

Evaluating Bus Emissions: What colour, how big and how much is that elephant in the window?

Gerda Kuschel¹, Andrew Cooper² and Jayne Metcalfe¹

¹ Director, Emission Impossible Ltd, Suite 2-3, 93 Dominion Road, Mt Eden,
Auckland 1024, NZ

² Programme Director – Bus Services Transformation, Greater Wellington Regional Council,
PO Box 11646, Wellington 6142, NZ

Email for correspondence: gerda@emissionimpossible.co.nz

Abstract

Despite improvements in control technology and the introduction of cleaner transport fuels, vehicle emissions and their impacts on human health and climate remain a challenge. This is especially true in cities where population growth and intensification are putting more and more people into closer proximity to major transport corridors - many of which are serviced by public transport bus fleets.

In New Zealand, greenhouse gas emissions from road transport are currently tracking well above 1990 levels (78 per cent from MBIE 2017) and levels of nitrogen dioxide (a harmful pollutant) remain elevated in a number of roadway locations (NZTA 2016). Whilst public transport represents a small fraction of all trips (2.8 per cent), its use is increasing with most of the growth being driven by bus trips (MoT 2017).

The Public Transport Operating Model (**PTOM**) that came into law in 2013 has changed the way public transport is planned and procured. It provides an opportunity for regions to work in partnership with operators to achieve improved competition and value for money outcomes that may not previously have been possible, while improving the effectiveness of services delivered to communities. In this spirit, buses are ideal leaders for showcasing and promoting sustainable transport initiatives.

In 2016, Greater Wellington Regional Council (**GW**) commenced tendering for bus services under the new PTOM. As part of this process, GW not only signalled to potential operators that sustainability was important, they also factored an emissions improvement premium into the evaluation criteria. However, whilst costing operational elements of a passenger transport service is well understood, costing the environmental externalities is less so and is often regarded as the “elephant in the room”. Consequently, the tendering process required the development of a robust and defensible bus emissions evaluation model.

This paper discusses the development of the model in terms of what colour the elephant is (i.e. which air pollutants matter and why), how big the elephant is (i.e. the relative emissions from different bus technologies), how much the elephant costs (i.e. damage costs per tonne of pollutant) and how GW successfully applied the model to ensure they were comparing apples with apples (or elephants with elephants!) in their latest tender round.

As a result, from mid-2018 operators will deliver a new, more environmentally friendly bus fleet that will improve air quality across the region and reduce emissions of harmful pollutants by at least 38 per cent in Wellington and 84 per cent in the Hutt Valley.

1. Why is there a need to understand elephants?

The Wellington region has a strong culture of public transport use. During 2016/17, 37.7 million passenger trips were taken on the Metlink Public Transport Network. With 74 trips per capita (2015/16), the Wellington region has the highest per capita public transport use in New Zealand. Over the last ten years, bus patronage has increased by 7 per cent and is currently just under 25 million boardings per annum.

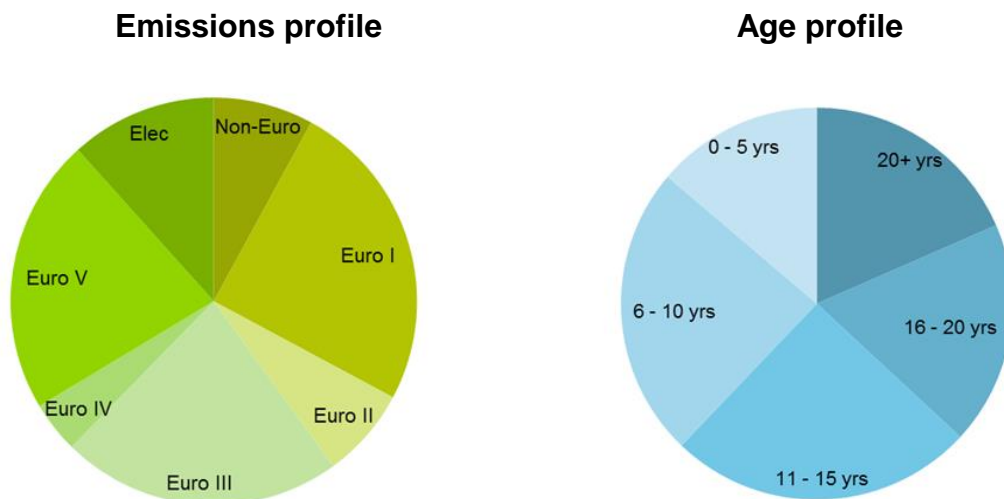
The Land Transport Management Act 2013 established a new framework for planning and contracting public transport services, known as the Public Transport Operating Model (PTOM). Greater Wellington Regional Council (GW) is transitioning to PTOM within a broader Public Transport Transformation Programme to provide better value for money and a better customer experience. In addition to new performance based contracts with bus operators, GW is also introducing major changes to the bus network and a modernised bus fleet to provide Wellingtonians with an attractive, easy to use public transport option to entice them out of their cars.

Customers are at the heart of GW's strategy to increase public transport use. People want a seamless public transport service that is easy to use and affordable. There is also growing public awareness of the need for sustainable, clean public transport solutions that will boost Wellington's status as a desirable place to live, work and play. PTOM seeks to grow patronage, while reducing reliance on public subsidies by meeting the dual objectives of growing the commerciality of public transport services and growing confidence that services are priced efficiently and the market is competitive.

In 2016, in accordance with PTOM, GW commenced a tender process for two thirds of bus services in the Wellington region. The remaining one third of bus services is directly appointed to the major incumbents with prices agreed by negotiation. At the time of writing, the tender process has been concluded and contracts executed with the successful tenderers, while the incumbent negotiations are underway.

The Wellington Region is currently characterised by a relatively old bus fleet, made up of diesel buses and a small number of electric trolleys. Over 40 per cent of the region's existing bus fleet needs to be retired and replaced when new PTOM contracts commence to comply with new national standards for urban buses. The characteristics of the current Wellington region bus fleet are illustrated in Figure 1 which follows.

Figure 1: Characteristics of current bus fleet



GW is on a pathway to provide a zero emission bus fleet for the region, with a stated ambition to be the first region in New Zealand to have a fully electric battery bus fleet. GW previously agreed that continued investment in the current trolley buses and supporting network is not the best way forward. In terms of vehicle numbers, trolley buses (which are owned and operated by bus operator NZ Bus Ltd) make up 12 per cent of the urban bus fleet that service the Wellington region. However, in practice, trolley buses represent a smaller proportion than this as many of these vehicles are off the road at any one time for maintenance and they do not operate on weekends to enable ongoing maintenance of the overhead wire network to occur.

Phasing out trolley buses was decided for many reasons, including the estimated \$52 million of public money required to upgrade the power supply system that dates back to the 1930s (including an estimated \$17 million just to bring the system up to modern safety standards) and the \$4 million to \$6 million annual cost of maintaining and upgrading the overhead wire network. The rapid improvements in battery technology and growing availability of full battery-electric buses would make further investment in the trolley network redundant.

Engagement with potential bus operators in the lead-up to, and during, the tender process clearly signalled GW's preference for lower emission vehicles and the desire to move to an all-electric bus fleet. Due to the potential cost implications and the need for GW to work with the NZ Transport Agency (**NZTA**), who co-funds the public transport subsidy, it was not possible to specify electric only buses in the tender. However, the methodology developed by GW to value bus fleet emissions was accepted by NZTA as a means of demonstrating improved overall economic outcomes of lower emitting, but potentially more expensive, bus fleets and therefore justifying a higher level of subsidy for the services that GW would run.

Tenderers were encouraged to offer the most cost effective fleet to meet GW's aspirations by including a specific step in the process for evaluating fleet emissions. GW recognised that capital costs generally increase with a more modern, lower emissions fleet. To counter possible higher whole of life costs from lower emitting fleets, GW sought to monetise improved emissions outcomes and apply this as an incentive in the tender process. The monetised value of fleet emissions was used to adjust the tendered prices in the same way that the monetised quality scores under the NZTA's Price Quality Method (**PQM**) was applied to reflect the additional value that GW would be prepared to pay for an improved quality outcome (see Figure 2).

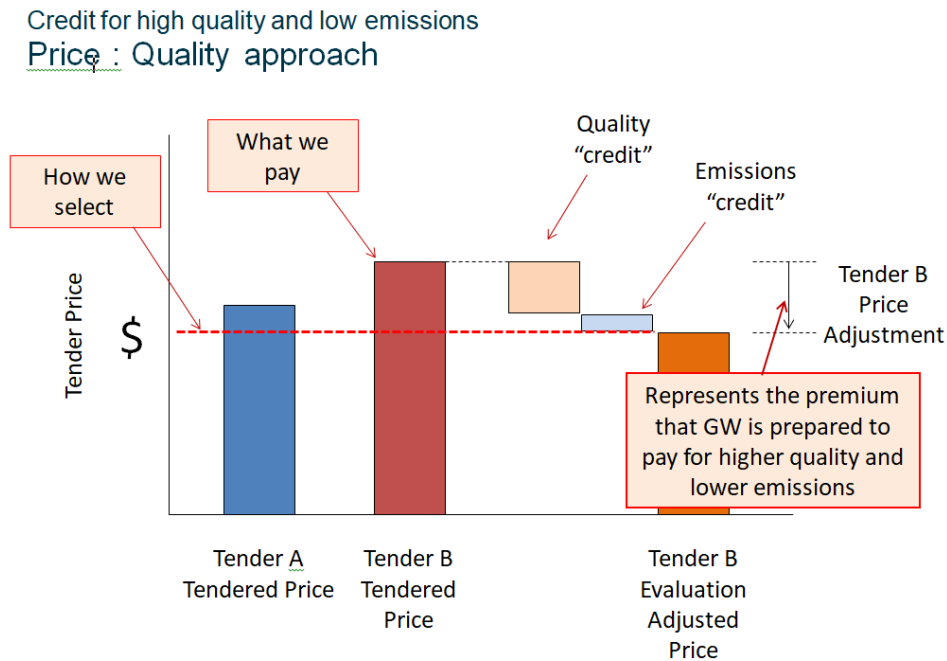
Generalised production rates of emissions were calculated for the different Euro standard of each bus tendered and for any alternative motive power (such as hybrids and fully electric buses), with total fleet emissions multiplied by factors reflecting the economic cost to society. The monetised value of emissions for each tendered fleet was then compared against the highest emitting fleet to calculate the emissions saving that each tender delivered. The result was the Emissions Improvement Premium (**EIP**) or "emissions credit" for each tender.

Note: The EIP was based on exhaust emissions only as non-exhaust emissions (e.g. brake and tyre wear) were assumed to be relatively constant across all buses regardless of fuel type or technology. Whole of life emissions were also excluded.

The emissions credit (EIP) was then applied to each tender as shown in Figure 2, which, for evaluation purposes, adjusted the tender price down by the value of the emissions credit. In this way tenderers who opted for cleaner technology buses were rewarded.

This step of the tender process required the development of a detailed methodology and a Bus Emissions Evaluation Model (key features of which are covered in the next sections).

Figure 2: GW approach taken to incentivise quality and lower emissions in the bus tenders



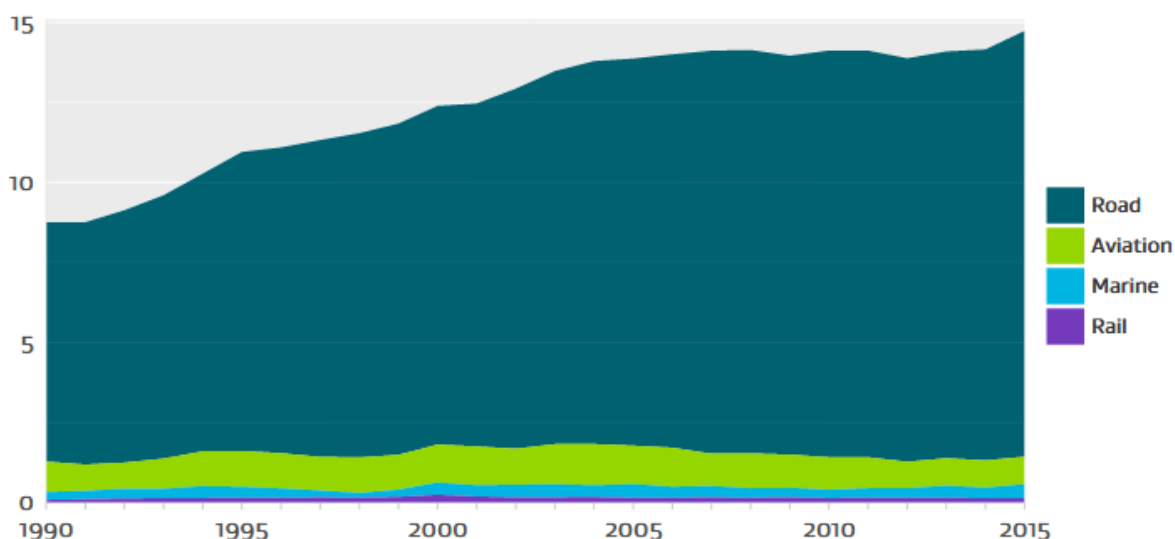
2. What colour is the elephant?

The transport sector emits a broad range of air pollutants, principally through the combustion of fossil fuels. The primary air pollutants are typically split into harmful air pollutants (which impact locally) and greenhouse gases (**GHGs**), also known as "climate pollutants" (which impact globally).

For road transport, the greenhouse gas of most concern is carbon dioxide (**CO₂**), which is the primary contributor to global warming. However, others such as methane (**CH₄**) and nitrous oxide (**N₂O**) can be significant. For ease of comparison, GHGs are typically expressed as CO₂ equivalents (**CO_{2-e}**), which is the amount of CO₂ which would have the equivalent global warming impact.

Figure 3 shows road transport emissions have grown steadily and in 2015 were 78 per cent over 1990 levels (MBIE 2017). This sector accounts for 13.3 Mt CO_{2-e} or 41 per cent of all energy sector emissions. New Zealand ratified the Paris Agreement on 4 October 2016 and has committed to reducing GHG emissions by 30 per cent below 2005 levels by 2030 (equivalent to 11 per cent below 1990 levels). As a consequence, initiatives addressing transport emissions will be critical to achieving this target.

Figure 3: Domestic transport emissions by mode (Mt CO₂-e) from 2007 to 2015 (MBIE 2017)



For road transport, the harmful pollutants of most concern are:

- Particulate matter (**PM₁₀** – particles smaller than 10µm), which impacts predominantly on respiratory and cardiovascular systems. Effects can range from reduced lung function to more hospital admissions through to reduced life expectancy and death.
- Nitrogen dioxide (**NO₂**)¹, which is a gas that causes increased susceptibility to infections and asthma. It reduces lung development in children and has been associated with reduced life expectancy.
- Carbon monoxide (**CO**), which is a gas that is readily absorbed from the lungs into the bloodstream. It attaches more readily to haemoglobin in the blood than oxygen and can cause headaches, dizziness, and can aggravate heart conditions.
- Hydrocarbons (**HC**), which include a wide range of chemicals, some of which are carcinogenic to humans. HCs can also react with NO_x to form ozone (O₃).

While health effects associated with exposure to PM₁₀ are significant, NO₂ is emerging as a critical pollutant in transport-impacted cities. A recent study found nearly 9,500 people die early each year in London due to long-term exposure to air pollution, more than twice as many as previously thought, once they had accounted for both NO₂ and particulate matter effects (Kings College 2015).

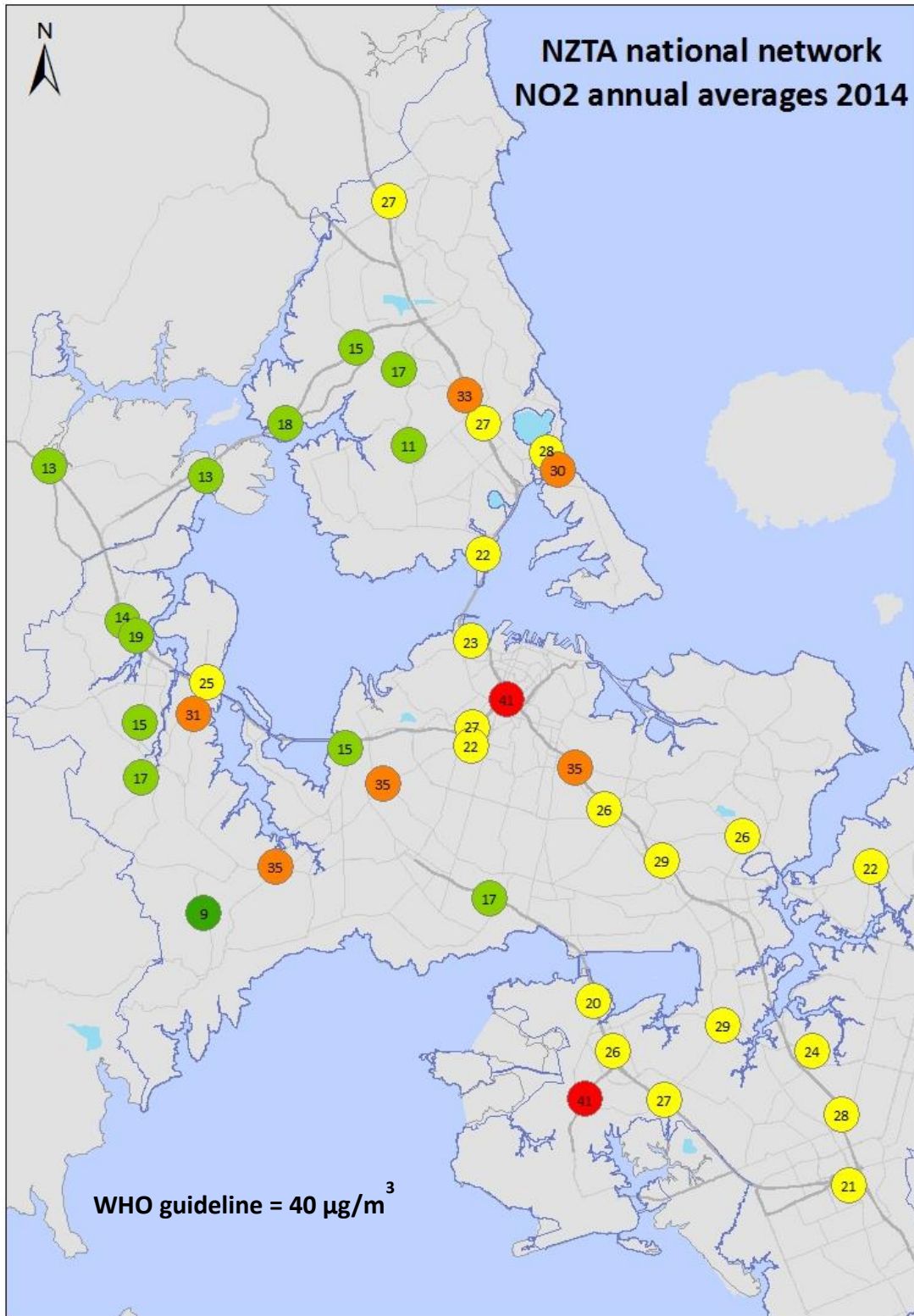
In New Zealand, hotspots have already been recorded near major roads in Hamilton, Wellington and Auckland (see Figure 4). In these locations, NO₂ concentrations have exceeded the World Health Organisation's annual NO₂ guideline of 40µg/m³ (NZTA 2016).

Many harmful pollutants can also impact the climate - either individually or in combination with other gases. Therefore initiatives which address harmful air pollutants typically yield both health and climate change benefits.

The GW bus emissions evaluation model focussed on **tailpipe (only) emissions of CO₂, PM₁₀, NO₂, CO and HC.**

¹ NO_x emissions cover NO and NO₂. NO is relatively harmless by itself but transforms to NO₂ (which is harmful) in the presence of other pollutants in the air. For transport sources, emission factors can easily be derived for NO_x but NO₂ is more difficult to quantify. Consequently, NO_x is used as a proxy for NO₂ in most evaluations of air pollution social costs.

Figure 4: NO₂ annual average concentrations in Auckland in 2014 (NZTA 2016)



3. How big is the elephant?

How much an individual bus emits depends on a number of factors including:

- fuel type (e.g. diesel, hybrid, natural gas etc.)
- exhaust emissions control technology (e.g. Euro IV, Euro V etc.)
- size and tare weight (e.g. small, double decker etc.)
- passenger carrying capacity and average loading
- average speed and distance travelled

Because the GW bus emissions evaluation model was developed for the tender process, the initial version was designed to cover the full range of bus and motive power options that might be expected - conceivably and reasonably - to be offered by prospective operators. The bus emission factors were based on those in the *European Computer Model to Calculate Emissions from Road Transport*, known as **COPERT** (Emisia 2015), and adjusted where necessary to cover all of the classifications included in the GW model.

3.1 Base factors from COPERT

COPERT is an average speed model. This type of model is predicated on the fact that average emissions for a pollutant and vehicle type/technology vary as a function of the average speed during a trip. The emissions factors are developed from emissions tests representing real life driving conditions rather than the drive cycles used for regulatory compliance. This is particularly important for heavy duty diesel vehicles, because Euro IV and V vehicles have been found to produce higher real world emissions than previously expected (ICCT 2015), particularly at lower speeds which are characteristic of urban bus operations.

COPERT emission factors were selected because:

- They are intended to be representative of real world performance, as opposed to regulatory emission limits.
- They are regularly updated, and have recently been updated to reflect real world emission test results from Euro IV, V and VI vehicles.
- They cover a wide range of Euro emission standards and bus types so directly comparable emission factors are available for all GW bus classifications.
- They are publicly available (together with their supporting technical publications).
- They are the same factors as those used in the NZ Transport Agency (2017) Vehicle Emission Prediction Model (**VEPM**) which is the preferred model for air quality assessments and emission inventories in New Zealand. These factors have been validated with local emissions test results.

Bus types in the GW model are different to those in COPERT. The GW bus types were assigned the closest equivalent COPERT type based on gross vehicle mass initially (see Table 1) then adjusted by operating mass according to the following equation:

$$\text{Mass adjustment factor} = 0.00004711 * \text{operating mass} + 0.446 \quad \text{Equation 1}$$

This equation provided factors for adjusting the emissions and fuel consumption of different buses relative to a standard bus with an operating mass of 11.75 tonne. It was originally derived in work done for Auckland Council on the development of a bus emission prediction model (EFRU 2005).

Table 1: Comparison of the bus classes in the GW model versus COPERT

GW classifications					COPERT classifications			
Type	Average tare wt (t)	Max pax	Est gross vehicle mass (t)	Est operating mass (t)	Closest equivalent type	Average tare wt (t)	Gross vehicle rating (t)	Average gross vehicle wt (t)
Small vehicle (SMV)	7.7	30	10.1	8.7	Urban bus midi	6.7	up to 15	11.5
Medium vehicle (MV)	9.2	55	13.6	11.0	Urban bus standard	10.4	15 to 18	17.8
Large vehicle (LV)	11.9	75	17.9	14.3				
Double decker (DD x 2 axle)	10.6	100	18.6	13.8				
Double decker (DD x 3 axle)	15.4	100	22.4	18.6				

Table notes:

1. Gross vehicle mass and gross vehicle rating assumes 100% loading of passengers
2. Estimated operating mass and average gross vehicle weight assume reduced (typically 40%) loading

3.2 Factors for alternative technologies

Factors for a range of alternative fuels and technologies were also required in the GW model and these were developed as outlined in the following subsections.

3.2.1 Natural gas buses

Most of the bus emissions factors in COPERT are for diesel-fuelled vehicles. However, factors are also provided for Euro I, II, III, and EEV compressed natural gas (CNG) buses. EEV stands for an Enhanced Environmentally Friendly Vehicle, which performs between Euro V and VI.

The EEV emission factors were selected for the GW model as being most representative of a modern CNG or LPG bus and adjusted for mass as required according to Equation 1.

3.2.2 Diesel-hybrid buses

COPERT does not currently include factors for diesel-hybrid buses because there are relatively few test results available. However, Transport for London has over 1500 diesel-hybrid buses on the road and has undertaken extensive testing for the Clean Fleet consortium (2014). Their testing found the following average reductions for diesel-hybrid vehicles versus equivalent conventional diesel vehicles:

- 20% for NO_x from Euro IV and Euro V buses
- 0% (i.e. no emission reduction) for NO_x from Euro VI buses
- 0% (i.e. no emission reduction) for PM from Euro IV, V and VI buses

These factors were used to calculate diesel-hybrid bus emissions from the COPERT emission factors in the GW model. Diesel-hybrid bus fuel consumption was assumed to be 67% of a Euro V conventional diesel bus - also taken from the Transport for London test results.

3.2.3 Low carbon emission buses

Emission factors for a specific Euro VI micro hybrid Low Carbon Emission Bus (LCEB) were also included in the GW model. These were based on Low Carbon Emission Bus Approval test results from Millbrook in the UK (LowCVP 2016) for two different micro hybrid buses travelling at 20km/hour:

- A single deck bus with passenger capacity of 73
- A double decker bus with passenger capacity of 99

Emission factors for other speeds in the GW model were calculated assuming the ratio of the low carbon emission bus emissions to equivalent Euro VI vehicles remained constant. This specific bus was included because an operator indicated that they were considering this vehicle and provided applicable emission test results.

3.3 Calculation of production rates (overall emissions)

Measured average speeds were available for the routes being tendered and these were rounded to the nearest 5km/h. Emission factors were then developed for these average speeds, ranging from 20km/h to 45km/h in 5km/h increments. These factors were then multiplied by the vehicle kilometres travelled (VKT) for each route, with the total divided evenly by the number of each bus type to get overall emissions for each pollutant.

Table 2 presents a selection of emission factors for different types of buses travelling at 20km/h.

Table 2: Exhaust emission factors for different bus types travelling at 20km/hour

Bus type	Bus size	Emission Factors in g/km @ 20km/hour				
		CO	HC	NOx	PM ₁₀	CO ₂
Euro III	Large (LV)	3.46	0.70	12.56	0.25	1281
Euro IV	Large (LV)	1.61	0.09	7.58	0.06	1175
Euro V	Large (LV)	2.82	0.07	8.96	0.07	1138
Euro VI	Large (LV)	0.33	0.05	0.62	0.01	1163
Euro V diesel hybrid	Large (LV)	2.82	0.07	7.17	0.07	759
Euro VI diesel hybrid	Large (LV)	0.33	0.05	0.62	0.01	776
Low carbon emission bus	Large (LV)	0.03	0.01	1.56	0.003	763
Electric	Large (LV)	0	0	0	0	0
Natural gas	Large (LV)	1.12	1.13	4.58	0.01	1392

4. How much does the elephant cost?

Social costs (also known as damage costs) are a way to value changes in air emissions in order to compare the benefits to society of a change in policy/operation versus the cost of implementing the change. They can also be used to compare a range of options to see which will yield the best overall outcome. Most government agencies internationally publish relevant values to be used in the assessment of costs and benefits of various policy options in their jurisdictions.

The *Guide to Project Evaluation Part 4* published by Austroads (2012) was chosen as the starting point for assigning social costs in the GW model. This guide includes unit values of emissions in AUD\$ per tonne (as at 2010), shown in Table 3. Austroads states that **these figures are intended for use in Australia but may also be applicable to New Zealand provided country variations are accounted for.**

Table 3: Unit values of emissions in \$/tonne published by Austroads (2012)

Pollutant	Costs in AUD/tonne	Value Base Date
CO ₂	\$52.40	2010
PM ₁₀	\$332,505.90	2010
NO _x	\$2,089.20	2010
CO	\$3.30	2010
HC	\$1,046.80	2010

These estimates were then refined in the light of more recent literature on air pollution damage costs for New Zealand and other countries, together with inflation and relevant exchange rates, as outlined in the following subsections. All damage costs were derived in NZD as at June 2015 for the GW model.

4.1 PM₁₀ costs

PM₁₀ typically dominates air pollution health impacts and it is the only air pollutant for which actual health impacts and associated social costs have been estimated for New Zealand. Health impacts of air pollution in New Zealand were first comprehensively quantified in a study known as **HAPINZ** (Health and Air Pollution in New Zealand) by Fisher et al. (2007). This study was revised in 2012 using the 2006 Census and more complete monitoring records (Kuschel et al. 2012). The annual cost of anthropogenic (human-generated) air pollution in New Zealand was estimated at NZD\$4.28 billion (as at June 2010), as a result of 1,175 premature deaths, 607 hospitalisations for respiratory and cardiac illnesses and 1.49 million restricted activity days².

The cost ascribed to each premature death was taken to be the Value of a Statistical Life (**VoSL**) used by the Ministry of Transport (**MoT**) to value deaths attributed to road crashes. MoT publishes these values each year and they are used in the assessment of costs and benefits associated with road safety improvement projects. Most countries use the same (or even higher) VoSL for environmental effects as for road safety and therefore use of the road

² Restricted activity days are days on which people cannot do the things they otherwise have done if air pollution was not present.

safety VoSL figures in New Zealand is considered reasonable. Table 4 presents the published VoSL for New Zealand and their associated cost update factors (MoT 2016).

The HAPINZ figures were most recently updated during the Auckland Unitary Plan Hearings to incorporate the 2013 Census and the latest monitoring data (Nunns 2015). As part of this, an average cost of PM₁₀ pollution per tonne was developed which incorporated the OECD (2014) recommendation that PM₁₀ morbidity (illness) costs should be valued at 10 per cent of PM₁₀ mortality (death) costs to more accurately reflect the cost to society of air pollution. The Unitary Plan work derived a figure of NZD\$438,900³ per tonne of PM₁₀ (as at June 2014), which becomes NZD\$451,123 per tonne of PM₁₀ (as at June 2015).

This figure of **NZD\$451,123 per tonne of PM₁₀ (as at June 2015)** was used in the **GW model**. It compares favourably with Austroads when their 2010 figure is updated to June 2015⁴, and multiplied by 1.1 to reflect increased morbidity (NZD\$460,600).

Table 4: Value of statistical life (VoSL) published by Ministry of Transport (2016)

Value Base Date	VoSL (NZD)	Cost Update Factors
June 2006	\$3,050,000	1.331
June 2007	\$3,190,000	1.273
June 2008	\$3,350,000	1.212
June 2009	\$3,500,000	1.160
June 2010	\$3,560,000	1.140
June 2011	\$3,670,000	1.106
June 2012	\$3,770,000	1.077
June 2013	\$3,850,000	1.055
June 2014	\$3,950,000	1.028
June 2015	\$4,060,000	1

4.2 NO_x costs

Health impacts from NO₂ exposure in transport-impacted cities are now thought to be comparable to those from PM₁₀ exposure. A study in 2015 found more than twice as many people died prematurely each year in London than previously thought once the researchers had accounted for both NO₂ and PM effects (Kings College 2015). The most recent work undertaken to value impacts of NO₂ has been by the UK Department for Environment Food and Rural Affairs (**DEFRA**).

In 2013, DEFRA (2013) recommended relatively modest costs of NZD\$1,712⁵ per tonne of NO_x (as at June 2015). This figure compares favourably with the Austroads (2012) value of NZD\$2,630⁶ per tonne NO_x (as at June 2015). However, DEFRA's (2015) guidance

³ Based on the change in VoSL between 2006 (the HAPINZ update) and 2014 (the Unitary Plan update).

⁴ Based on a VoSL cost update factor of 1.140 and a currency conversion rate of 0.9056 for AUD to NZD using three year historical average currency conversion rates (NZ Forex 2016).

⁵ Based on a VoSL cost update factor of 1.140 and a currency conversion rate of 0.4955 for GBP to NZD using three year historical average currency conversion rates (NZ Forex 2016).

⁶ Based on a VoSL cost update factor of 1.140 and a currency conversion rate of 0.9056 for AUD to NZD using three year historical average currency conversion rates (NZ Forex 2016).

significantly increased the damage costs to between NZD\$16,986 and NZD\$67,047 per tonne NO_x (as at June 2015) to reflect the more recent findings.

Different countries value social costs differently. Based on the annual emissions and the estimated number of deaths, there are approximately 0.01 deaths per tonne of NO_x and 0.25 deaths per tonne of PM₁₀ in the UK (DEFRA 2015b). The NZ value for PM₁₀ mortality only is NZD\$410,112⁷ per tonne (as at June 2015). If the ratio of NO₂ to PM₁₀ deaths per tonne of emissions in New Zealand is assumed equivalent to that in the UK (i.e. ~0.01/0.25) then the equivalent cost per tonne of NO_x would be NZD\$16,031 (as at June 2015).

This figure of **NZD\$16,031 per tonne of NO_x (as at June 2015)** was used in the **GW model**. This value is just below the low end of the range quoted by DEFRA (2015) of NZD\$16,986 but seems reasonable as New Zealand has a much lower level of dieselisation in its fleet (17 per cent) versus the UK (36 per cent). Higher levels of dieselisation typically result in increased exposures and consequently damage costs at the upper end of the range.

4.3 CO costs

For CO emissions, no new literature was found to suggest damage costs should be revised. In addition, CO is emitted in relatively small amounts from diesel-fuelled vehicles such as buses so is much less of a concern than other pollutants.

Consequently, a figure of **NZD\$4.16⁸ per tonne of CO (as at June 2015)** was used in the **GW model**, based on Austroads (2012).

4.4 HC costs

As with CO, no new literature was found to suggest damage costs for HC emissions should be revised and HC is also emitted in relatively small amounts from diesel-fuelled vehicles such as buses.

Consequently, a figure of **NZD\$1318⁹ per tonne of HC (as at June 2015)** was used in the **GW model**, based on Austroads (2012).

4.5 CO₂ costs

Valuing CO₂ emissions appropriately is becoming increasingly important, given the longevity and impact of these emissions in the atmosphere.

The US Environment Protection Agency (**USEPA**) published a factsheet in 2015 specifically addressing the longer term societal costs (not just the cost of carbon credits) associated with CO₂ emissions. The costs range from NZD\$17.87 to NZD\$90.96 per tonne CO₂ (as at June 2015), depending on the discount rate selected. For a discount rate of 3 per cent (which is commonly used to value health impacts in New Zealand), the costs are NZD\$58.47¹⁰ per

⁷ This equals \$451,123 divided by 1.1 to exclude 10 per cent morbidity to get mortality cost only.

⁸ Based on a VoSL cost update factor of 1.140 and a currency conversion rate of 0.9056 for AUD to NZD using three year historical average currency conversion rates (NZ Forex 2016).

⁹ Based on a VoSL cost update factor of 1.140 and a currency conversion rate of 0.9056 for AUD to NZD using three year historical average currency conversion rates (NZ Forex 2016).

¹⁰ Based on a VoSL cost update factor of 1.273 and a currency conversion rate of 0.7836 for USD to NZD using three year historical average currency conversion rates (NZ Forex, 2016).

tonne of CO₂ (as at June 2015). This value is consistent (only 11 per cent lower) than the Austroads (2012) figure of NZD\$65.99¹¹ per tonne of CO₂ (as at June 2015).

This figure of **NZD\$65.99¹² per tonne of CO₂ (as at June 2015) was used in the GW model**, based on Austroads (2012), which seems reasonable given the valuations from the US and Australia, and the duration of the bus contracts being nine years into the future.

4.6 Summary of social costs

Table 5 summarises the social costs per tonne of the pollutants used in the GW bus emissions model.

Table 5: The social costs of emissions in NZD\$/tonne used in the GW model

Pollutant	Costs in NZD/tonne	Value Base Date	Basis
CO ₂	\$65.99	2015	Austroads (2012) - consistent with USEPA (2015)
PM ₁₀	\$451,123	2015	Nunns (2015) - consistent with Austroads (2012)
NO _x	\$16,031	2015	Pro-rated on Nunns (2015) - consistent with DEFRA (2015)
CO	\$4.16	2015	Austroads (2012) - no new references and a minor emission
HC	\$1,318	2015	Austroads (2012) - no new references and a minor emission

5. Key learnings and conclusions

The relative social cost of emissions generated by each engine type is illustrated in Figure 5. This graph compares the combined effect of the pollutants included in the emissions evaluation as modelled for a Large (LV) bus for bus routes with an average speed of 20km/hr. (Note that the Euro VI value is highlighted for reference purposes.)

Nine contract areas (or units) were tendered by GW, with EIPs generated for each unit. As some tenderers submitted multiple tenders, covering different combinations of units as well as individual units, large numbers of tenders were received by GW for some units. In total, GW received 86 tender submissions from nine different tenderers.

The results were consistent with expectations, with EIPs reflecting the relative differences in the various fleet configurations proposed by tenderers. In all circumstances, the tenders with high numbers of Euro III, IV and/or V vehicles scored the lowest EIPs. Conversely those tenders with high proportions of Euro VI, hybrid and/or electrics scored the highest EIPs.

¹¹ Based on a VoSL cost update factor of 1.140 and a currency conversion rate of 0.9056 for AUD to NZD using three year historical average currency conversion rates (NZ Forex 2016).

¹² Based on a VoSL cost update factor of 1.140 and a currency conversion rate of 0.9056 for AUD to NZD using three year historical average currency conversion rates (NZ Forex 2016).

Figure 5: Emission cost by engine type¹³

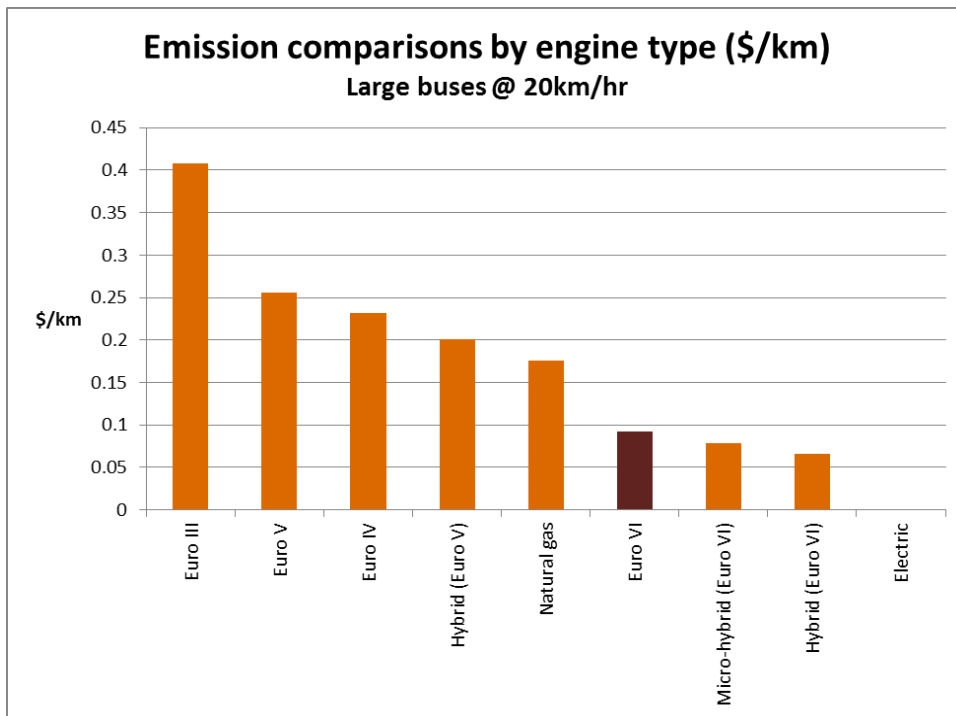
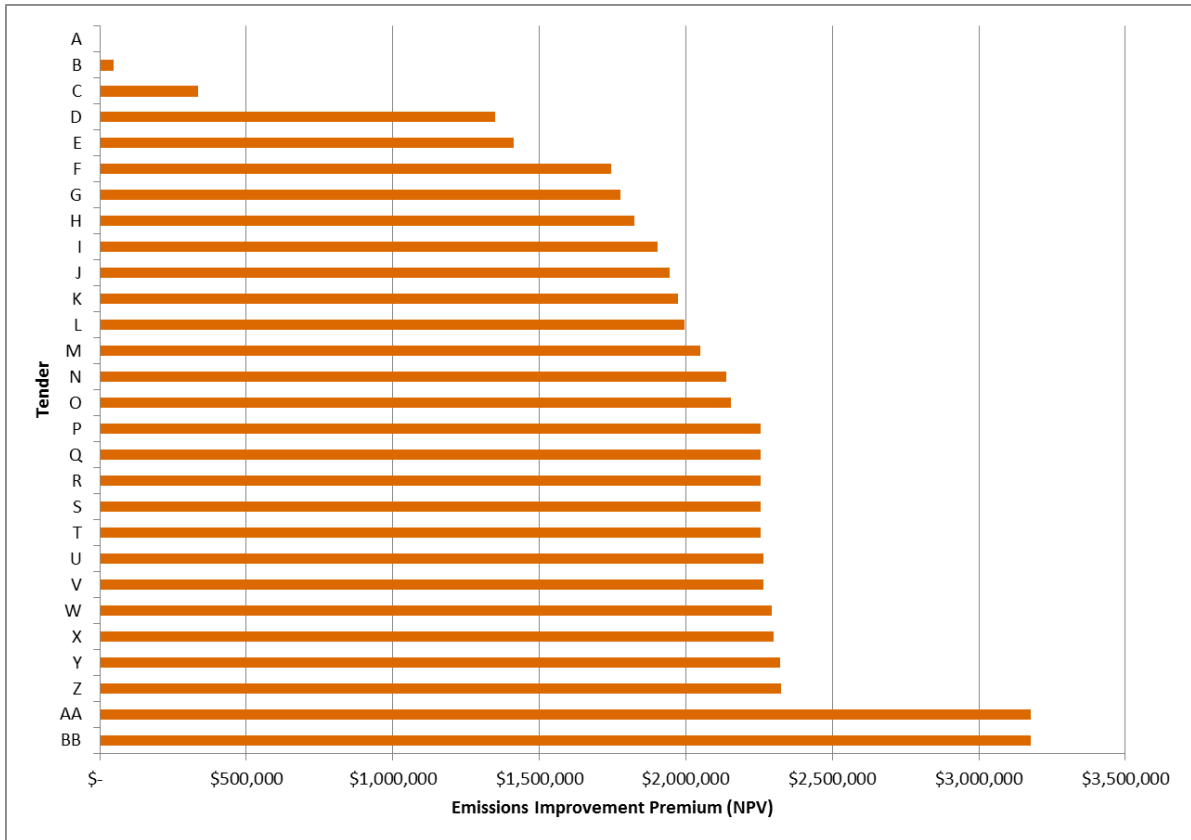


Figure 6 shows the EIP comparison for each tender received for one of GW’s contract units. In this example Tender “A” had the worst emitting fleet of all the fleets tendered for this particular unit, and therefore scored an EIP of 0. Tenders “AA” and “BB” had the best performing fleets for the unit and each scored the highest EIP of around \$3.2 million on a Net Present Value basis. This means that GW would be prepared to pay \$3.2 million more for Tenders AA and BB than for Tender A due to the social ‘benefit’ offered by the lower emitting fleets in Tender AA and BB.

The incentives and signals given for low emission fleets in the request for tender (RFT) achieved GW’s desired outcome. The two companies that won the tenders have committed to delivering a new, more environmentally friendly bus fleet that will improve air quality across the region and reduce emissions of harmful pollutants by at least 38 per cent in Wellington city and 84 per cent in the Hutt Valley. The majority of the buses to be introduced by the new operators will be new, Euro VI diesel vehicles. This fleet mix represents the most significant improvement gain in emissions for the region.

¹³ The minimum national emissions standard for urban buses from the commencement of PTOM is Euro III.

Figure 6: Emissions Improvement Premium (EIP) for Contract Unit 1¹⁴



When compared against the emissions from a bus fleet that complies with the minimum emission standards specified in the RFT¹⁵, the tender outcome delivers an 89 per cent reduction in harmful pollutants, as illustrated in Figure 7. Of particular note is the significant reduction in the most harmful diesel pollutants, NO_x and PM₁₀.

With all new diesel buses, primarily of Euro VI standard, the tender outcome will also deliver 3 per cent lower GHG emissions than a bus fleet that complies with the minimum emission standards specified in the RFT, as illustrated in Figure 8.

¹⁴ Note that the graph compares the Emissions Improvement Premiums for one contract unit only. The tender with the highest EIP is not necessarily the overall winning tender. The EIP is combined with the tender price and a monetised value for quality to determine the Evaluation Adjusted Price. As there were multiple contract units tendered in the Greater Wellington region, the preferred tender outcome was the combination of tenders that delivered the lowest combined Evaluation Adjusted Price to GW at a region wide level.

¹⁵ The minimum emission standard in the RFT was specified in accordance with the *Requirements for urban buses in New Zealand* (NZTA 2014), which requires a minimum of Euro III for existing buses and a minimum of Euro V for new buses that enter service under the new PTOM contracts.

Figure 7: Economic social cost of emissions of harmful pollutants

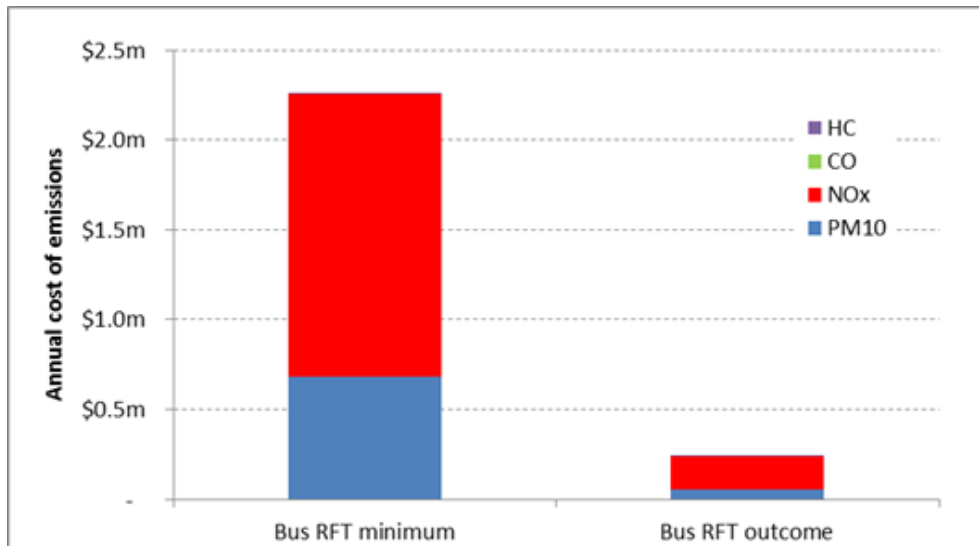
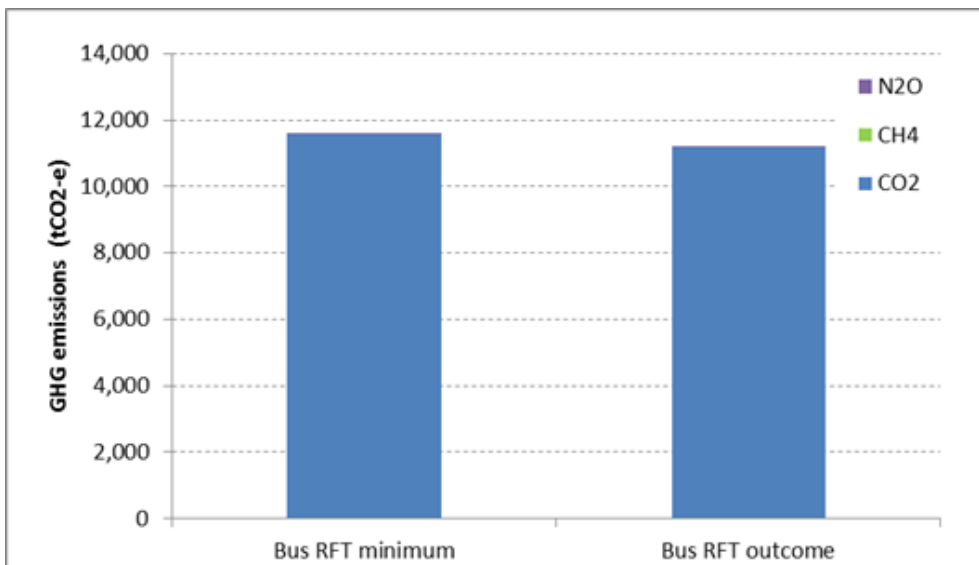


Figure 8: Economic social cost of emissions of greenhouse gases



GW pays an annual operating fee to the bus operators, from which the bus operators recover their capital and operating costs. Ultimately it is the operators, as owners of the buses, who make the decision on the capital versus operating cost trade-off between different vehicle technologies. While GW offered an emissions premium in the tender process, it was the bus operators' decision as to whether the premium offered by GW was sufficient to warrant investment in cleaner technology, after factoring in the capital versus operating cost trade-off as well as the technology obsolescence risk of the different technologies.

It is generally accepted that modern Euro VI buses have both higher capital and higher operating costs than equivalent Euro V buses. As the majority of the fleet in the winning tenders are Euro VI, it would appear that the emissions premium has had an effect on encouraging investment in cleaner burning, but more expensive technology.

In terms of electric buses, there is a very obvious trade-off between capital and operating costs and at present, due to the still relatively high capital costs of electric buses, a whole of life approach is required to enable investment in electric buses. This requires a different partnering approach to be taken between the operator and the contracting authority than is possible through a straight tendering process.

As a result of such an approach being taken by GW and one of the successful tenderers, a subsequent agreement to the tender process will see the introduction of 10 double-decker electric buses to Wellington in July 2018, followed by another 10 in 2020 and a further 12 in 2021. This will represent a further improvement in the region's transport emissions and a significant step towards GW's goal of an all-electric bus fleet.

This shows that being able to understand and value "elephants" means we can all tread more lightly into the future!

References

Austrroads 2012, *Guide to Project Evaluation Part 4: Project Evaluation Data*, Austrroads, Australia, August.

Clean Fleets 2014, *The New Bus for London, Diesel/Electric Hybrid*, case study for the Clean Fleets project consortium, UK, September.

Department for Environment Food and Rural Affairs (DEFRA) 2013, *Valuing impacts on air quality: Supplementary Green Book Guidance*, prepared by R Dickens, J Gill, A Rubin and M Butterick for Department for Environment Food and Rural Affairs, UK, May.

Department for Environment Food and Rural Affairs (DEFRA) 2015, *Valuing impacts on air quality: Updates in valuing changes in emissions of Oxides of Nitrogen (NO_x) and concentrations of Nitrogen Dioxide (NO₂)*, Department for Environment Food and Rural Affairs, UK, September.

Department for Environment Food and Rural Affairs (DEFRA) 2015b, *National Statistics Release: Emissions of Air Pollutants in the UK, 1970 to 2014*, Department for Environment Food and Rural Affairs, UK, December.

Emisia 2015, *Computer Model to Calculate Emissions from Road Transport (COPERT 4), Version 11.3*, Windows application prepared for European Environment Agency and Institute for Energy and Transport of the European Commission Joint Research Centre, June.

Energy and Fuels Research Unit (EFRU) 2005, *Bus Emissions Prediction Model*, model developed for the Auckland Regional Council, NZ, May.

Fisher et al. 2007, *Health and Air Pollution in New Zealand*, prepared by G Fisher, T Kjellstrom, S Kingham, S Hales, R Shrestha, A Sturman, M Sherman, C O'Fallon, J Cavanagh and M Durand for Health Research Council of New Zealand, Ministry for the Environment and Ministry of Transport, NZ, June.

International Council on Clean Transportation (ICCT) 2015, *Comparing real world off cycle NO_x emissions control in Euro IV, V and VI*, International Council on Clean Transportation, March.

Kings College 2015, *Understanding the Health Impacts of Air Pollution in London*, prepared for Transport for London, UK, July.

Kuschel *et al.* 2012, *Updated Health and Air Pollution in New Zealand Study*, prepared by G Kuschel, J Metcalfe, E Wilton, J Guria, S Hales, K Rolfe and A Woodward for Health Research Council of New Zealand, Ministry of Transport, Ministry for the Environment, NZ Transport Agency, March.

Low Carbon Vehicle Partnership (LowCVP) 2016, *Low Carbon Emission Bus (LCEB) scheme*, Low Carbon Vehicle Partnership, UK, <http://www.lowcvp.org.uk/initiatives/lceb/what-is-lceb.htm>, accessed 29 September.

Ministry of Business, Innovation and Employment (MBIE) 2017, *New Zealand Energy Sector Greenhouse Gas Emissions, 2015 Calendar Year Edition*, Ministry of Business, Innovation and Employment, Wellington, NZ, May.

Ministry of Transport (MoT) 2016, *The Social Costs of Road Crashes and Injuries 2015 Update*, Ministry of Transport, Wellington, NZ, March.

Ministry of Transport (MoT) 2017, *Transport Outlook Current State 2016*, Ministry of Transport, Wellington, NZ, July.

Nunns 2015, *Statement of Evidence on Behalf of Auckland Council before the Auckland Unitary Plan Independent Hearings Panel*, Peter Nunns, 2 March.

NZ Forex 2016, *3 year historical average currency conversion rates*, NZ Forex, <http://www.nzforex.co.nz/forex-tools/historical-rate-tools>, accessed 29 March 2016.

NZ Transport Agency (NZTA) 2014, *Requirements for urban buses in New Zealand: New Zealand's common standard for urban bus quality (2014)*, NZ Transport Agency, Wellington, NZ, December.

NZ Transport Agency (NZTA) 2016, *Ambient air quality (nitrogen dioxide) monitoring network. Annual report 2007-2015*, NZ Transport Agency, Wellington, NZ, October.

NZ Transport Agency (NZTA) 2017, *Vehicle Emissions Prediction Model, Version 5.3*, model prepared for NZ Transport Agency, Wellington, NZ, June.

Organisation for Economic Co-operation and Development (OECD) 2014, *The Cost of Air Pollution: Health Impacts of Road Transport*, Organisation for Economic Co-operation and Development, 21 May.

United States Environmental Protection Agency (USEPA) 2015, *Social Cost of Carbon*, EPA Fact Sheet, United States Environmental Protection Agency, December.