may also override all values with their own assumptions for any input on ***Dashboard B***.
Cost-build up	Three parameters have cost build-ups developed on another tab. These are the delivered costs of blue and green H_2 on the ***H_2 cost calculator*** and the BEV payload capacity on the ***BEV payload calculator***. These cost build ups are the default assumptions set on ***Dashboard B***. However, if the user wishes to directly input their own values for these three parameters, both *Trend* and *User input* options are available here from year one onward.

Comparison tool overview

H_2 cost calculator

This calculator allows the user to build up, at a relatively high level, the costs of delivered green and blue H_2. **Additional footnotes** are provided for more guidance on specific inputs, and all cells allow review for transparency of underlying calculations (although only the same white and green input cells may be edited).

Green H_2

Electricity cost: This input allows the user to apply a different (or the same) electricity cost to the production of green H2 than what is being applied for BEV charging.

Electrolyser: By requiring the cost per kW of the electrolyser, the user must also input assumptions around the cost of installation, the operator's weighted average cost of capital (WACC), and the economic life of the asset to obtain the annualised capital cost. Additionally, electrolysers require a stack replacement after the stack life hours have been surpassed. Given the utilisation, if the stack life ends before the economic life of the electrolyser, the cost of stack replacement will be incurred and added to the cost of production.

Network costs and emissions: The default scenario assumes captive wind generation for production (for centralised production), which means no network charges are incurred. When the user adds a network cost, such that the electricity is being sourced from the grid, grid emissions costs are automatically applied.

Estimated cost of distribution: This includes the cost of compression, storage, transportation (when assuming a centralised production scenario), and distribution (i.e., service station).

Blue H_2

Plant/SMR cost: A very high-level capex approach has been taken here since steam methane reformation (SMR) to produce hydrogen is a well-established process.

Natural gas cost: This cost is highly subject to future demand – note that the default scenario has not assumed any annual change due to uncertainty, but the user may want to experiment with scenarios where there is increased cost.

Carbon capture and storage: The costs of carbon capture and storage are still relatively unknown as this technology is not available in New Zealand at time of publishing. Carbon storage costs will be highly site-specific (potentially restricted to the Taranaki area), so these costs should be interpreted with caution at present.

Comparison tool overview

BEV payload calculator

A large BEV truck is likely to have its payload capability penalised due to the weight of batteries required to power the vehicle for the distance required. This calculator allows the user to estimate the payload of the specified BEV given the size of the battery specified on ***Dashboard A*** and ***Dashboard B***.

Payload gain from powertrain weight reduction

The electric motor powertrain of a BEV is lighter than an internal combustion engine powertrain

This provides an overall weight *reduction* to the BEV truck

Battery energy density

The energy density (or specific energy) of the batteries in the truck and the battery capacity specified will determine the overall weight of the batteries

This provides an overall weight *increase* to the BEV truck

Together, the *net change* is applied to the non-BEV payload input to estimate the BEV payload

Note: Although an FCEV also has an electric motor powertrain, the fuel cell system plus the H_2 tank in the FCEV are generally agreed to roughly equal the overall powertrain+tank weight of an ICEV and therefore the calculator does not provide the same payload alteration for FCEVs.

NERA 60 YEARS

ECONOMIC CONSULTING