# THE NEW TRANSPORT EMISSIONS TOOLSET

## (This paper has been peer reviewed)

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## ABSTRACT

The Government has committed to reducing carbon produced by the transportation network. To inform its carbon reduction goals, Victoria University of Wellington and other partners developed decision support tools for assessing public transport fuel emissions, and compared these against other transport modes. These were tested for the Wellington region. A methodology was developed, prototype tools created and used to inform carbon studies and decarbonisation pathways.

A key challenge with previous methods is that they are based on estimates of fuel consumption. Typically, bus operators engage in a mix of public and private services, e.g. coach hire, cruise ships, Ministry of Education (MoE) school services, etc. Identifying emissions for scheduled services requires a “guesstimate” of the fuel split between these various services. To get around this problem, prototype software was developed to calculate emissions for every publicly funded bus trip. The tools were then used to identify:

- Wellington fuel emissions trends 2017-2020
- The benefits of mode shift, i.e. the carbon footprint for each transport mode
- The benefits of the Euro V & VI vehicles deployed in 2018
- The likely benefits for introducing 108 electric buses
- Scenarios for meeting carbon reduction targets for 2030

The new analytical tools have informed Wellington public transport emissions reporting to the Ministry for the Environment, the Ministry of Business Innovation and Employment, the Ministry of Transport, the Energy Efficiency & Conservation Authority, and Waka Kotahi NZ Transport Agency. A follow-up study has since expanded our understanding to include a national inventory identifying the data sources available to each regional council and unitary authority that operates a bus network, in order to inform whether a nationally consistent methodology can be developed. Stakeholders in Auckland and Christchurch have also expressed interest in using the tools to improve their understanding of public transport emissions. A pilot study is currently underway in Auckland for adopting the methodologies outlined in this paper. This paper outlines the approach taken, key findings, and a brief summary of data needed for this approach to be adopted by public transport operations across the country.

## BACKGROUND AND CONTEXT

The release of carbon pollutants can generate an atmospheric warming effect through gases’ absorption of sunlight and have detrimental impacts on human health (Health Effects Institute, 2010; Kheirbek, Haney, Douglas, Ito & Matte, 2016). Policies intended to reduce transport emissions are supported by strong arguments from both a climate change, and a public health standpoint. In addition to CO2, vehicles that are pre Euro VI also produce elevated quantities of nitrous oxides (NOx), carbon monoxide (CO), potentially carcinogenic micro particulate matter (PMx) and considerably more noise pollution than Euro VI or electric vehicles.

Reducing carbon emissions is a key focus of the *Government Policy Statement on Land Transport 2021* as determined by the key strategic priority:

> *Transforming to a* ***low carbon*** *transport system that supports emissions reductions aligned*

*with national commitments, while improving safety and inclusive access*

The current GPS 2021 does not exist in isolation, and is the result of a series of central government and international policy initiatives going back a number of years, including:

- In 1992 the United Nations Framework Convention on Climate Change was adopted by 182 countries including New Zealand
- In 1997, New Zealand signed up to the Kyoto Protocol
- In 2013, the Government announced an unconditional target to reduce greenhouse gas emissions to **5% below our 1990** emissions by 2020
- In 2015, the Government finalised the target of reducing greenhouse gas emissions to **30% below 2005** levels by 2030. The target is equivalent to an 11% decrease below 1990 levels. These targets have been adopted by successor governments and are reflected in the desired outcomes of the current GPS 2021.
- Carbon reduction goals have been incorporated into New Zealand legislation with the *Climate Change Response Act 2002* and the *Climate Change Response (Zero Carbon) Amendment Act 2019*

In addition to this national guidance, councils across the country are also forming policies to combat climate change. The Greater Wellington Regional Council (GWRC) has developed both a *Corporate Carbon Neutrality Action Plan* (GWRC, 2019) and declared a regional climate emergency. The *Wellington Region Climate Change Projections and Impacts* report, (GWRC, 2017), identified that climate change could have a significant detrimental impact on the Wellington region. Risks identified include the increased risks of coastal erosion and storm inundation, species disruption and/or habitat loss for native flora and fauna, changes to river levels, potential adverse impacts on local fisheries and shellfish, a more attractive environment for harmful tropical pests and mosquitos, and an increase in the duration of summer fire risk periods. There are also resourcing risk impacts required to combat all of the above.[1] The *Wellington Greenhouse Gas Inventory 2019* identified that transport emissions account for **40%** of Wellington's greenhouse gases (Aecom 2020). Transportation is therefore an area with an opportunity for carbon reduction efforts. In response to these emerging risks, GWRC set climate change targets in 2019. These are:

- Become carbon neutral by reducing and offsetting the organisations' greenhouse gas ('carbon') emissions
- Reduce net emissions by **40% by 2025**
- Introduce 5-yearly carbon budgets
- Become carbon negative (producing more carbon credits from our land than we need for offsetting) by 2035.[2]

In order to identify a pathway towards meeting these targets, improved data and new tools were required to inform understanding of baseline emissions and to inform target-setting discussions.

# PUBLIC TRANSPORT EMISSIONS STUDY

## Emissions from Fuel Consumption Data

There are several ways to estimate bus carbon emissions. From discussion with other councils, the most common approach in New Zealand appears to be based on operator fuel purchase estimates. However, early investigations identified a lack of accuracy for this approach. The buses provided for Council funded services typically also engage in other commercial activities such as coach-hire, cruise ships and MoE school services. Operators have no commercial or contractual reason to collect information that distinguishes fuel consumption between private and scheduled services.

For emissions such as PM10, hydrocarbons, CO, and NOx, the Euro Class influences how 'cleanly' the fuel is burned and the emissions produced per km. Bulk fuel consumption is therefore not an accurate guide to emissions unless the bus fleet is of a completely uniform Euro standard. Otherwise the emissions will vary between the different buses on the network.

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[1] https://www.gw.govt.nz/assets/Climate-change-2/FINAL-WellNCC-projectionsimpacts.pdf

[2] https://www.gw.govt.nz/assets/Climate-change/Greater-Wellington-is-committed-to-climate-actions-v4.pdf

For non-GHG pollutants the efficiency of the fuel burn plays a major role in the rate of the emissions. Both the speed and the Euro Class of the vehicle play a role in the calculations. An example of the relationship between emissions, Euro Class, and speed travelled has been visualised in Figure 1 below. This illustrates the difference in NOx emissions produced for different Euro Classes, and how this differs by the speed of the vehicle. As can be seen in the graph, emissions increase at lower speeds, particularly for lower Euro Class buses. A study of **14 million km** of Wellington bus data found an average speed of **22km/h** for urban services. The Auckland pilot study found an average speed of **19km/h**. Both are sub-optimal for fuel emissions.

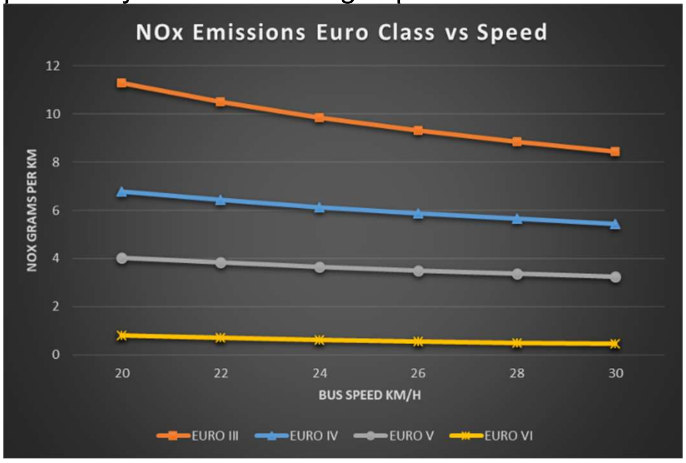

*Figure 1 NOx emissions by Euro Class and Speed*

A method was developed to avoid the inaccuracies of self-reported fuel purchasing, as well as to enable the Council to distinguish between the differences in emissions generated at different travel speeds and by Euro Class. The study timeframe from 2017 to 2019 included a period in 2018 where a large number of old Euro I and pre-Euro buses were retired from service, so it was important to capture these changes in the study. As can be noted from Figure 1 the average speed of the bus has a less influence than the Euro Class of the vehicle. This should be noted when it comes to decarbonisation levers. Bus priority might not result in a direct reduction in emissions, although it could be necessary for encouraging modeshift.

## A pilot methodology for calculating fuel emissions

The first step was to create an inventory of all the buses in GWRC's fleet going back to January 2017. This resulted in a Fleet List, i.e. a record of each bus, its tare weight, and Euro Class. For each bus trip, the individual bus would be identified and the (static) properties of that bus would then be pulled from the Fleet List. Next, data about scheduled bus trips was gathered. This included the following information:

1) The specific bus that ran each bus trip
2) The bus operator that ran each bus trip
3) The passenger loading for each bus trip
4) The distance travelled for each bus trip
5) The average speed for each bus trip
6) Whether or not the scheduled service ran as scheduled and was completed

Additional analysis was undertaken for partially completed routes, and for unscheduled services (such as rail replacement buses). The data collated for the specific trip: distance travelled, average speed, passenger loading, partial completion, etc, is combined with the specific bus that ran the service (tare weight and Euro Classification). This collated data then informed the calculations used to identify the fuel consumption and fuel emissions for every bus trip on the network.

## Source Data and Formulae

GWRC commissioned *Emissions Impossible Ltd* to research and source the most suitable formulae for calculating fuel emissions by Euro Class. *Emissions Impossible Ltd* provided formulae to calculate emissions by Euro Class, vehicle speed, and the loaded vehicle mass. Emissions Impossible then undertook a small pilot using a limited data set. It soon became apparent that the amount of data necessitated the need to automate a lot of the data processing, calculations and interpolation. The calculations include the weight of the passengers and the driver.

A one-off study was undertaken to prepare a bus Fleet List with the unique weight and Euro Class of each bus in operation since January 2017 (about **900** vehicles). This information was obtained from the four bus operators. The pilot study then applied the various formulae to Wellington-specific scheduling, mileage, vehicle occupancy data, and the information collated in the Fleet Lists, to derive values specific to the Wellington region. The tare weight of the bus was considered a constant for each trip. To calculate total mass the variable weight of the passengers was also included in the calculations.

Passenger loading data was derived from Wellington's Snapper electronic ticketing system. Waka Kotahi provides guidance for an average adult passenger weight of **80kg**. This was used to calculate passenger weight loading for regular services. The NZTA average child weight of **65kg** was used for dedicated school bus services. To account for the driver mass, an additional **80kg** adult weight was also added to all vehicle movements for both scheduled services as well as bus repositioning. Scheduled operations, cancellations and partially completed trips were identified using the Wellington Real Time Traveller Information Vix system. The result was a study of roughly **14 million bus vehicle km** of data per year for three years. Passenger loading was identified for each bus trip, roughly **150 million passenger km** of travel per year.

### Data Gaps and Interpolation

The study identified a number of gaps in the source data sets, particularly for the trips undertaken prior to November 2018. The vast majority of trips were captured accurately, but there were occasional issues such as missing operator ID or missing Bus ID. These are likely to be issues faced in other locations, particularly if any part of the system requires manual driver entry (e.g. entering a trip ID at the start of a route). For this study, a system was developed whereby all of the known data was computed and the gaps were interpolated based on a weighted aggregation of the known data. E.g. if 100% of the observed trips were made in a Euro VI bus, we could be reasonably certain an unidentified bus would also be Euro VI. If half the fleet are Euro III and the other half Euro VI the odds of a bus being either Euro Class would be fifty/fifty but could never be identified with absolute certainty. The researchers referred to this as “The Schrodinger's Bus Problem.” This was resolved using probabilistic algorithms. The regular changes to buses from one day to the next meant that the interpolation method was applied to the vehicles observed running the route on each specific day the gap was identified.

Another gap in the data relates to passenger loading. For Wellington, cash fares, Gold Card holders and some other types of concession do not need to tag on and off. This results in a gap in the data needed to assess the passenger loading on the bus at any given time or location or the for the route as an average. Analysis identified that this gap in the data includes roughly **15%** all boardings across the region it varies between suburbs. Poorer areas were found to have a higher proportion of cash trips, even though cash transactions are **25%** more expensive for the customer than a Snapper card transaction for the same trip. This gap in passenger loading could have resulted in an under-reporting of vehicle mass, and therefore vehicle emissions. To resolve this issue, the average trip distance was derived using the which introduces a margin of error for understanding average trip distances and therefore bus loading / total mass. Ignoring these trips entirely would result in an underreporting of the loaded bus weight and therefore underrepresent fuel consumption. To rectify this issue, the average distance travelled for passengers on a bus trip was calculated based on the observable data. The total mass was calculated by scaling up the passenger loading to account for all boardings, not just those with a known end point. For example if a bus had 20 passengers, but only 15 had known trip distance. The average trip distance used for identifying average passenger loading on the trip would be derived using the 15 known trip distances, but applied to all 20 boardings. This method assumes that the passengers using cash and gold cards have the same average travel distance as Snapper holders.

The per vehicle and per pax km emission results were compared to that of other jurisdictions in New Zealand and overseas, as well as with prior GWRC analysis using fuel consumption data. The results were similar, close enough to have confidence the software was performing as intended (noting that gradient and weather were excluded from the study). However the methodology also provided the additional benefit of having the ability to drill down into individual routes and details.

It should be noted that the study included only trips that formed part of a GWRC scheduled bus service. Prior to Covid disruption, there were two private companies operating their own private commercial services on the Wellington network: NCS Ltd and the Airport Flyer. These operate outside of GWRC remit and were therefore beyond the study remit, as they do not provide any data to GWRC. Coach hire, cruise ship shuttles, tourist tours, and other private bus operations were also excluded from the study.

# FINDINGS

## Euro Classification and Emissions Trends

The first major result was a trend series identifying the trips on the network by Euro Classification for all scheduled services going back to January 2017. These trends are visualised in Figure 2 below. Each of the colours represents a different Euro Class for vehicles operating on the Wellington network. The proportion of each colour represents the trips made by vehicles with that Euro Class for each month. The lower the Euro Classification of the vehicle the more tailpipe emissions would be expected from the vehicle, particularly when fuel is burned inefficiently at slower speeds.

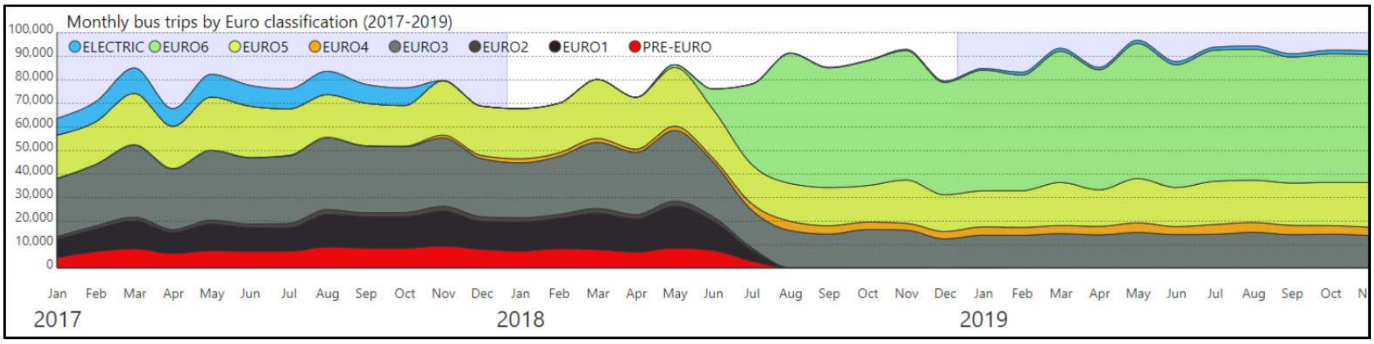

*Figure 2 Wellington bus trips by Euro Classification 2017-2019*

There was an overhaul of routes and contracts in mid-2018 and a new bus operator entered the Wellington market. As can be seen from Figure 2, these changes resulted in a significant change in the composition of fleet, with an increase in the average Euro Classification of trips on the network. GWRC required a minimum Euro V for the tendered routes, however one new operator exceeded this minimum requirement by introducing a fleet of new Euro VI vehicles. Whilst the worst polluters (Euro I, II, and pre-Euro buses) were removed from the network, 53 of the older Euro III vehicles have remained from routes that were not competitively tendered in 2018. These Euro III vehicles are sometimes referred to as the “interim fleet.” GWRC have committed the funding needed to replace them with electric buses between now and the end of 2022.

The changes to Euro Classification have a direct impact on the pollutants produced by the fleet. The next stage of the research was to visualise these changes, with the resulting trend results provided in Figure 3 below. This visualises the CO2, CO, NOx, HC and PMx emissions produced each day by scheduled bus services from 2017 to 2019.

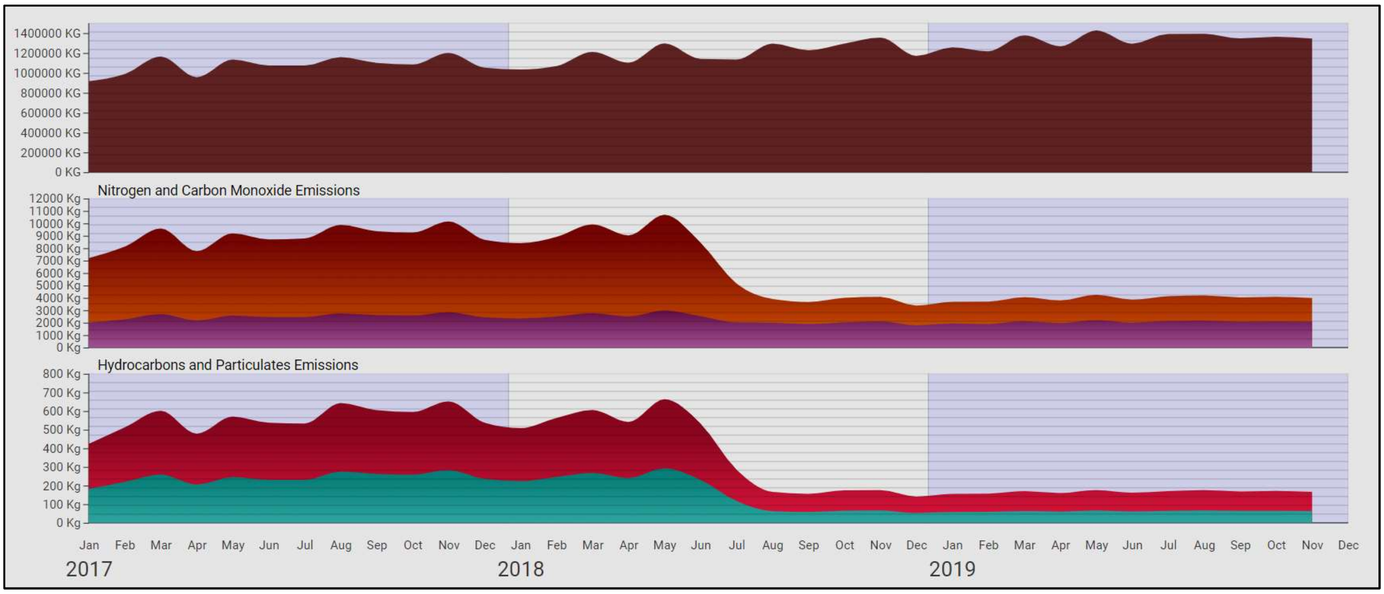

*Figure 3 Wellington Bus Emissions Trends 2017-2019*

The top graph illustrates the carbon emission on the network, including its continued growth after the introduction of the Euro VI fleet. The second graph illustrates Nitrogen and Carbon Monoxide, the later of which dropped when the Euro VI fleet was introduced replacing older bus services. The third graph illustrates hydrocarbons and particulate emissions. It is possible to compare the change in Euro Class introduced in 2018 (Figure 2) with the change in pollution visualised in Figure 3. This comparison indicates that the Euro Class makes a significant different to non-GHG pollutants. The local pollutants (CO, hydrocarbons and particulate emissions) all dropped in 2018. However, Figure 3 also indicates that CO2 emissions continued to climb. This suggests that the minor reduction carbon emissions from the improved Euro Class has been lost to background growth in demand. Further analysis identified a growth in demand, with additional buses burning additional fuel in order to deliver an additional **1.3 million** more passenger trips in 2019 than in the year prior to the PTOM changes.

While many harmful emissions have dropped, carbon emissions are an unavoidable by-product of the chemical reaction used to generate energy when burning diesel fuel. The underlying chemical reaction cannot be changed by improving the Euro Standards of the fleet and can only be removed by the introduction of zero emissions vehicles. Having the tools to observe a trend of increasing carbon emissions has informed discussions that have led to the Council adopting policies to electrify a portion of the fleet. All new growth vehicles will be zero-emissions vehicles from 2021, as will any vehicles replaced due to old age. The interim fleet are scheduled for replacement, with committed funding to increase the total number of funded electric buses to 108 by the end of 2022.

While carbon emissions are a key government focus, they are not the only type of tailpipe emissions. The analysis illustrated in Figure 3 indicates that the changes to fleet in 2018 has resulted in a drop in potentially harmful non-GHG bus emission by up to 70%. Eliminating these non-C02 emissions is particularly important for high frequency routes through sensitive, densely populated areas such as the Golden Mile. The non-GHG emissions reduction will continue as the Council achieves its objective of phasing out Euro III buses and replacing them with electric buses that produce zero tailpipe emissions.

### Carbon Emissions by Bus Route

Once the overall emissions were identified, further work was undertaken to identify the bus emissions for specific bus routes. A comparison was made between the carbon produced by passengers taking the bus (using pre-Covid data), and the amount of carbon that would be produced if the same number of people travelled the same distance by private car. A visualisation of this type of analysis methodology is provided in Figure 4 below. Each row is a specific bus route. Each column is a day of the week.

Each panel represents the entire emissions produced by that route on that day, as compared to equivalent private car travel. The analysis takes into account the mass of the bus, the weight of the driver, the weight of the passengers, all the Euro Classifications of each bus operating each day, and the average speed and distances travelled for every individual bus trip. In this instance, the gaps in the chart reflect the difference between weekday and weekend operations on the network.

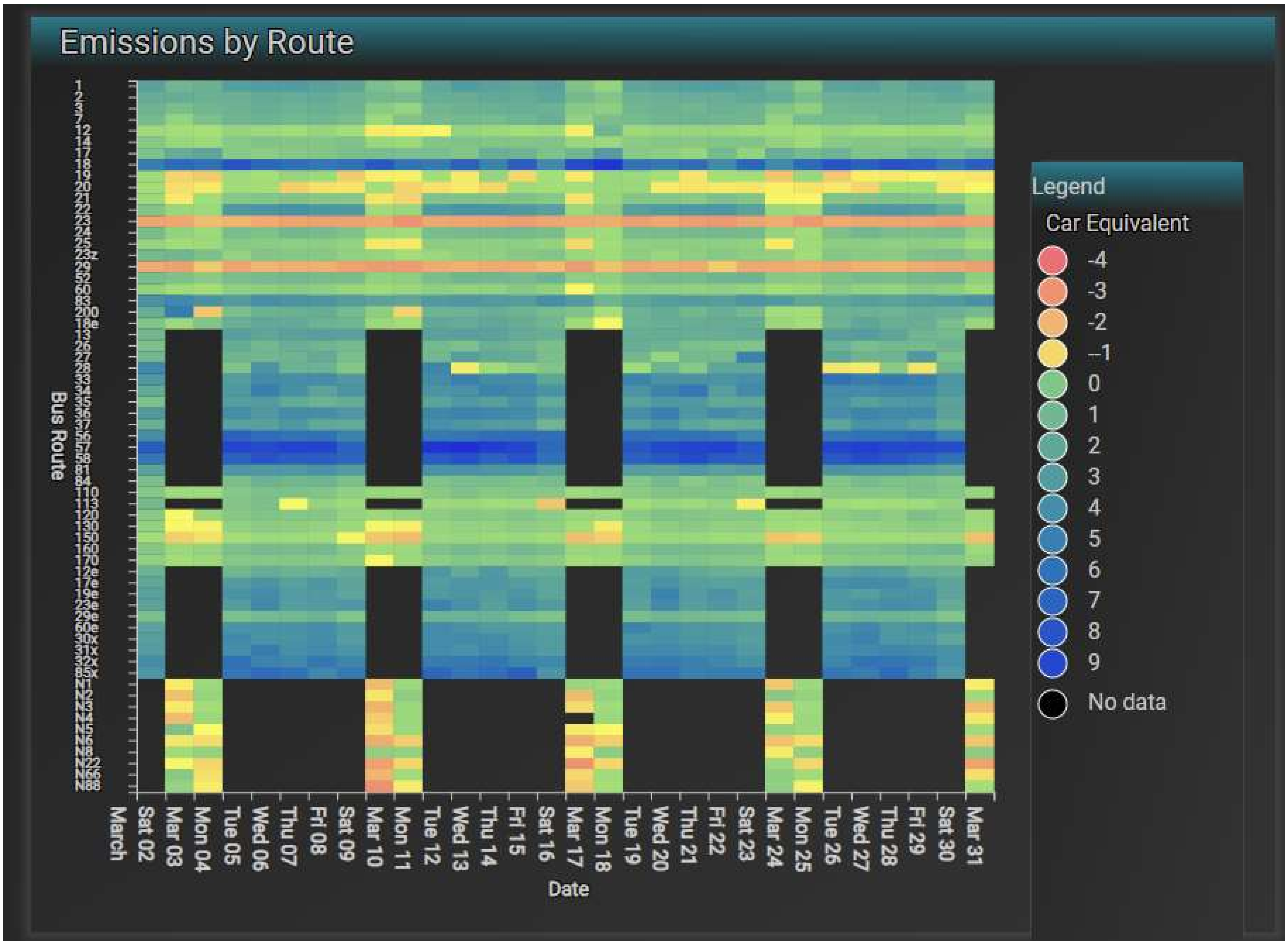

*Figure 4 Car Equivalent Bus Emissions by Bus Route, per bus km travelled (pre-Covid 2019 data)*

The routes in blue are up to eight times more carbon efficient than an equivalent distance travelled by the same number of people in private cars. Needless to say there is a lot of data sitting behind the visualisation. A route with 10,000 bus vehicle km delivered at 8 times car equivalency would effectively remove the carbon emissions of 54,000 car trips. A limitation of this visualisation style is that within the figure, a weekend service that runs a few times per day to improve mobility options takes up the same space as a high frequency route running every 10 minutes. Despite this issue with perspective, the heatmap method can be useful for directing further analysis. The heatmap illustrates two routes that appear in orange. These were routes where the patronage was low and the people using the service would have generated less emissions if they had travelled by private car. Since this analysis was undertaken, both routes have now been altered to improve patronage, as part of the GWRC internal bus network review.

In effect, the tools developed to identify the most carbon-efficient routes were actually a form of route utilisation. The car equivalent is a proxy for the how well the loading profile of the trip matched the size of the vehicle. By making minor changes to this function, the carbon tools were also repurposed to understand capacity issues and constraints during Covid distancing.

**Benefits of Mode Shift**

Whilst public transport represents a relatively small percentage of New Zealand's total carbon footprint, it is one where the government has direct control over funding and outcomes, which enables a relatively direct decarbonisation pathway. The 2019 Wellington Greenhouse Gas Inventory identified that transport emissions account for 40% of Wellington's greenhouse gases (Aecom, 2019). The benefits of decarbonising public transport are therefore further improved if public transport is coupled with mode shift, i.e. where public transport becomes a suitable choice for shifting people from private car usage. Assuming public transport can keep pace with demand, this presents an opportunity to reduce the carbon emissions of the total transport system. To improve understanding of the potential decarbonisation benefits of mode shift, the new model was used to compare emissions by different modes. The findings are illustrated in **Figure 5** below.

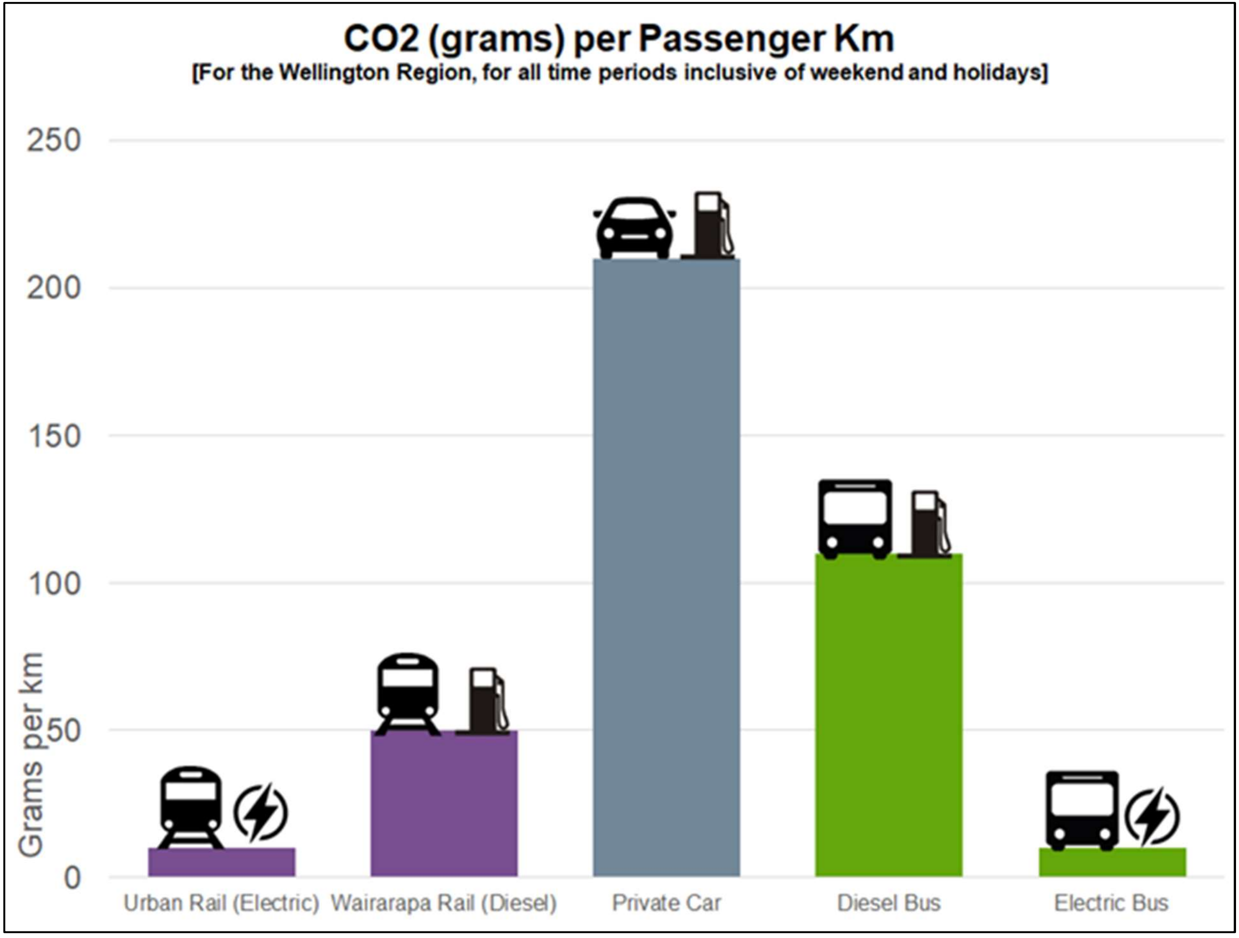

*Figure 5 Comparison of Carbon Emissions by Mode Choice (Wellington Data for 2019, all time periods)*

Note that an allowance was made for carbon produced from generation and distribution of electricity. The actual tailpipe emissions are eliminated entirely with electrification. Note also that the comparison would be even more favourable during commuter peak periods, when buses and trains tend to have a higher passenger loading for the amount of mass being moved.

Further analysis identified that, as a general rule of thumb, if a bus has 6 or more passengers it will generate less carbon than equivalent car travel (depending on the size of the bus). This is because of the economy of scale afforded by public transport. Part of this relates to mass. A car weighs roughly 1,000kg with a capacity of five people, although typically has an average occupancy of about 1.3 people. A bus with a capacity of 53 weighs about 6500kg. A bus with an occupancy of 108 weighs about 13,500kg. When including passenger weight, a fully laden bus moves 80kg less mass per person than a fully laden car. The physics of these comparisons means that as long as a bus is reasonably well utilised it can carry more people a lot more efficiently than cars, both from a decongestion point of view and in terms of energy requirements. Car occupancy/utilisation rates tend to be low, which makes it an inefficient travel mode from a carbon (and congestion) perspective because of the space and mass required to move people on the network. Note also that the comparison Figure 5 is based on 24/7 data and would be even more favourable during commuter peak periods, when buses and trains have a higher passenger loading for the amount of mass being moved.

As can be seen from Figure 5, shifting from private car to an electric bus or train can reduce fuel emissions by roughly 95% per trip. Even shifting to a diesel bus will reduce individual emission per km travelled by roughly half, thus reducing the emissions for the total transport system as a whole. The physics for Wellington trains is even more favourable than buses, as they can move people with considerably less energy per person, drawing their energy straight from the national grid. The Wellington urban rail network rollingstock consists of twin-carriage electric multi units (EMU). Each EMU (2 connected carriages) have an average occupancy of 83 people per EMU. A typical train of 3 EMU (6 carriages) would carry an average of 250 people (more during peak periods). This efficiency influences the results in Figure 5. The difference in emissions by mode identified in Figure 5 provides even more evidence that mode shift is an important area of consideration for efforts to reduce the total emissions generated by the transport system.

## GWRC TRANSPORT EMISSIONS SOURCES

In order to understand transport emissions and reduce them, it is necessary to identify where the emissions sources are coming from. Figure 6 below illustrates the emissions by source separated into each class of public transport (PT) activity provided by GWRC. Note, allowances have been made to include carbon produced by generation and distribution.

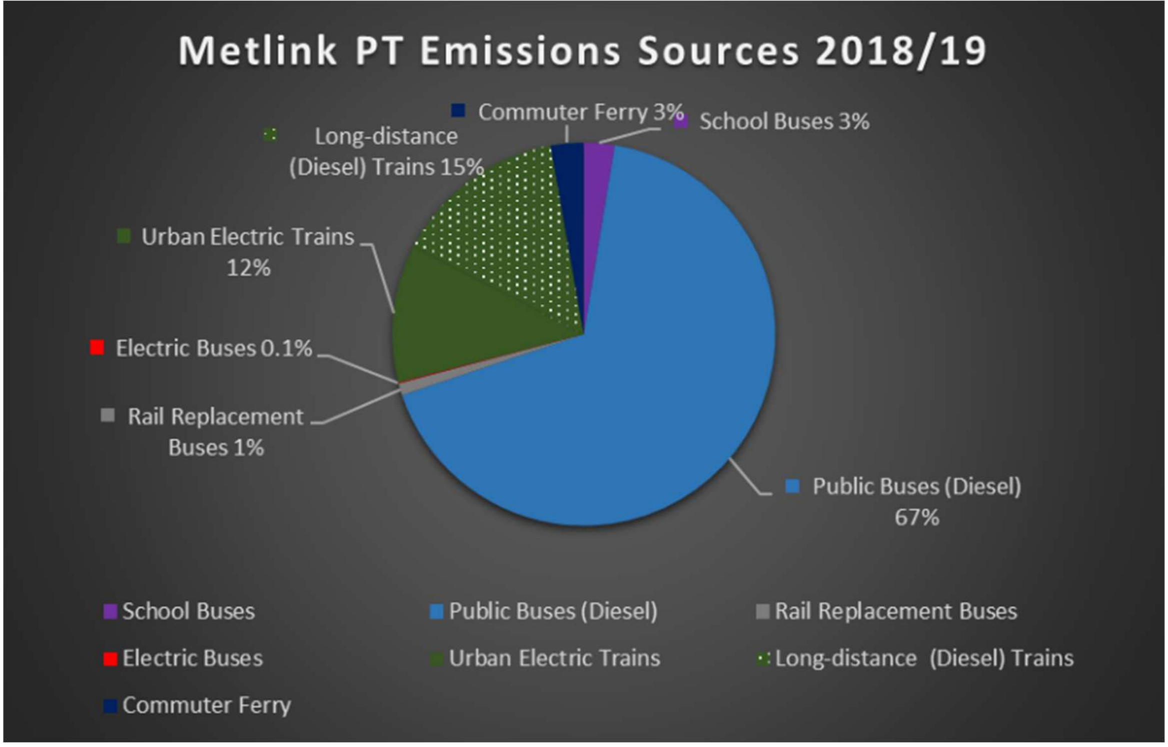

*Figure 6 GWRC Transport Emissions Sources*

As can be seen by Figure 6, the diesel from scheduled bus services contributes two thirds of the emissions generated by GWRC public transport activities. The next largest source of emissions relates to long-distance rail. Decisions relating to carbon emissions for rail relate to a single investment procurement decision for replacing the aging diesel locomotives on the Wairarapa Line. Ferry emissions will change with the introduction of a new electric ferry, which is currently undergoing sea trials. This will reduce ferry emissions by half, or 275 tonnes of carbon per year. For comparison, this is the equivalent of roughly 8.5 Wellington buses. The carbon produced by electric trains, buses and ferries will reduce as government investment decreases the consumption of fossil fuels for powering the grid. This leaves the main area of uncertainty the question of what to do with close to 500 diesel buses. Most of which are on contracts that come up for renewal in 2027, but some are on legacy contracts that last through to 2031. Further, the buses introduced in 2018 are not scheduled for age replacement until 2038.

# PATHWAYS TOWARD DECARBONISATION

## Typical Bus Carbon Emissions

Once it became possible to accurately identify existing carbon emissions it became possible to investigate different scenarios to inform a pathway towards reducing/removing the carbon of the public transport fleet. This reduction would be coupled with other measures such as modeshift to reduce the carbon emissions of the wider transport network. When investigating low emission public transport, the first step was to try and profile typical bus emissions to identify where to best direct decarbonisation efforts. The initial analysis identified that there is a huge spread across the fleet. This is illustrated in Figure 7 below. Note, this is not a line-graph. It is a *scatter graph* where each dot represents the annual footprint of a bus, plotted from highest to lowest carbon emissions footprints for 2019, derived from 14 million km of bus travel.

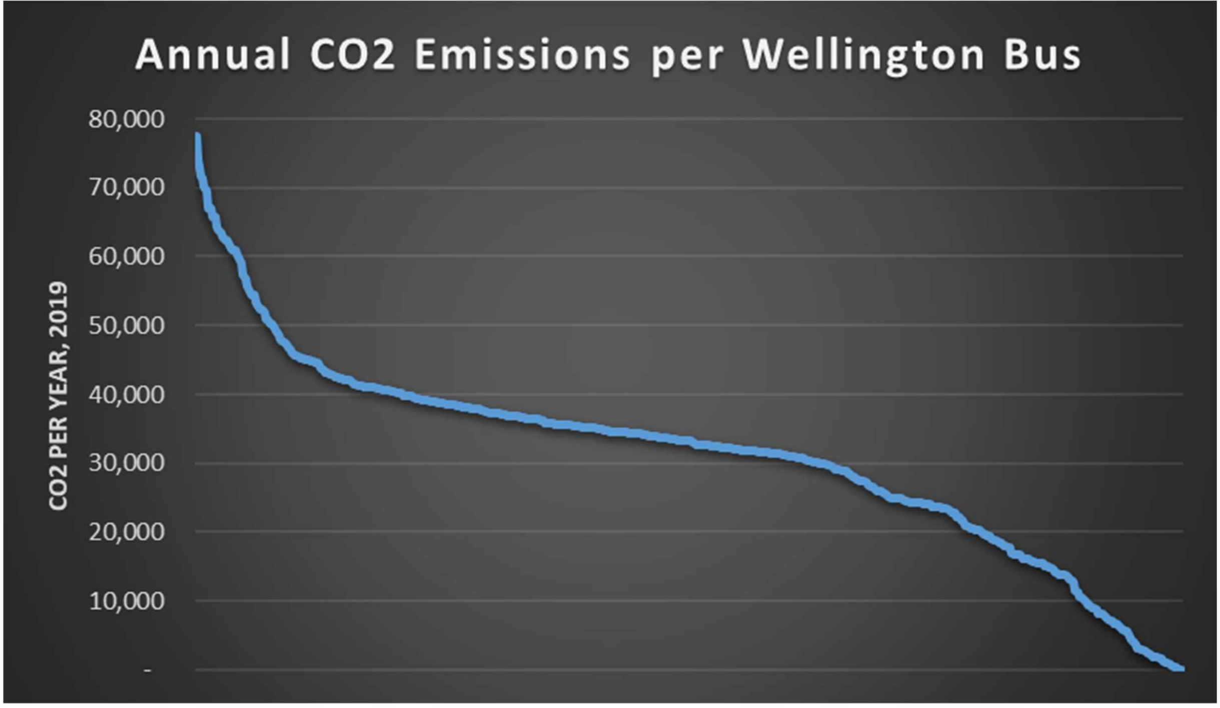

*Figure 7 Annual emissions for each bus (pre-Covid 2019 data)*

As can be seen in Figure 7, there is a wide range between the highest carbon emitters on the network (on the left) and the lowest emitters (on the right). Part of this relates to the need for spares. Operators are required to provide a specific number of buses every day (peak vehicle requirements or PVR). Buses will occasionally be taken out of service for reasons such as maintenance, incidents, or repairs. A reserve vehicle or ‘spare’ will then be placed into service. A spare might only run a limited number of trips each year (while otherwise engaging in other commercial activities). The requirement to have a surplus number of vehicles means that it is also possible for bus operators to rotate the specific buses that are in service on a daily basis.

Another complication is the extent of peak loading on the network. The need for vehicles during peak periods exceeds the need for vehicles during the off peak. Thus a portion of vehicles will be on the road for only a limited period of time during the day, with operators potentially rotating which buses are in service peak vs interpeak on any given day. The comparative scale of peak loading is illustrated in Figure 8 below to provide a visual context for this issue. The red indicates buses in service, the orange indicates buses relocating.

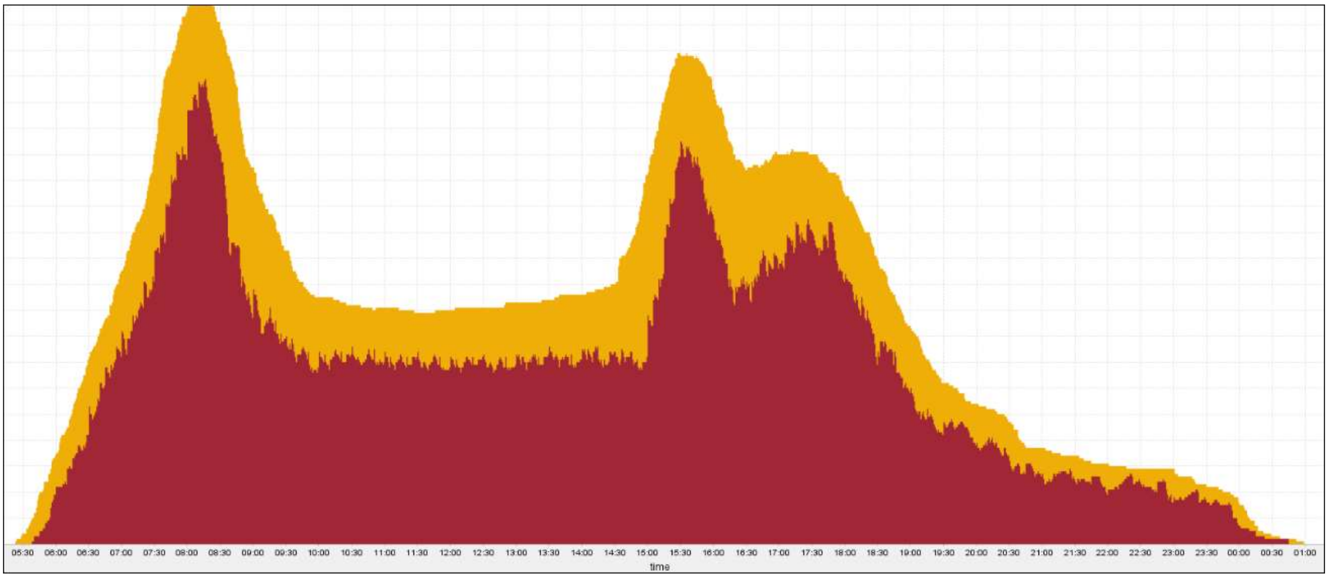

*Figure 8 Buses deployed on the Wellington Network by time of day*

The height of the graph represents the number of buses on the network by time of day. This is provided purely to illustrate the significance of the morning peak, school peak, and evening peak relative to the interpeak period. Peak loading provides a challenge for decarbonisation. Historically, the emphasis for new buses has been to manage growth in peak demands. The buses suited for this purpose are typically double deck buses with capacity for over 100 people. Given the marginal effort required to extend a peak service through the interpeak, the visualisation also alludes to the potential benefits of flattening the peak through encouraging working from home or travel behaviour change as this could make the peaks less 'peaky' and therefore reduce the number of buses required to serve the peak periods.

Analysis of Wellington bus emissions confirms that the heaviest buses consume the most amount of fuel per km travelled, as expected. However, they do not produce the highest total emissions. This is because spatial constraints (tunnels, narrow streets, overhead limitations, etc) limit options for utilising double deck buses during the interpeak. The buses with the highest total carbon footprints are actually single deck vehicles. These are 'work-horses' that are on the road seven days a week, up to sixteen hours a day. Historic patronage growth has meant that new vehicles have been added to the fleet every year.

Purchasing diesel growth buses would work against decarbonisation targets, by introducing a carbon producing asset with a 20 year lifespan. As a result, GWRC have introduced a policy to procure zero emissions vehicles only. This will cap emissions, however, in order to meet GWRC targets to reduce emissions, the 'work-horse' vehicles will also need to be considered. A trial is underway investigating the feasibility of converting existing diesel buses to electric, without having to replace the entire asset prior to it reaching the end of its 20-year operating lifespan.

Another issue studied by the project was that of 'range anxiety'. There is a perception that converting to electricity may cause issues with the effective range of the bus. This is a known complication with heavy freight vehicles, which tend to be on the road 24/7. However, the buses used in Wellington have an opportunity to recharge overnight. The drop in the number of buses required during the interpeak also provides some opportunities for charging during the day. A study of daily bus movements across the fleet identified that during 2019, only 1% of buses exceeded 350km in a single day (a consistent group of buses did so regularly), and 97% travelled less than 300km per day. Given the small number and identifiable patterns, these range limitations can be addressed either through opportunity charging, or by modifications to daily operation. Roughly a third of buses re-join the network in preparation for the school peak. It would likely be possible to address range limitations by switching vehicles during this daily reshuffle. As a result of this analysis, the range of the electric bus fleet is considered to be of limited relevance to decarbonising the Wellington bus fleet.

## Future Carbon Pathways

Having a better understanding of current emissions profiles has informed multiple future scenarios. Figure 9 illustrates the carbon impacts of a patronage growth scenario without further electrification, and Figure 10 illustrates one potential decarbonisation pathway. These are provided as examples only, and neither scenario should be taken as reflecting GWRC procurement policy. As at the time of writing, the exact procurement details have yet to be determined beyond 2022. The bars indicate the tonnes of CO2e produced per year, and the source (buses, bus spares, or electric vehicle). The red line on the second axis indicates potential numbers of electric buses in these two draft scenarios. The purpose of this is to illustrate that without further zero carbon buses the gains from the initial 108 vehicles will soon be lost if growth buses are diesel.

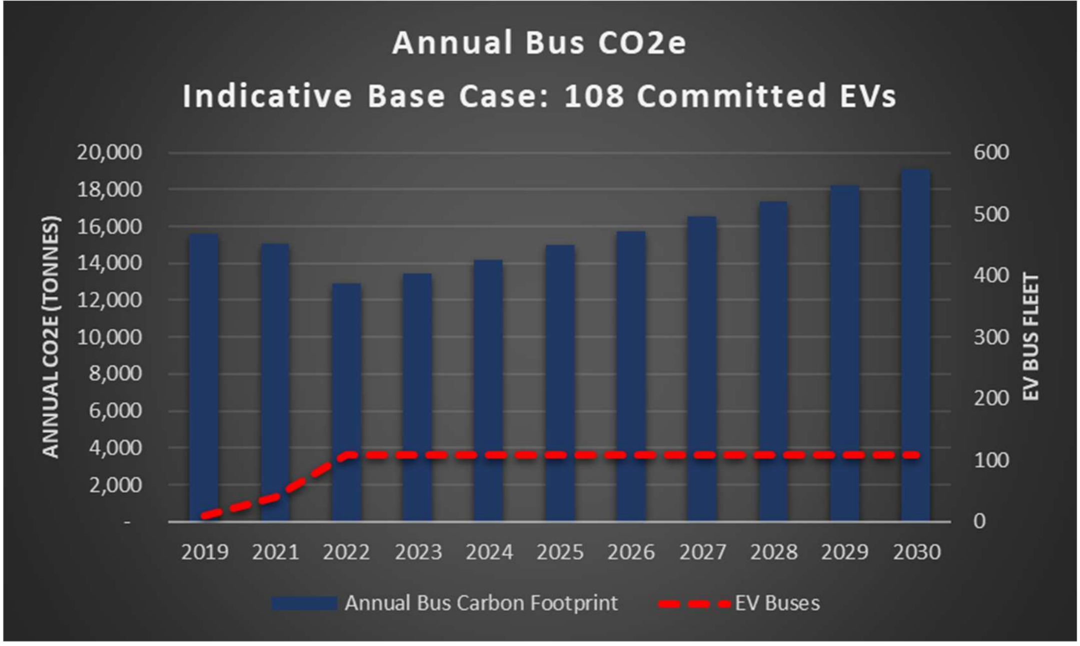

*Figure 9 Scenario 1 (hypothetical): No new EVs after 2022*

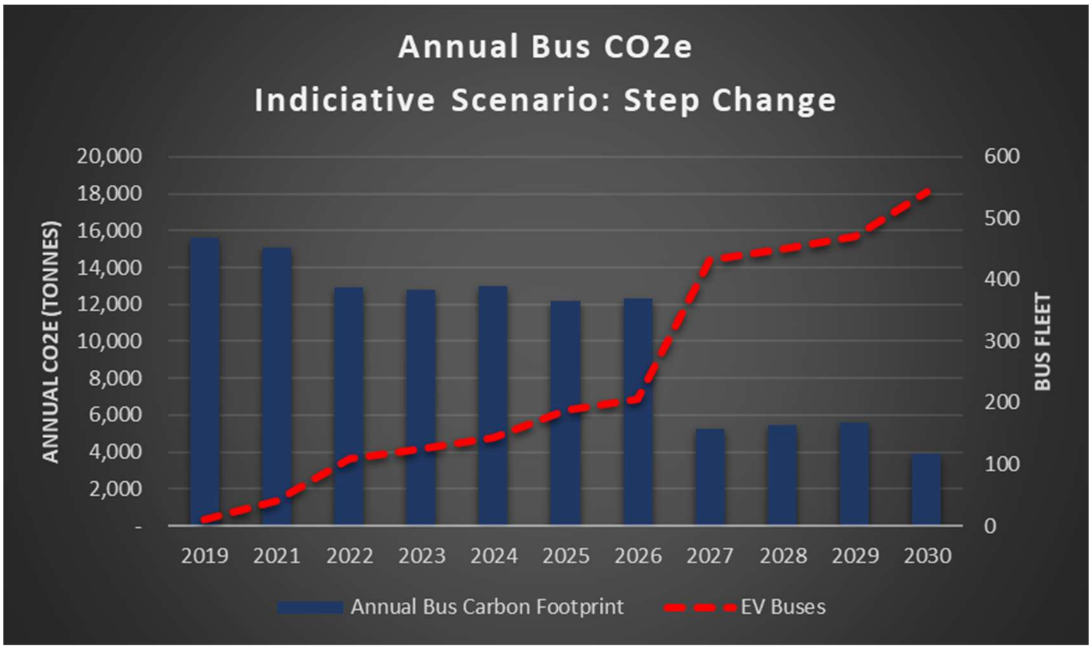

*Figure 10 Scenario 2 (hypothetical): All new growth and replacement buses are EVs, all new bus contracts require EVs*

It would be theoretically possible to expand the methodology to develop carbon reduction scenarios for other urban centres, or for New Zealand as a whole. 2021 pilot investigations have already been initiated for Auckland and Christchurch.

## A NATIONALLY CONSISTENT SYSTEM

Following Wellington's successful implementation of a system for calculating fuel emissions from trip data, an initial investigation has been undertaken to identify how easily this system could be scaled to develop a nationally consistent system of identifying fuel emissions across the country. New Zealand has 14 regional or unitary authorities/ councils operating scheduled public transport services. Each of these councils were contacted to identify whether or not they already had access to the data necessary to calculate fuel emissions, including:

- A system that captures the specific bus that ran each trip
- A fleet list of the properties of the bus (tare weight and Euro Class)
- Positional information that could be used to identify average speed & distance travelled
- Ticketing information that could be used to derive passenger loading
- The size of the fleet providing scheduled services (for a sense of scale)

The stocktake identified just under 3,000 buses operating scheduled services across New Zealand. The councils surveyed confirmed that their bus operators also engaged in activities outside of scheduled services (coach hire, cruise ships, MoE school services, etc). None of the Councils had a means of tracking fuel consumption purely for commercial services, which confirmed the need for emission measures other than self-reported fuel transactions. A brief summary of findings is provided as follows:

- **Auckland:** Detailed data collection for each bus trip, but the sheer quantum of data poses its own challenges. Bus Euro Classifications known, but tare weights need to be collected for about half the bus fleet
- **Wellington:** Pilot tools already developed
- **Christchurch and Gisborne:** Euro Class and tare weights need to be collated. Flat fare structure will make passenger loading difficult to quantify until the national ticketing system (NTS) is rolled out
- **Waikato (including Hamilton), Horizons (Palmerston North), Hawke's Bay (Napier/Hastings), Taranaki (New Plymouth), Nelson, Otago (Dunedin & Queenstown), Invercargill:** Fleet lists will need to be compiled to identify tare weight and Euro classifications. Bus schedules may be suitable for identifying distances travelled, as travel times are likely to remain relatively consistent day-to-day compared to congested urban centres. Bus loading and trip information will be known once Regional Integrated Ticketing System (RITS) data becomes available and has been backdated to installation dates
- **Bay of Plenty:** As per other regional centres, except that the council is relatively confident it can extract most of the required bus trip data from their existing bus tracking system. The RITS system would only be required for identifying average passenger loading
- **Northland:** As per other regional centres, except that early adoption of electronic ticketing means it might be possible to obtain historic passenger loading data back to 2015
- **Marlborough:** The information captured for scheduled services in Marlborough is limited and there are no plans to sign up to RITS, but the low number services suggests this area is unlikely to be a priority for calculating national fuel emissions
- **Timaru:** One of the easier jurisdictions to calculate, as the ride share trial collects information on the distances travelled (assuming this can be anonymised/averaged and made available).

Collaboration with Auckland Transport has identified that the staging for decarbonisation will be a something that needs to be determined sooner rather than later. A bus procured tomorrow will have an expected operational life providing scheduled services for the next 20 years. Therefore current age replacement will have an impact on 2035 and 2040 milestones. This is visualised in Figure 11 below. The slice in red is the proportion of the fleet due for replacement prior to 2025, but any vehicles procured within this time period will still be in the fleet in 2040.

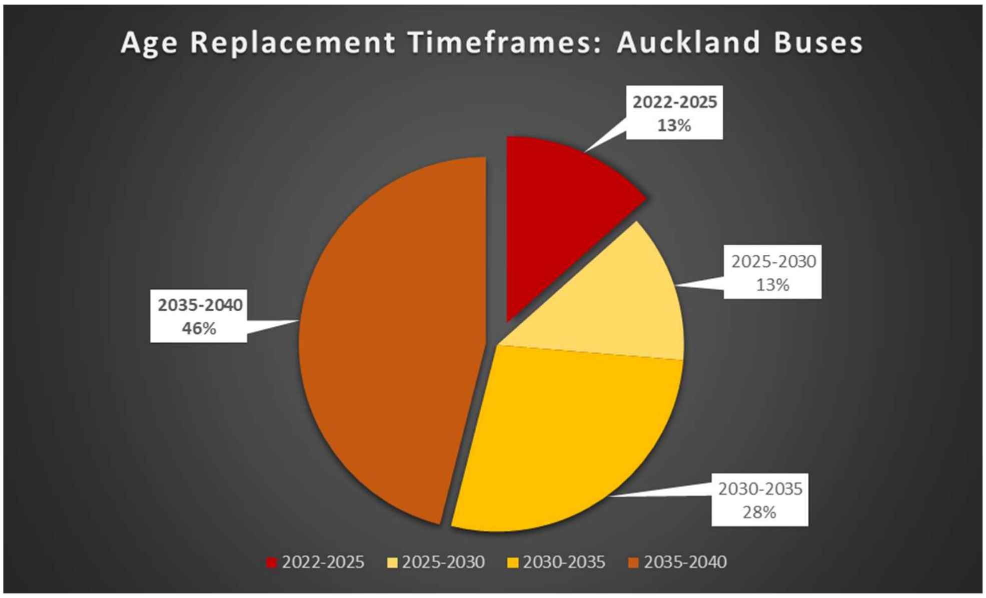

*Figure 11 Age Replacement timeframes for the Auckland Bus Fleet*

## CONCLUSIONS AND RECOMMENDATIONS

The study improved understanding of current and recent historic fuel emissions, including by Euro Class, bus route and passenger km travelled. Analysis using the new prototype tools made it possible to confirm a 70% reduction in local harmful emissions as a result of introducing a fleet of new Euro V and VI buses in 2018. This reduction in pollution reduces the potential harm for people breathing the air in areas with a lot of bus movements (e.g. the Golden Mile). However, the study also confirmed a trend of public transport carbon emissions steadily increasing due to (pre-Covid) growth in demand, resulting from a growth in the number of vehicles and bus trips required on the network. The additional 1.3 million passenger trips added to the public transport in 2019 required more bus movements, burning more fossil fuels, and resulted in an increase in carbon emissions.

Analysis revealed that continued growth in patronage would continue to increase the carbon footprint if relying on fossil fuels. Decarbonising public transport will reverse this trend. Some very minor improvement can be made by speed and fleet optimisation, but the comparison of carbon footprint by mode type confirmed the substantial decarbonisation gains that can be made by mode shift from car use to public transport. A traveller can reduce their transport carbon footprint by more than half shifting to a diesel bus, and by more than 90% shifting to an electric bus or train. A typical bus trip only needs six or seven people to be more carbon efficient than a car. Thus, the most effective means to reduce transport carbon emissions would be to simultaneously reduce the carbon emissions of the public transport and implement mode shift to public transport. If the bus fleet can’t keep up with growth in transport demand, the resulting reliance on car trips would undermine efforts to reduce carbon on the network as it would potentially force people back to high carbon mode choices.

Encouraging more work-from home or behaviour change to flatten the peaks would also have the potential to reduce emissions, and reduce costs for providing public transport, as it would take pressure off the network and mean less vehicles required solely to meet peak period demands. This in turn could assist with managing the competing priorities of managing growth, encouraging modeshift, and the cost of procuring new zero emissions vehicles.

There would be some benefit in having a nationally consistent means for measuring bus carbon emissions, rather than have separate approaches potentially creating differences in methodology. The possibility of expanding the Wellington pilot study was explored. The effort required to implement the system will differ from region to region, but the key ingredients are available in most locations. These requirements are as follows:

1) Bus fleet information would need to be compiled, although this is a relatively straightforward process
2) Almost all buses have locational positioning needed to identify trip movement data
3) With the rollout of RITS, it should be possible to identify average passenger loading information for most locations, although further investigation will be required to assess this for locations with the flat fare structure.

The preliminary investigation confirmed that a nationally consistent approach would be beneficial to quantify public transport emissions and interventions accurately, as there are likely to be differences in calculation methods across different jurisdictions. Having a consistent means of calculating emissions at a trip level would help inform and prioritise interventions and benefits, and avoid the risk that differing methodologies produce subtly different results. A nationally consistent approach could take the form of a single piece of software, as a means of ensuring that consistent methods are used for calculations, scalability, gap identification and interpolation. And to provide a consistent means of comparing emissions across regions.

## REFERENCES

The graphs and numbers provided in this report are the result of original research, using base calculations provided by *Emissions Impossible Ltd*, processed in bespoke software developed in collaboration with Victoria University. The following references provide background context.

Aecom May 2020. *Wellington Greenhouse Gas Inventory 2019*.
Prepared for Greater Wellington Regional Council, Wellington
https://www.gw.govt.nz/assets/Climate-change/GHG-Summary-Report-Wellington2019WRFinal.pdf

KHEIRBEK, HANEY, et al (2016). *The contribution of motor vehicle emissions to ambient fine particulate matter public health impacts in New York City: a health burden assessment*
*https://ehjournal.biomedcentral.com/articles/10.1186/s12940-016-0172-6*

Greater Wellington Regional *Wellington Region Climate Change Projections and Impacts* report, (GWRC, 2017)
https://www.gw.govt.nz/assets/Climate-change-2/FINAL-WellNCC-projectionsimpacts.pdf

Greater Wellington Regional *Greater Wellington is Committed to Climate Action*
https://www.gw.govt.nz/assets/Climate-change/Greater-Wellington-is-committed-to-climate-actions-v4.pdf

*Corporate Carbon Neutrality Action Plan*, Greater Wellington Regional Council
https://www.gw.govt.nz/assets/Climate-change-2/Corporate-Carbon-Neutrality-Action-Plan.pdf

Greater Wellington Regional Council *Future Fleet,* Report *RPE 19.509* to Council 12th December 2019

Greater Wellington Regional Council *Proposed Diesel to Electric Bus Trial*, Report *PE20.487* to Council 10th December 2020

## ACKNOWLEDGEMENTS

The author would like to acknowledge the hard work of the software development team, including Craig Anslow, Hamish Clark, Joshua Berkhan and Chris Todd for their efforts developing the prototype decision support tools utilised in this study. Nina Ives for her efforts in compiling the national stocktake. Paul Blane and Simon Cross from Metlink for their contribution to understanding bus operations and procurement requirements. Greg Pollock, Scott Gallacher, Sharon Aitken, Greg Nielsen, Waka Kotahi, Auckland Transport, Metlink and Victoria University Wellington for their contributions to funding & resourcing to make these studies possible, as well as Gerda Kuschel and the guidance and advice supplied by Emissions Impossible Ltd.