WORKING PAPER

The Congestion Question

Could road pricing improve Auckland's traffic?

Workstream 3

Environmental outcomes

January 2020

Working draft vD

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1 Executive summary

Implementing congestion pricing in Auckland could have environmental benefits for Auckland. The key benefit from implementing congestion pricing is an improvement in network performance from a reduction in vehicle kilometres travelled (VKT) and a reduction in time spent idling. This has flow on environmental benefits for greenhouse gas emissions, air quality and water quality.

Road transport emissions contribute 37.6% of total greenhouse gas emissions in Auckland, directly linked to total VKT, and vehicle types. Congestion pricing could reduce total emissions, through fewer kilometres being travelled. Reducing time spent idling will also have a positive impact on air quality.

Greenhouse gas emissions in Auckland from road transport have increased slightly over recent years. Emissions of black carbon has health impacts but is also an important climate change contributor. It is relatively short-lived in the atmosphere so quick action could have a quick impact. The central city has relatively high concentrations of black carbon when compared to international cities.

Road transport is a significant contributor to concentrations of air pollutants like $PM_{2.5}$, PM_{10}, NOx and VOC. Road transport accounts for 32% of total PM_{10} emissions, and 67% of regional NO_x emissions. These pollutants have significant health impacts, vary greatly across the region, and are elevated in the central city area. Looking ahead to 2040, concentrations are forecast to decline, helped in part by a move to cleaner propulsion methods. Implementing congestion pricing could help speed up these declines, and maintaining them will require a reduction in VKT and improvement in vehicle emissions.

Contaminated run off from roads contributes to reduced water quality in Auckland streams, rivers and estuaries. Heavy metals, like copper, found in brake pads, collect on roads and make their way into streams, where they can have toxic impacts on aquatic species. A reduction in VKT and less start-stop traffic, would support reduction in these contaminants.

The relative environmental benefits are summarised using a high/medium/low scale in Table 1.

TABLE 1: BENEFIT ASSESSMENT SUMMARY

	Transport Pressure	Potential benefit
Greenhouse gas emissions	CO_2	Medium
Air Quality	NOx	Medium
	$PM_{2.5}$ and PM_{10}	Medium
	Black Carbon	Medium
	VOC	Low
Water Quality	Heavy Metals (Cu, Zn)	Low

The environmental benefits of congestion pricing align with a range of national and local level policies and strategic directions, regarding climate change, water quality and air quality.

There are similarities between congestion pricing and low emission zones, but their end goals, and therefore configurations are very different. Congestion pricing restricts all movements, regardless of their emissions, where low emission zones charge specific polluters. For clarity a low emission zone and a congestion pricing zone could theoretically use the same zone but this would only work easily for cordon-based schemes. In Auckland, the central city area is the logical place for a low emission zone, as it has the worst air quality and has also been identified by Auckland Council programmes.

It is difficult to fully quantify the environmental benefits of a scheme without a study commissioned specifically for such a purpose. If this was desired it is possible that modelling using a Vehicle Emissions Prediction Model (VEPM) (or similar) could be commissioned to more fully understand the potential outcomes under a range of scenarios.

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2 Purpose

The purpose of this paper is to provide a high-level summary of the potential environmental outcomes from introducing congestion pricing to Auckland. The Congestion Question (TCQ) terms of reference require an assessment of environmental benefits alongside the other assessments to help inform a decision about whether or not to implement congestion charging. The paper also considers the further work that would be required to quantify the actual environmental impacts of implementing congestion pricing.

3 Context

Quantification of city and regional scale environmental trends is typically difficult, and largely considered impractical. This is due to the cost of collecting and maintaining data, and the need for long datasets to accurately assess trends. Similarly, regional scale air quality / emission models are difficult to scope and are often too inaccurate for decision making purposes. It is also difficult to decouple the trend from the noise, and demonstrate correlation with the intervention made. Therefore, detailed assessments of environmental outcomes are challenging, but a conceptual exploration of the range of outcomes is a useful exercise.

This paper explores the range of outcomes conceptually, to identify the environmental indicators which could change if congestion pricing was implemented. The Appendix to the paper also provides further detail on these indicators.

In order to more fully assess the environmental benefits of implementing congestion charging, some additional modelling could be commissioned. The parameters and configuration of potential modelling is also identified by this paper.

Environmental outcomes are not a key deliverable of congestion pricing, but they are a consideration when assessing wider impacts.

4 Introduction

The primary objective of congestion pricing is to improve the performance of Auckland's transport network. Accordingly, the major environmental outcomes from congestion pricing come through reductions in Vehicle Kilometres Travelled (VKT) and reducing time spent idling on the network. Changes to these can bring environmental benefits. Reducing VKT, or influencing when travel occurs, could potentially have a range of environmental benefits, including (but not limited to):

- Reduction in fuel consumption (fewer trips made, less time spent idling)
- CO_2 emissions (fewer trips made, less time spent idling)
- NOx emissions (fewer trips made, potentially fewer HGV trips at peak)
- $PM_{2.5}$ and PM_{10} emissions (fewer trips made, less time spent idling)
- Change distribution of emissions (shift a proportion of peak emissions to off-peak)
- Improvement in quality of road run-off (fewer trips made)

5 Potential environmental outcomes

It is anticipated that implementing a congestion charging scheme could deliver region-wide reductions in congestion. It is likely that improvement will be unevenly spread around the region. This makes quantification of region-wide environmental benefits difficult in the absence of region-wide environmental modelling and comprehensive monitoring. Therefore the assessment of environmental benefits outlined here is conceptual and qualitative rather than quantitative.

5.1 Vehicle emissions in Auckland – Context

Vehicles burning petrol and diesel emit a range of exhaust emissions. Diesel vehicles tend to emit less carbon monoxide (CO) and carbon dioxide (CO_2), but are worse for particulate matter and NOx emissions and can also emit sulphur dioxide[1], particularly where lower quality fuels are used. New research is also suggesting that very small particulate matter (often referred to as black carbon) is also an important contributor to total particulate matter (Davy and Trompetter, 2018).

Motor vehicles are the most significant source of air pollution in the Auckland region. Emissions from motor vehicles represent 32% of total PM_{10} emissions, and 67% of regional NO_x emissions. Inside the Auckland Urban Airshed (Appendix 1 Auckland urban airshed) vehicles account for 71% of total PM_{10} and NOx (Sridhar and Metcalfe, 2019).

Around 120 premature deaths in Auckland per year are attributable to air pollution from vehicles, with an estimated cost of $466 million per year (Kuschel et al., 2012a). Land transport emissions are also the largest contributor to Auckland's greenhouse gas emissions (Auckland Council, 2014; Xie, 2017). Data between 2003 and 2011 (Kuschel et al., 2012b) found that emissions from petrol vehicles declined significantly, largely attributed to improved fuel specifications and better emission control technology (Kuschel et al., 2012b; Reid, 2014; Davy et al., 2017).

Emissions from diesel vehicles measured by Kuschel et al. (2012b), replicated the result reported by Davy et al (2014) in that these emissions had not declined as much as predicted, possibly due to the lower 'real world' performance of Euro emission standards (Ligterink et al., 2013; Kadjik et al., 2015; Miller & Franco, 2016). Despite these gains, since 2009 the rate of emissions reduction has plateaued. This plateau has generally been attributed to higher polluting vehicles remaining in the fleet, and not being replaced by newer, cleaner (and more fuel efficient vehicles) (Kuschel et al, 2012b; Ministry of Transport, 2016).

Despite these reductions, vehicle emissions in Auckland fell short of the 2016 reduction targets in the Auckland Plan by approximately 30 per cent (Auckland Council, 2015)[2]. It was predicted that PM_{10} emissions from vehicles in 2016 would total 504 tonnes, and drop to 355 tonnes by 2031, before

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[1] SO_2 and CO concentrations from road transport in Auckland are relatively low.

[2] Note that the Auckland Plan 2050 (adopted 2018) does not have an emissions reduction target. Auckland emission reduction will largely be driven through the Auckland Climate Action Framework (which was publicly consulted on between July and September 2019). It will be considered by Auckland Council for adoption around March 2020.

increasing again in 2041 due to an increase in vehicle numbers and kilometres travelled. NOx emissions are predicted to follow a similar trend, declining through to 2031, before increasing to 2041.

5.2 Reduction in VKT

The key environmental benefit of congestion charging is reducing the volume of emissions of both greenhouse gases and air quality contaminants through burning less fuel, by reducing total VKT.

Modelling results indicated in 2016, 35.2 million kilometres were travelled on average per day (Table 2). NZTA data indicates that around 12-13 billion kilometres were travelled on Auckland roads in 2016[3]. On average between 2010 and 2014, 139 million person kilometres were travelled yearly in Auckland (MoT, 2015).

TABLE 2: AUCKLAND TOTAL DAILY VKT AND VKT FOR HEAVY AND LIGHT VEHICLES (2001-2040). SOURCE: SRIDHAR AND METCALFE 2019)

Year	Total VKT (million km/day)	Light (<7.6t) (million km/day)	Heavy (>7.6t) (million km/day)
2001	27.5	26	1.5
2006	31.6	29.9	1.7
2011	31.8	29.8	2.0
2016	35.2	33.1	2.1
2026	42.3	39.5	2.7
2036	46.4	43.2	3.2
2040*	47.8	44.5	3.3

* VKT interpolated between 2036 and 2046 from ART 3.2.

TABLE 3: AUCKLAND TOTAL VKT 2008/09 - 2017/2018. SOURCE: NZTA

Financial year	Total vehicle Kilometres travelled (billion/km)
2008/09	12.09
2009/10	12.21
2010/11	12.35
2011/12	12.64
2012/13	12.72
2013/14	12.69
2014/15	12.65
2015/16	12.63
2016/17	13.32
2017/18	13.17

[3] http://www.nzta.govt.nz/assets/userfiles/transport-data/VKT.xlsx

As part of the assessment of the potential impact of congestion pricing, TCQ has modelled the impact on VKT and emissions (Table 4) through the Auckland Macro Strategic Model (MSM). This modelling found that a strategic corridors scheme could reduce peak (am) VKT by around 6%, and total daily VKT by around 2%.

The modelling is also useful for setting expectations for the scale of the impact on emissions that could be expected. The improvements seen are modest, as they are driven by the small improvements in VKT and average speeds. For all emissions, expected improvements are in the order of 2-3%. This assessment could be further refined through additional modelling, and is discussed in section 10.

TABLE 4. MODELLED DIFFERENCE IN VKT AND EMISSIONS, 2016 BASELINE AND WITH CONGESTION PRICING. SOURCE: AUCKLAND FORECASTING CENTRE.

		Baseline (2016)	With Congestion Pricing (Strategic Corridors option)	% Difference
VKT	AM period VKT	6,068,278	5,708,780	-5.9%
	Daily VKT	37,088,756	36,356,336	-2.0%
	AM period average speed (km/h)	35.91	38.06	6.0%
CO_2 (tonnes)	Total	9,287,757	9,083,507	-2.2%
	Car	7,116,099	6,929,566	-2.6%
	HCV	2,066,400	2,049,174	-0.8%
VOC (tonnes)	Total	4,166	4,022	-3.5%
	Car	3,877	3,738	-3.6%
	HCV	257	252	-1.7%
PM (exhaust) (tonnes)	Total	623	609	-2.2%
	Car	354	343	-3.0%
	HCV	241	238	-1.3%
PM (brake and tyre) (tonnes)	Total	413	405	-1.8%
	Car	366	359	-2.0%
	HCV	45	45	-0.2%

5.3 Reduction in time spent idling

Peak congestion has increased significantly since 2014, with 33% more of the arterial network congested (Figure 1). From an environmental perspective, idling time is important as it impacts the rate of emissions. Congestion has spread to the interpeak, and across the region, with some parts of the network in key strategic areas consistently congested across most of the day. Between 2013 and 2017, average speeds on the network fell by around 7km/h.

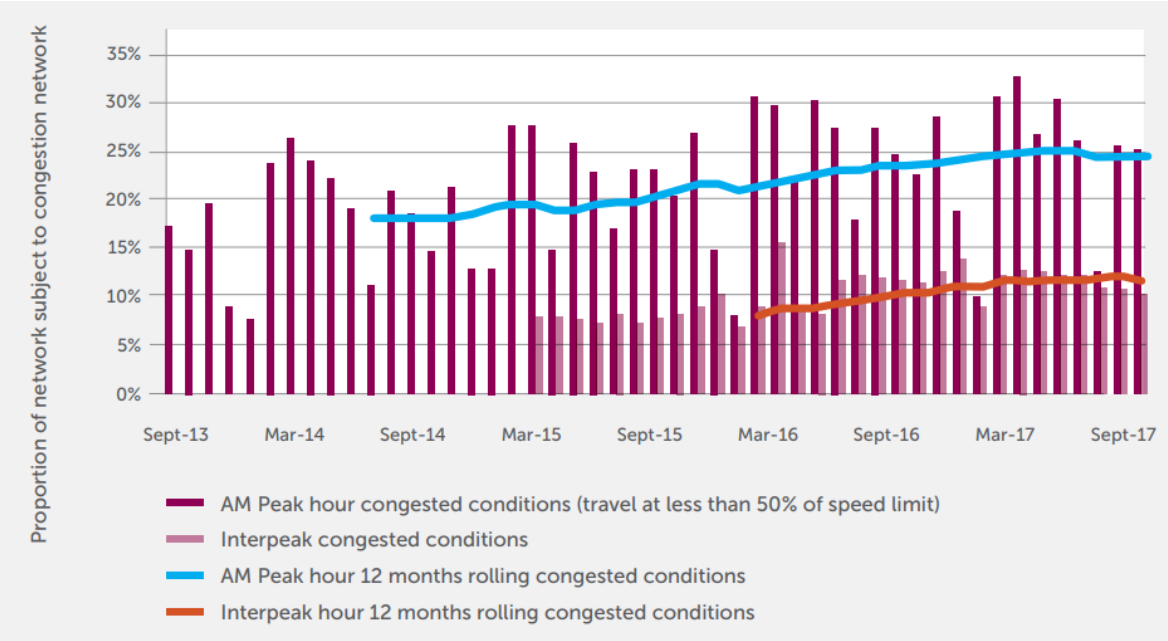


FIGURE 1. PROPORTION OF ARTERIAL NETWORK SUBJECT TO CONGESTED CONDITIONS DURING THE AM PEAK HOUR AND INTERPEAK. SOURCE: THE CONGESTION QUESTION PHASE 1 REPORT.

Free-flowing traffic emits less pollution per kilometre travelled than congested or stop start traffic. In free flowing traffic, vehicles are moving at a more or less constant speed, and engines are operating at a 'cruise' speed. This has two effects: less frequent acceleration generates lower emissions than stop-go acceleration for brief periods, and the turbulence created by vehicles helps to disperse pollutants (particularly in poorly ventilated locations, like tunnels and street canyons). (Ma et al. 2011; Zhang and Batterman, 2013; Thaker and Gokhale, 2016).

To account for the variation in speeds across the network, transport emissions models often use average speeds to account for variation. The Vehicle Emissions Prediction Model (VEPM)[4], commonly used for emissions inventories and impact assessments describes this:

> *VEPM is an average speed model which predicts emission factors for the New Zealand fleet under typical road, traffic and operating conditions. Average speed models are based on the fact that the average emissions factor for a pollutant and vehicle type/technology varies as a function of the average speed during a trip. A low average speed is typical of driving in congested traffic and a high average speed is typical of free flowing traffic* (Metcalfe et al. 2013)

VEPM uses emissions factors to assess overall emissions. They provide an estimate of emissions per km travelled. Figure 2 shows the fleet-weighted emissions factors for trips of various average speeds, based on the 2019 fleet (including fuels) default settings in the model. From these emissions factors, trips which

[4] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/air-quality-climate/planning-and-assessment/vehicle-emissions-prediction-model/

average slower speeds will tend to emit more, particularly in to 10-30km/h range. Similarly, if the proportion of time spent travelling at a slower average speed increases, then that trip emits more. Thus if speeds were to improve in the slowest (10-30km/h) sections of trips, then total emissions for that trip would decrease. For NOx, NO_2 and VOC, speeds faster than 40-60 km/h tend to emit slightly more. Similarly, $PM_{2.5}$ exhaust increases above 70 km/h. Note that VEPM distinguishes between exhaust emissions for $PM_{2.5}$ and particulate matter from brake and tyre wear (PM).

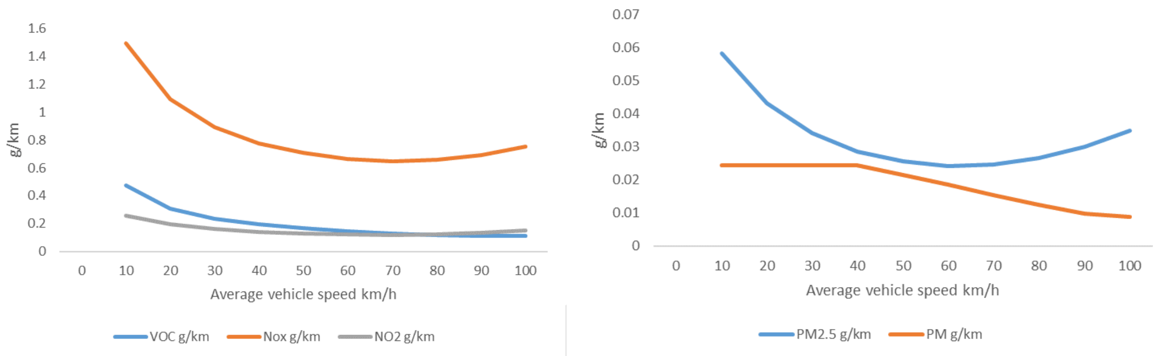


FIGURE 2 SELECTED FLEET-WEIGHTED EMISSIONS FACTORS FOR AVERAGE SPEEDS FROM VEPM (2019 INPUT YEAR)[5]

If congestion pricing was implemented, a reduction in time spent idling across the network could mean that some journeys (particularly those in the 30-60 km/hr average speed) whose average speed increased would emit less. The effect of this, given the number of trips being made could be significant for those roads.

5.4 Potential impact on CO2 emissions

Road transport accounts for 37.6% of CO_2 emissions in Auckland. Greenhouse gas emissions from transport in Auckland have been relatively stable between 2009 and 2014 before increasing in both 2015 and 2016. These increases are probably due to increases in VKT over the period, and possibly due to lower than anticipated performance of emissions from heavy vehicles. On a per capita basis, total emissions appear to have declined, due to population growth offsetting emissions. In other words, population has grown faster than growth in emissions.

Congestion pricing could reduce CO_2 emissions from road transport by:

- Reducing total VKT
- Reducing fuel consumption
- Encouraging shift to public transport and active modes which emit less CO_2 per person per journey.

[5] Default values used for fleet composition. For VEPM HCV class, 86km is maximum speed. This was used for the 100 and 90 km/h average speed classes. Note that PM in the graph is from non-exhaust sources (e.g. brake and tyre wear).

5.5 Potential impact on NOx emissions

NOx is the collective term used to describe emissions of nitrogen monoxide (NO) and nitrogen dioxide (NO_2). Ambient concentrations of NOx in urban areas are the result of combustion at high temperatures in vehicle engines, particularly diesel engines. NOx has a range of health impacts. High concentrations of NO_2 can irritate airways in the human respiratory system.

Concentrations of NOx vary greatly across the region but are generally elevated where traffic is highest, (Xie et al. 2007) particularly on roads and motorways with higher proportions of heavy vehicles like buses and trucks. In the central city, where buildings create 'canyons' these concentrations are particularly high, and some locations have the highest concentrations seen in New Zealand (Talbot and Lehl, 2018). In less built up locations, concentrations decline quickly moving away from the source. Concentrations close to motorways are generally low, driven by meteorology conditions and generally smooth travel patterns promoting dispersion (Longley et al. 2015).

Congestion pricing could reduce NOx emissions from road transport by:

- Reducing total VKT
- Reducing fuel consumption
- Reducing numbers of vehicles in built up are areas
- Reducing time spent idling on the network.

5.6 Potential impact on particulate matter emissions (PM2.5 and PM10)

Particulate matter can be easily inhaled and the largest particles in this size fraction are deposited in the upper airways, while the smaller ones can deposit deep in the lungs. Health effects include decreased lung function. or heart attack, and mortality. Children, the elderly, and people with existing heart or lung problems have a higher risk of health effects from particulate matter exposure (WHO, 2013A, 2013B).

Particulate emissions in Auckland come from a range of sources, but road transport is the major year-round contributor. Auckland Council's emission inventory (Xie et al. 2014) found that emissions from transport make up 43% of $PM_{2.5}$ and 29% of PM_{10} and are present consistently during the whole year.

Auckland Council's source apportionment monitoring programme further classifies sources, using monitoring data from approximately five representative sites across the region. 43% of $PM_{2.5,}$ and 29% of PM_{10} is emitted by motor vehicles (all fuels). Vehicles, through emission of NO_x and SO_2 also contribute to total PM concentrations as through photochemistry and secondary sulphate.

Congestion pricing could reduce $PM_{2.5}$ and PM_{10} emissions from road transport by:

- Reducing total VKT
- Reducing fuel consumption
- Reducing numbers of vehicles in built up are areas
- Reducing time spent idling
- Further contributing to the declining trends reported
- Helping maintain the Auckland Airshed's non-polluted status.

5.7 Potential impact on black carbon (BC)

BC is a major component of soot and in the transport sector is emitted from incomplete combustion, particularly from light and heavy diesel vehicles. BC is an important contributor to both ambient air quality and climate change. BC has a short lifespan in the atmosphere, so reductions in BC could help deliver quick gains for climate change. Both the Climate and Clean Air Coalition and Intergovernmental Panel on Climate Change (IPCC) have indicated BC as one of their respective priorities (Davy and Trompetter, 2018).

While most aerosols in the atmosphere scatter incoming solar radiation, resulting in a net cooling effect on the atmosphere, BC absorbs significantly more light than it reflects, resulting in a net warming effect. BC has been estimated to be the 2nd highest contributor to warming (next to CO_2) (Bond et al. 2013). BC also has implications for human health. Over shorter timeframes, BC is likely to be a significant indicator of health impacts, especially from transport sources (WHO, 2012). In Auckland, diesel vehicles are the main contributor to ambient BC (Davy and Trompetter, 2018).

Congestion pricing could reduce BC emissions from road transport by:

- Reducing total VKT
- Reducing fuel consumption
- Reducing numbers of vehicles in built up are areas
- Reducing time spent idling.

5.8 Potential impact on volatile organic compounds (VOCs)

Volatile organic compounds (VOCs) are organic chemical compounds that vaporise under normal ambient conditions to enter the atmosphere as gases. 52% of VOCs in ambient air in Auckland are from transport emissions, particularly from petrol vehicles (Stevenson and Narsey, 1998). Results reported in 2009 and 2014 (Smith et al., 2009; Reid, 2014), confirmed significantly elevated levels of benzene at the two Khyber Pass sites.

Many VOCs are hazardous to human health (especially benzene and 1,3 butadiene). Health effects are broad, ranging from dizziness and unconsciousness from short-term exposure to cancer from long-term exposure (group one carcinogen).

Congestion pricing could reduce VOC emissions from road transport by:

- Reducing total VKT
- Reducing fuel consumption
- Reducing time spent idling.

5.9 Potential impact on emission distribution

Pollutants in Auckland tend to follow distinct patterns. Emissions from transport greatly influence this pattern. Generally, transport related emissions rise to an early morning spike, associated with the morning travel period. During the middle of the day, concentrations decline, before rising to an early evening peak, which, in winter is exacerbated by home heating emissions. Emissions are highest during the week, with low concentrations during the weekend. If congestion pricing was implemented, and people made decisions to shift their travel patterns and times, this pattern could change, in that the observed trough between peaks may shift, so that the trough between peaks is less pronounced (i.e. the peak reduce and the trough increases).

5.10 Road related water quality in Auckland - Context

Auckland's road network makes up a significant proportion of total land use in the region. Run off from sealed roads is generally quick because efficient removal of stormwater is essential for safety. A range of contaminants are present in road run off, including fuels, additives, oil and brake and tyre residues. These contain a range of toxic pollutants including heavy metals (Gardiner et al. 2016). Run off from roads makes a significant contribution to reduced water quality in Auckland.

Freshwater quality across Auckland ranges from excellent in catchments with predominantly native vegetation cover, good or fair in those with exotic forest and rural land use, and is generally poor in urban catchments (Auckland Council, 2015; Hamil & Lockie; 2015; Holland et al., 2016). Results for 2015 classified only 4 of the 36 sites as having 'excellent' water quality. Nine sites were classified as 'good' and the remainder were 'fair' and 'poor' (Holland et al., 2016). In 2017, only 1 site (West Hoe Stream – west of Orewa) was classified as having excellent water quality, and more streams had shifted into the "poor" classification (Buckthought, 2017).

The quality of run off from roads is mainly influenced by the volume of traffic travelling on them, as vehicles generate contaminants which settle on the road. More traffic means more of these contaminants are deposited. Heavy metals (copper and zinc) are the major contaminants which are linked to the traffic volume on a road. Other factors in the quality of run off from roads are independent of traffic volume and more a product of impervious surfaces and modified hydrology.

5.11 Potential Impacts on heavy metals

Heavy metals in Auckland streams frequently exceed protection guidelines (e.g. Australian and New Zealand Guidelines for Freshwater and Marine Water Quality (ANZECC)) (Gadd et al. 2019). At these concentrations there are impacts on in-stream ecology (including macro-invertebrates and fish). Gadd et al. (2019) found that between 2005 and 2014 the ANZECC 80% protection level for soluble copper in urban streams was exceeded by 10% of samples, and the 90% level by 30% of the samples. These contaminants eventually end up in harbours where they accumulate and can continue to have ecological impacts.

In the absence of strict source control (e.g. mandatory ceramic brake pads) a reduction in VKT could have an impact on heavy metal concentrations.

Congestion pricing could reduce heavy metals in waterways from road transport by:

- Reducing total VKT

6 Summary of potential outcomes

Environmental benefits from implementing a congestion charging scheme are mostly linked to reduction in VKT, and changes in flow. If less vehicles are traveling, and they are able to do so more efficiently (i.e. less stop-start movement), then a reduction in emissions is possible. Table 5 provides a pressure-state-impact summary of potential impacts from congestion charging.

It is likely that reduction in emissions will be seen in successive emissions inventories, as these are accounting exercises using known emission factors and VKT data. There are some assumptions and inherent difficulties, but it is more likely to be seen here than in ambient concentration data, since this is impacted on by factors like meteorology and street canyons.

Quantifying improvement through data is difficult. Monitoring data is subject to a range of influences, including site location, meteorology, building footprint and sizes. The environmental benefits would not be evenly spread across the region, and some locations would experience more improvement than others. These sorts of benefits would be picked up by highly targeted monitoring programmes (which are not proposed to progress with) rather than region-wide modelling. In London, (see later section) there were some highly localised improvements (e.g. at a particular monitoring site, or particular street) but these benefits did not accumulate to a region wide improvement.

As well as environmental benefits, there may be some amenity benefits which are related, although these may be limited to urban centres with larger public realm spaces like squares, wider footpaths or similar. Example amenity benefits could be:

- Lower traffic volumes allowing easier transition to shared spaces
- Less noisy spaces, which encourage people to linger
- Road corridor capacity freed up for other uses.

Reducing VKT and associated environmental impacts align well with central and local government policy directions, across environmental and transport policy. Table 6: provides a summary of related policy and strategy.

Table 5. Summary of current state and potential benefits

Domain	Transport pressure[6]	State	Impact	Potential impacts of congestion pricing
Fleet and speed descriptors	Vehicle Kilometres Travelled (VKT)	• Currently increasing (since 2015). • Increase in VKT from both light and heavy fleets • Increase in vehicle numbers	• Loss in productivity due to time spent in congestion	• Reduction in VKT, especially during peak charged period • Potential retirement of vehicles in the fleet • May slow growth in the fleet
	Vehicle speed / traffic flow	• Approximately 25% of network congested • Average speeds declined 7km 2014-2017	• Slow travel times across the region, across the day rather than just at the peak	• Reduction of proportion of network congested • Increase in average speed, through less time stopped • Some peak load shifted to interpeak
Greenhouse gas emissions	**CO_2** *Greenhouse gas emissions inventory*	**1990** 6175 CO_2e **2015** 4361 CO_2e **2016** 4552 CO_2e • Road transport emissions make up 37.6 % of total emissions (2016) • On-road transport accounts for 86% of emissions attributed to transport • Increase in emissions from the transport sector 2014, 2015 and 2016	• Climate change impacts for Auckland include increased frequency of storms, flooding and extreme weather, flooding, drought and temperature change (Pearce et al. 2018)	• Reduction in emissions due to reduction in VKT • Shift to lower carbon-emitting modes, including active modes • Reduction in climate change impacts • Contribution to emission reduction targets (ACAF, C40)
Air quality	**NOx** *Ambient monitoring data* *Emissions inventory* *VEPM*	• Forecast to decrease by roughly 50% to 2040 • Elevated in many areas of Auckland but especially high in the central city • Exceedances recorded in the central city area • Higher concentrations closer to arterial roads and motorways • Higher where buildings influence dispersion	• Around 120 premature deaths in Auckland per year are attributable to air pollution from vehicles, with an estimated cost of $466 million per year (Kuschel et al., 2012a). • Key cause of 'brown haze' events and ozone formation in summer	• A study found that a crude congestion charge might reduce NO_2 by 15% in the city centre (Talbot and Lehl, 2018). • Reduction in emissions due to reduction in VKT • Reduction in emissions due to increase in vehicle speeds
	$PM_{2.5}$ and PM_{10} *Ambient monitoring data* *Emissions inventory* *VEPM*	• Contribution for transport forecast to decrease by roughly 50% to 2040 • From both exhaust emissions and brake and tyre wear • Elevated in the central city • No exceedances of PM_{10} NES since 2013 • $PM_{2.5}$ annual average concentrations are close to relevant standards and guidelines	• Around 120 premature deaths in Auckland per year are attributable to air pollution from vehicles, with an estimated cost of $466 million per year (Kuschel et al., 2012a). • Influences Auckland Airsheds compliance with the NES-AQ • Health impacts for sensitive groups • Impacts on ability to issue consents for industrial emissions	• A study found that a crude congestion charge could reduce PM2.5 by 4% in the city centre • Reduction in emissions due to reduction in VKT • Reduction in emissions due to less stop-start travel (from brake and tyre wear) • Greater benefit for $PM_{2.5}$ as higher contribution to $PM_{2.5}$ from transport
	Black Carbon *Ambient monitoring data*	• Important contributor to both ambient air quality and climate change • Elevated in the city centre, to similar/higher concentrations to other large cities (no current guideline values) • Mostly from heavy diesel vehicles	• A key contributor to climate change, and reductions could make measurable change quickly • Heath impacts for sensitive groups, particularly in the central city area.	• Reduction in emissions due to reduction in VKT • Reduction in climate change impacts • Potential health benefits, particularly in the central city • Reduction in $PM_{2.5}$ as BC is subset of $PM_{2.5}$
	VOC *Ambient monitoring data* *Emissions inventory* *VEPM*	• Indicator of petrol vehicle emissions • Declined from peak in early 2000s. • Benzene concentrations have stabilised at or slightly below relevant standards and guidelines	• Health impacts, particularly close to roads at kerbsides • Concentrations close to the MfE guidelines and Unitary Plan standard	• Reduction in emissions due to reduction in VKT • Potential health benefits, particularly in the central city, and busy roads
Water quality	**Heavy Metals (Cu, Zn)** *Water Quality Monitoring*	• Elevated concentrations in urban streams, rivers and estuaries • Concentrations approaching levels which have ecological impact • Key sources are brake pads and tyre wear	• Monitored sites approaching ecological thresholds and guideline values • Toxic impacts on ecology	• Reduction in VKT may generate lower loadings • Changes in flow may generate lower loadings

[6] *Italics* indicate data source

TABLE 6: SUMMARY OF RELATED CENTRAL AND LOCAL GOVERNMENT POLICY AND STRATEGY

	Policy / strategy	Relationship
Central Government	**Government Policy statement on Land Transport 2018** Government's vision for the land transport system, which prioritises how government will invest the National Land Transport Fund. The environmental strategic priority aims to: • reduce greenhouse gas emissions • reduce adverse effects on the environment and public health	• Prioritises reducing greenhouse gas emissions from transport and supports a mode shift to lower emission forms of transport. • Links to the wider environmental commitments of the Government, such as achieving the Paris Agreement target of reducing greenhouse gas emissions to 30 percent below 2005 levels by 2030, and setting a more ambitious reductions target for 2050. • Recognises the public health benefits of reducing harmful transport emissions. • Recognises the importance of urban form for creating liveable cities that value public space and improve access.
	National Environmental Standard for Air Quality • Set minimum standards for air quality • Requires councils to manage air quality and restricts consenting abilities in polluted Airsheds • Requires regional councils to monitor and report air quality	Sets standards for some transport pollutants ($PM_{2.5}$, PM_{10}, NO_2, CO) and guideline values for other pollutants. The standards help councils assess how polluted their Airsheds are and whether interventions are required. Guides councils for setting standards in their regional plans, and targeting interventions towards sources (e.g. transport / home heating).
	Transition to a low-emissions and climate – resilient Aotearoa Central Government's climate change work programme, which includes: • The Zero Carbon Bill • Independent climate change commission • Climate change adaptation • Clean Car Standard and Clean Car Discount	Transport emissions are the fastest growing source of emissions in New Zealand, accounting for nearly 20% of all CO2 greenhouse gases produced. This could include improving the fuel efficiency, and thereby reducing the emissions, of light vehicles as they account for nearly 70% of all transport emissions.
	National Policy Statement for Freshwater Management Provides direction for how councils should manage freshwater under the Resource Management Act. Requires councils to set objectives for the state of fresh water bodies in their regions and to set limits on resource use to meet these objectives. Provides a set of standards for assessing current state setting goals to progress towards (National Objectives Framework).	Councils are implementing the NPS-FM through implementation plans, either by 2025 or 2030 depending on the situation. Most will be making changes to their regional plans to support the objectives of the NPS-FM. These will seek to improve water quality outcomes regionally, and will control transport related pollutants from roads including sediment and heavy metals. Regulation of brake pad material would require legislative change.
	Essential Freshwater Package A collaborative work programme designed to halt further decline in water quality, reverse past damage and fairly allocate freshwater resources. Developed in collaboration with mana whenua, regional councils and other government agencies.	Actions range from changes to the NPS-FM, new rules for wastewater and drinking water, to specific, on the ground intervention in priority catchments. All of this is designed to improve water quality nationally, which run off from roads contributes to.
Local Government	***Auckland Plan 2050:* The Environment and Cultural Heritage Outcome** sets out the need to balance growth and environmental outcomes rather than 'trading off' the environment to support growth. **The Access and Connectivity Outcome** describes the way Auckland's transport system should evolve to support equitable access and sustainable transport options. The outcome also suggests that the transport system should better respond to its environmental and safety issues. **The Development Strategy** sets out how and where the region will provide for growth required and how this is phased.	
	10 Year Budget: Targeted Rates for Water and Natural Environment provided funding to tackle significant environmental issues**.**	
	Auckland Climate Action Framework (ACAF) Sets out a plan to get Auckland to keep rise in temperature to 1.5°C and get to net zero emissions by 2050. The Framework is made up of several key moves to support these goals.	• ACAF outlines the steps required to meet Auckland's climate change commitments, through reducing overall emissions. Transport emissions are a key focus including a possible low emissions zone in the central city. • Provides reduction targets to meet climate change goals.
	Fossil Free streets declaration signatory (C40) A commitment by a group of mayors to reduce the climate change impacts from transport emissions in their cities. One third of greenhouse gas emissions from C40 cities comes from transport and traffic is the biggest source of air pollution, globally responsible for up to one quarter of particulate matter in the air.	The major commitments made by all signatories are: • Electric buses should be procured by bus companies by 2025 • An area of Auckland should be fossil fuel-free by 2030.

7 Environmental outcomes - international examples

7.1 London

The London congestion charge, implemented in 2003, was hoped to deliver improvements in air quality. While the scheme has delivered some small improvements in air quality, these have generally been lower than anticipated. A range of studies have been carried out, ranging from long term heath impacts studies to assessment of ambient data. Their results are mixed; some finding small, localised changes, and some finding small changes across the city. However, none have found a step-change in emissions as possibly expected, and modelling studies have not necessarily translated into improvements in measured air quality. This could be the result of multiple factors, including the failure of the Euro emission standard, or small-scale local improvements not translating into regional scale change.

Shortly after the scheme was implemented, a modelling study (Beevers and Carslaw, 2005) found improvements in air quality from implementing the scheme. There were issues with data representativeness, but none the less they found a 12% reduction in NOx, and an 11.9% reduction in PM_{10} in the charging zone. Most usefully, they reported an increase in vehicle speeds across the scheme (Figure 3), which was found to have the most impact on air quality.

	NO_X emissions $\pm 12\%$ (2σ) (see AQEG NO_2, 2004)		PM_{10} emissions	
	IRR	Charging zone	IRR	Charging zone
CCS speed changes	−4.1	−7.9	−4.8	−8.5
CCS vehicle km changes	5.6	−4.1	−3.4	−3.4
CCS overall change	1.5	−12.0	−1.4	−11.9
Additional benefit of improved vehicle technology	−5.7	−3.9	−5.4	−4.0
Total change in emissions	−4.2	−15.9	−6.8	−15.9

FIGURE 3. THE PERCENTAGE CHANGE IN NOX AND PM_{10} EMISSIONS ON MAJOR ROADS IN THE CONGESTION PRICING ZONE AND INNER RING ROAD (IRR). SOURCE: BEEVERS AND CARSLAW, 2005.

A modelling study (Tonne et al. 2008) found modest improvements (reductions of < 1 µg m^{-3} for both PM_{10} and NO_2 annual averages) across the study area. Over 10 years, this translates to 183 years of life gained per 100,000 people in the congestion charge zone.

A small study (Ellison et al. 2013) looked at five years of ambient PM_{10} and NO_x data, in London. They found that PM_{10} concentrations declined by around 3% inside the congestion charging zone, while concentrations outside the zone declined by around 1%. No trend was observed for NO_x. The study did find however, that controlling vehicle type encouraged a shift to different vehicles, which were mostly Euro III or better.

Green et al. 2018 found improvement in pollutant concentrations (CO and PM_{10}) when compared to other 'comparator cities'. This study reported an increase in NO_2 concentrations, and attributed this to diesel vehicles travelling more kilometres, and mode shift from private vehicle to diesel buses and taxis, since these are exempt from the scheme.

Mudway et al. 2019 found no change in lung function in children over their study period (2009-2014). The modelling carried out by the study found that the percentage of children living at addresses exceeding the European Union limit value for annual NO_2 (40 µg m^{-3}) fell from 99% 2009 to 34% 2013. Reductions in NO_2 concentrations at both roadside and background sites was also reported, most significantly at the inner London roadside sites (reduction of around 8 µg m^{-3} in annual average), but there was no dramatic step change in NO_2 concentrations observed (Figure 4). The study found no change in PM_{10} and was inconclusive for $PM_{2.5}$.

This lack of a clear trend in pollutant concentrations after the scheme was implemented meant that something else was required to manage vehicle emissions other than pricing for congestion. The solution to this is the Ultra-Low Emission Zone (ULEZ) and Low Emission Zone (LEZ), implemented progressively since 2008.

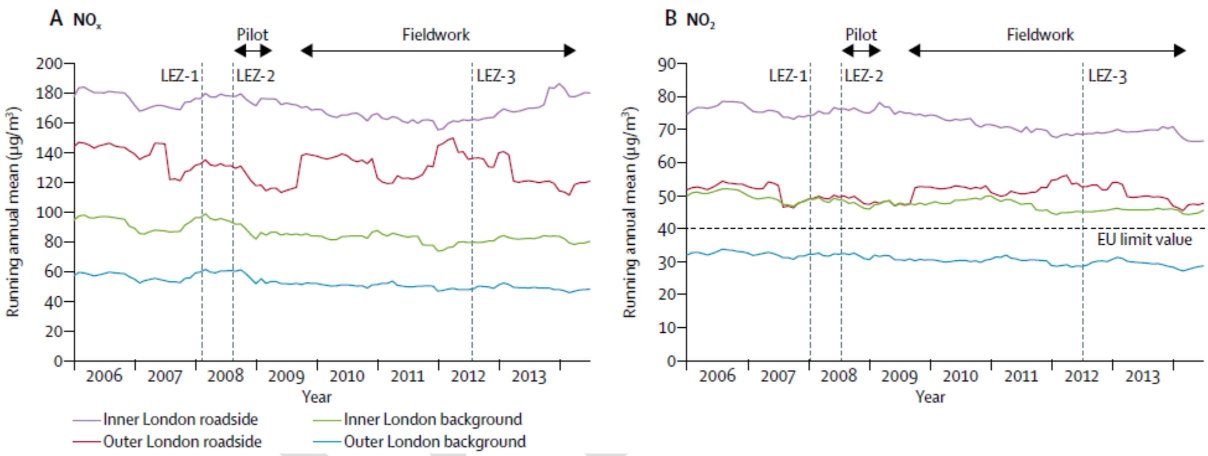


FIGURE 4. MONTHLY AVERAGE NO_X AND NO_2 CONCENTRATIONS AT LONDON SITES, 2006-2013. SOURCE: MUDWAY ET AL. 2019).

7.2 Stockholm

Stockholm's congestion charging scheme and the associated reduction in traffic in the inner city meant the Parliament's environmental goals were met, with post-pricing reductions of 14% for CO_2, 7% for NOx and 9% in particulate matter (PM_{10}). Outside of the cordon, greenhouse gases were reduced by roughly 2.5%. The use of air pollution modelling shows estimates that there will be 20-25 fewer premature deaths per year in Stockholm's inner city and a total of 25-30 fewer premature deaths annually in the Stockholm metropolitan area (Eliasson, 2014).

7.3 Hong Kong

Hong Kong has trialled congestion pricing three times[7]. The most recent trial (2004-2006), reported emission improvements in the order of 12-16% (ICCF, 2010). These gains were however relatively concentrated and offset by deterioration in areas surrounding and adjacent to the charging zone, due to

[7] 1983-85; 1997-2000 and 2004-2006.

diversion and redistribution. Charging was seen as helpful to environmental improvement but couldn't deliver the reductions required.

However, the environmental conditions of other areas, especially the by-pass routes and areas surrounding the charging zone would witness some deterioration due to the overall redistribution of traffic. Congestion pricing therefore would assist in the overall improvement to the environment, but was not seen as the sole solution to air quality issues.

7.4 Singapore

The Singapore department of land transport reported reductions in CO_2 of around 15% post implementation of congestion pricing in the central city, post the launch or ERP in 1998 (Palliyani and Lee, 2017; TSTC, 2018)

8 Low emission zones

Low emission zones and congestion charging share some similarities, but they are for fundamentally different purposes. Low emission zones aim to reduce transport emissions within a zone, by limiting the kinds of vehicles permitted to enter it (e.g. the highest emitters or diesel vehicles). Congestion pricing charges all vehicles to enter an area or scheme, regardless of their emissions.

Low emission zones are often implemented over a smaller area (e.g. in a town centre), aiming to manage health and amenity impacts, and to shift public behaviour. Cities which have implemented low emission zones have generally had more significant issues with air quality, for example significant and consistent breaches of relevant standards and guidelines exposing a greater number of people. In Europe, this has been driven by high proportions of light diesel vehicles in the fleet. In these cases, cities tend to implement low emissions zones rather than congestion pricing.

Low emission zones are designed to restrict or create disincentives for vehicles which pollute more from travelling in a certain area. While they are not designed with congestion reduction specifically in mind, they may have impacts on traffic volumes. Around 250 cities in Europe have implemented low emission zones, ranging from controlling vehicle based on emission performance, to bans on diesel (e.g. Paris from July 2019) (Transport & Environment, 2018; McGrath, 2019).

They could however be used in conjunction with congestion pricing to support both reduction in emissions and reduction in congestion. For example, in London, the new ULEZ is the same area as the current Congestion Charge. The ULEZ will be expanded to inner London from 2021, and then as a LEZ London wide by 2020 (Figure 5). Using the same boundaries for schemes makes them more straightforward to understand.

A successful low emission zone needs to understand the types of vehicles entering it, and their impacts in order to assess the appropriate intervention. For example, a corridor affected by emissions from light diesels would require a different intervention to one dominated by heavy diesel vehicles (e.g. buses). Similarly, a low emission zone targeting CO_2 emission could target all vehicles, or just significant fuel users like trucks.

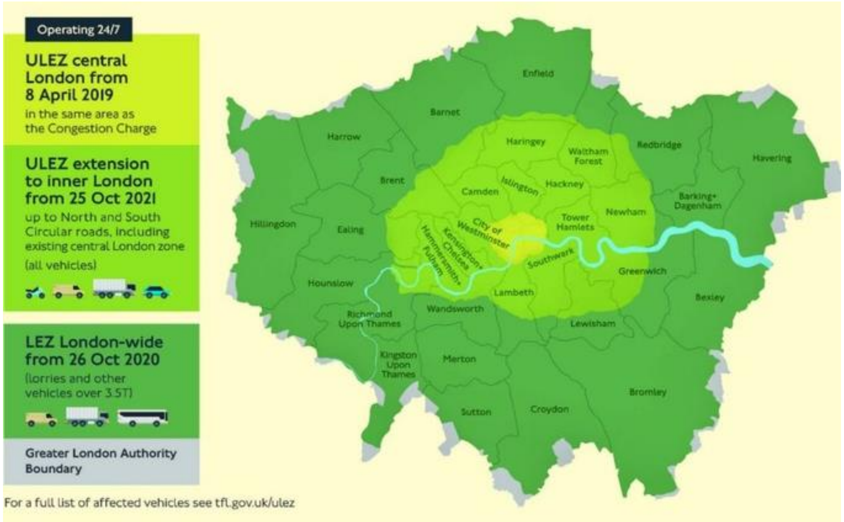


FIGURE 5 LONDON ULEZ AND LEZ ROLL OUT. SOURCE: HTTPS://TFL.GOV.UK/MODES/DRIVING/ULTRA-LOW-EMISSION-ZONE

9 Supporting other emissions reduction initiatives

The potential environmental outcomes described by this paper, could augment other emission reduction programmes (and vice versa). Climate change adaptation and mitigation is a key focus for Auckland Council, and accordingly Auckland Council has plans and strategies which are related to emissions reduction, including:

- **Declaration of a Climate Change emergency:** In June 2019 Auckland Council declared a climate change emergency, aiming to accelerate responses to climate change. Shifting to lower emission transport options is a key part of this.

- **Signing up to the C40 Fossil Free Streets initiative:** In October 2017, the Mayor of Auckland signed this declaration. The key policy steps as part of this are the procurement of zero-emission buses only by 2025, and zero emissions in the city centre by 2030. Congestion pricing could support and augment this policy.

- **A low emissions zone as part of the Centre City Masterplan**: To support the declaration above, the city centre masterplan provides a framework and wider outcome for the centre city. It focuses on enhancing connectivity, and providing access for all modes. These initiatives will improve the city centre and support Auckland's growth as an international city. Congestion pricing will support this through managing demand for vehicle trips into the city centre and could be used to support managing traffic volumes through the area, improving amenity and reducing emissions.

- **Auckland Climate Action Framework (ACAF):** Provides a framework, and key strategic directions for how Auckland will tackle climate change. The ACAF provides a range of approaches, one of the key directions being to reduce fossil fuel use, and encouraging use of low-carbon options for transport. Congestion pricing supports this, through encouraging the shift to public transport and reducing the reliance on private vehicles.

10 Refining and extending this assessment

If it was required, this conceptual assessment of environmental outcomes could be extended through modelling. The Vehicle Emissions Prediction Model (VEPM) could be used to assess the impact of congestion pricing, by using a set of scenarios and testing their impact on emissions. A VEPM modelling run would require:

- Which year to use as base year. Currently, VEPM is configured with 2019 as a base year.
- Potential years for modelling. This could be informed by planned investment in public transport, or by the roll-out options paper.
- Potential VKT scenarios (e.g high-medium-low scenarios). This could be based on the transport modelling the project has done to date.
- Vehicle fleet composition scenarios. VEPM allows composition of the fleet to be modified, meaning higher or lower proportions of certain types of vehicles. This means assumptions can be made about the numbers of heavy and light vehicles in the fleet for each year or scenario.

At this stage, there is no requirement or recommendation to extend this assessment through modelling, as the key outcome the project is concerned with is the improvement in network performance, and any such modelling would be more appropriate as part of work related to the ACAF.

The conceptual assessment of environmental outcomes could also be extended through monitoring. A bespoke environmental monitoring programme would be complex to design and could be expensive to operate, depending on the methodology chosen and is therefore not recommended at this time.

For example, a simple and indicative study undertaken in 2016 estimated the air quality impact of a congestion charge on the central city area (Floater et al. 2016; Talbot and Lehl 2018). Using a model created by C40[8], reductions in $PM_{2.5}$ and NO_2 from an example congestion charge were estimated (no other pollutants where modelled).

The study estimated a 4% reduction in $PM_{2.5}$ and a 15% reduction in NO_2 (Figure 6). This was based on an assumption of the charge applying to private vehicles, rather than the heavier diesel fleet (buses). The economic impact of doing so was around $1million a year (Floater et al. 2016, Talbot and Lehl 2018).

[8] https://www.c40.org/

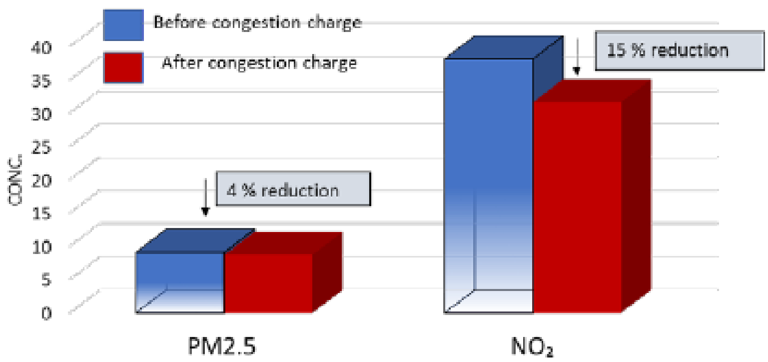


FIGURE 6. ESTIMATED REDUCTION IN NO_2 AND $PM_{2.5}$ FROM A $10 CENTRE CITY CONGESTION CHARGE. SOURCE: TALBOT AND LEHL, 2018).

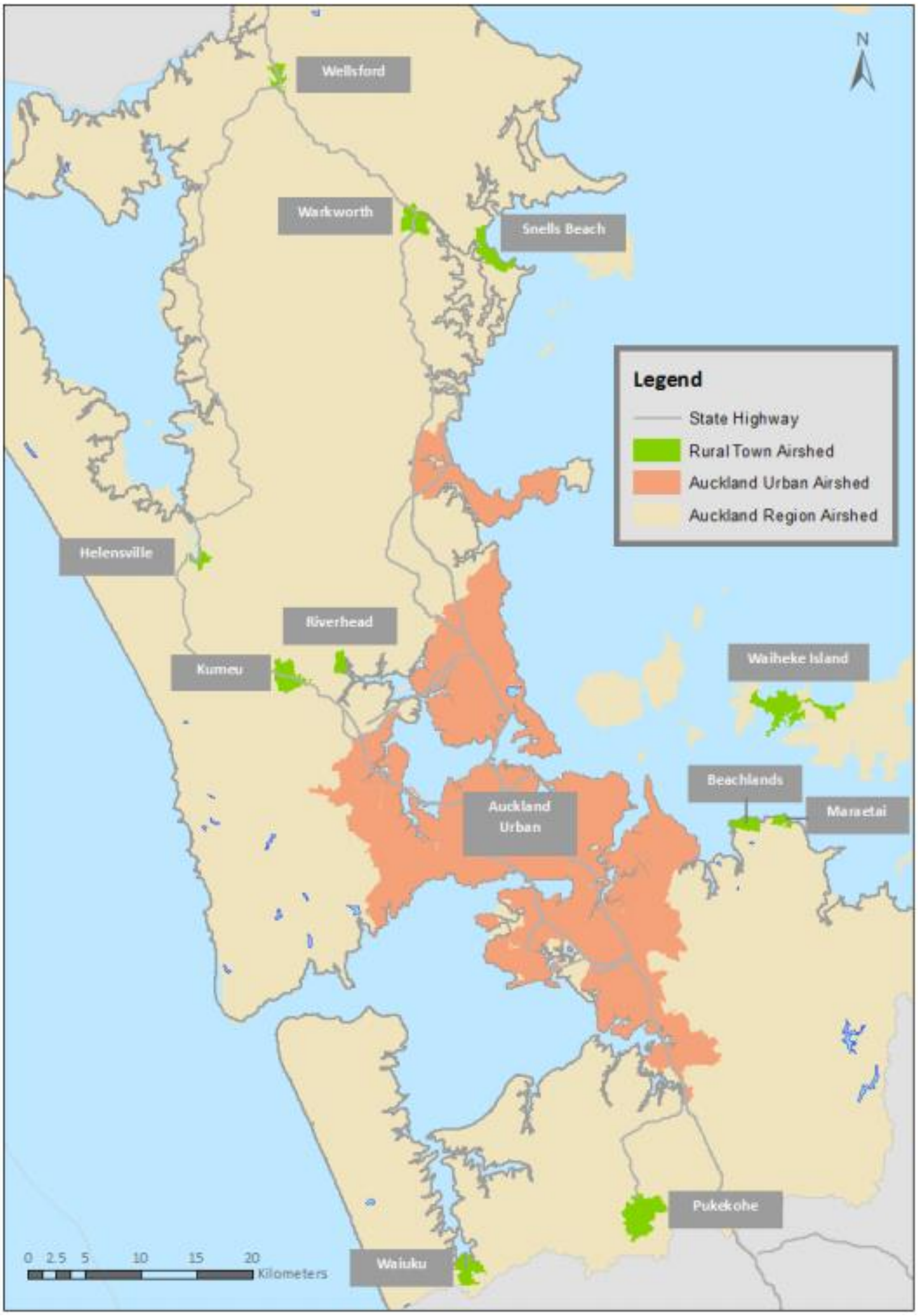
To assess environmental outcomes a range of data types could be compiled and assessed as a scheme is deployed. This would be made up of existing and new datasets, probably targeted spatially. Table 7 provides a summary of existing potential data sources should it be decided that would be useful.

TABLE 7. SUMMARY OF POTENTIAL DATA SOURCES FOR A MONITORING PROGRAMME

Domain	Source	Datasets
Traffic	Auckland Transport	Traffic volumes and flow
	Ministry Of Transport / NZTA	VKT and fuel consumption
Air	Auckland Council SoEM	Black Carbon, $PM_{2.5}$, PM_{10}, CO, NOx, VOC
	NZTA Monitoring	$PM_{2.5}$ and PM_{10} (at Waterview and Cook St)
		Vehicle Emissions Prediction Model (VEPM)
		NO_2 Network
Water	Auckland Council SoEM	Heavy Metals (Cu, Zn)
Emissions inventories	MfE GHG inventory	Total GHG emissions by sector (national scale)
	Auckland Council GHG inventory	Total GHG emissions by Sector (Auckland scale)
	Auckland Council emissions inventory	Emissions of pollutants by sector (Auckland scale)

11 Appendix 1 Auckland urban airshed

FIGURE 7: AUCKLAND URBAN AIRSHED



12 Appendix 2: Supporting information

12.1 CO_2 emissions – Current state

In 2016, Auckland gross emissions were 11,326 kilo-tonnes of carbon dioxide equivalent (kt CO_2e). When carbon sequestration from forestry was included this dropped to 10,128 kt CO_2e. Road transport accounted for 37.6% of this. When separated into constituent gases, CO_2 contributed 83.1%, methane 10.5%, nitrous oxide 1.7% and other gases 4.7%.

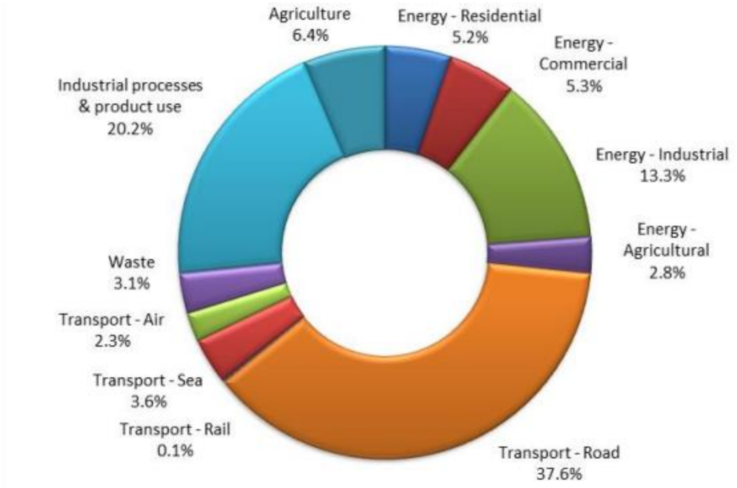


FIGURE 8 AUCKLAND'S GREENHOUSE GAS EMISSIONS (2016). SOURCE: XIE, 2019.

Greenhouse gas emissions from transport in Auckland have been relatively stable between 2009 and 2014 (Figure 9), before increasing in both 2015 and 2016. These increases are probably due to increases in VKT over the period, and possibly due to lower than anticipated performance of emissions from heavy vehicles. On a per capita basis, total emissions appear to have declined, due to population growth offsetting emission growth. In other words, population has grown faster than growth in emissions.

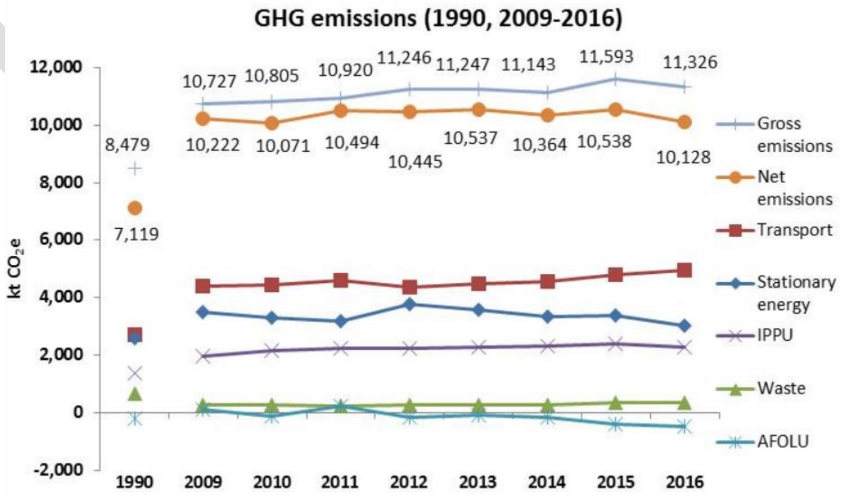
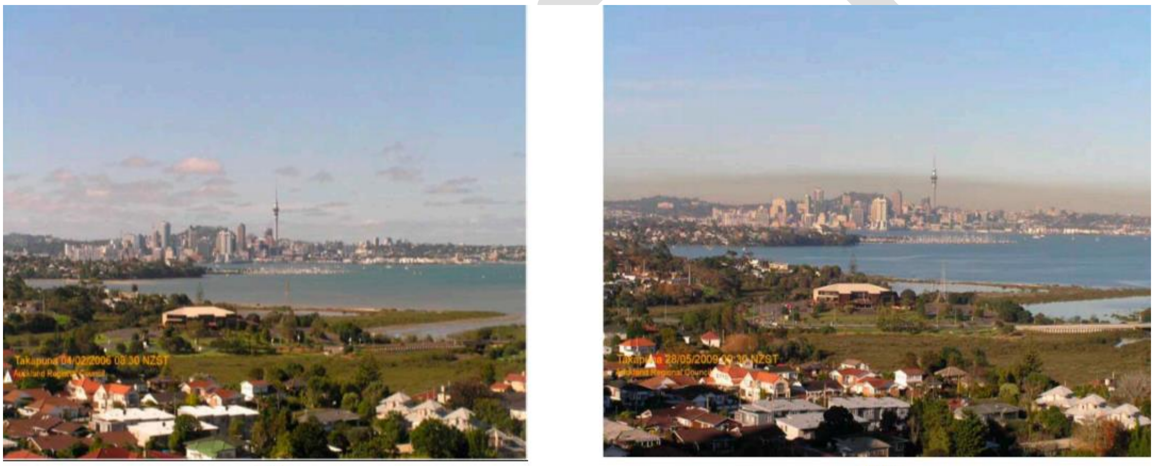


FIGURE 9. GREENHOUSE GAS EMISSIONS BETWEEN 1990 AND 2016. (SOURCE: XIE ET AL. 2019).

12.2 NOx emissions – Current state

NOx is the collective term used to describe emissions of nitrogen monoxide (NO) and nitrogen dioxide (NO_2). Ambient concentrations of NOx in urban areas are the result of combustion at high temperatures in vehicle engines, particularly diesel engines. NOx has a range of health impacts. High concentrations of NO_2 can irritate airways in the human respiratory system. Such exposures over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory issues (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms. Longer exposures to elevated concentrations of NO_2 may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. People with asthma, as well as children and the elderly are generally at greater risk.

NO_2 can react with temperature and sunlight, and is the key cause (along with the right meteorology) for the brown 'smog' haze sometimes seen in Auckland (Senaratne and Shooter, 2004; Dirks et al. 2017) (Figure 10).



(a) (b)

FIGURE 10 EXAMPLE OF THE CENTRAL CITY ON A CLEAR MORNING (A) AND ON A 'BROWN HAZE DAY' (B). SOURCE: DIRKS ET AL. 2017.

Concentrations of NOx vary greatly across the region but are generally elevated where the traffic is highest, (Xie et al. 2007) particularly on roads and motorways with higher proportions of heavy vehicles like buses and trucks. In the central city, where buildings create 'canyons' these concentrations are particularly high, and in some locations are the highest concentrations seen in New Zealand (Talbot and Lehl, 2018). In less built up locations, concentrations decline quickly moving away from the source. Concentrations close to motorways are generally low, driven by meteorology conditions promoting dispersion (Longley et al. 2015).

NOx emissions are forecast to decrease to 2040 (Figure 11)The bulk of this reduction is expected to be driven by improvements in Diesel heavy vehicle emissions and improvement in petrol vehicle emissions. The forecast improvement in emissions is projected despite increased VKT (Sridhar and Metcalfe, 2019), based on the assumption that cleaner vehicles will make up a greater proportion of the fleet.

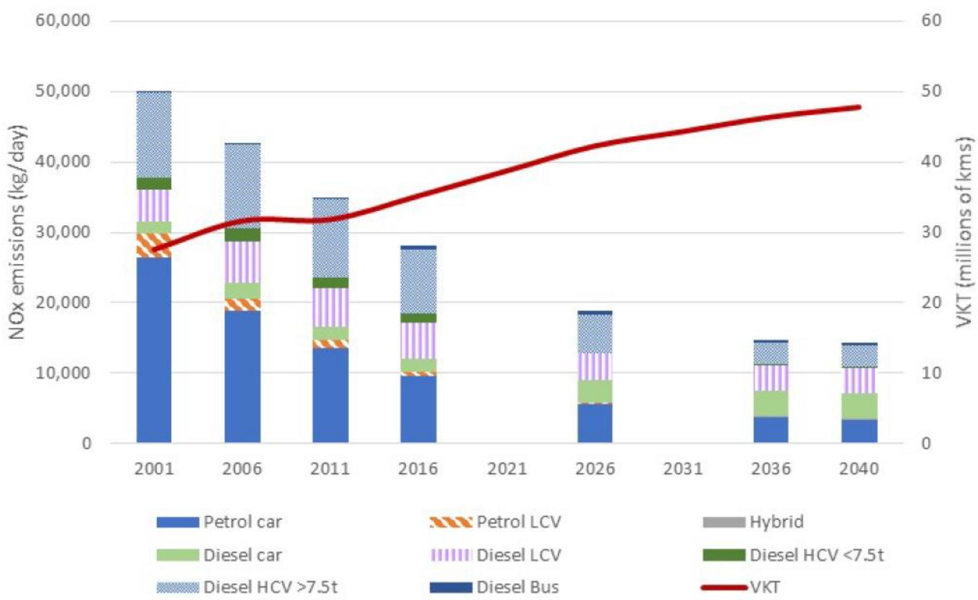


Figure 11 NOx emission estimates from 2001 to 2016 and emission projections to 2040 by vehicle type and total VKT. Source: Sridhar and Metcalfe, 2019.

Sites with traffic dominated emissions are most likely to have higher NOx concentrations. The Queen St monitoring site shows the influence of traffic volume and flow on ambient NO_2 concentrations. Between 2006 and 2017, concentrations declined by 1.93% / year. After changes were made to traffic flow and composition, the trend increases slightly from 2012 on (Figure 12).

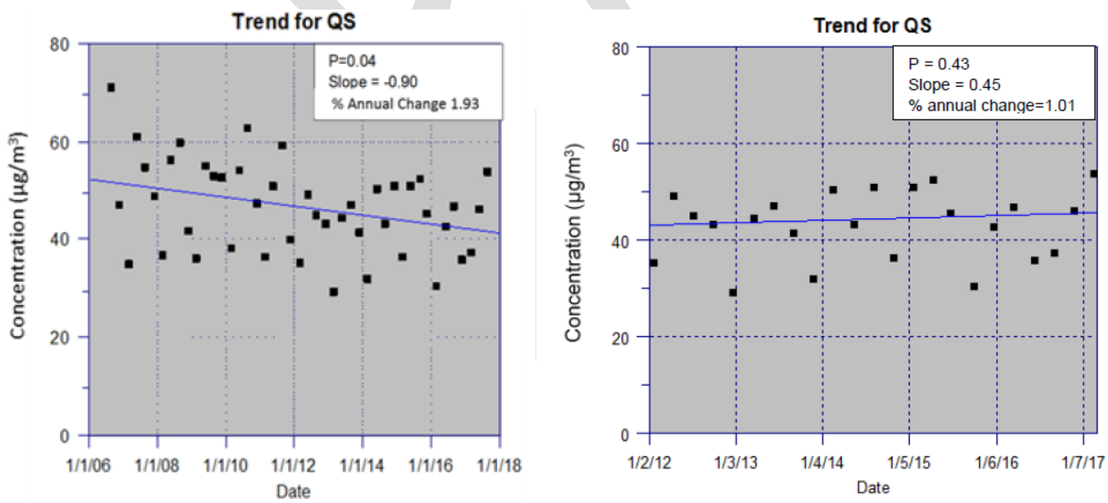


Figure 12 Trend analysis of NO2 concentrations for Queen Street monitoring station taken from seasonalised Mann-Kendall non-parametric statistical analysis. Trends provided for 2006-2017 (left) and 2012-2017 (right) Source: Talbot and Lehl, 2018.

Compared to other New Zealand monitoring sites, Auckland sites have noticeably high NO_2 concentrations (Figure 13). Even the Glen Eden site, which is in a residential neighbourhood, records higher concentrations than sites in Masterton and Upper Hutt. Peak sites in Auckland (Queen St, Khyber Pass) record relatively high concentrations which have breached the 200 µg m^{-3} hourly average standard[9] in the past. For reference, both Riccarton Road and Khyber Pass sites are true curb side sites, next to a roads which see about 28,000 vehicle movements daily.

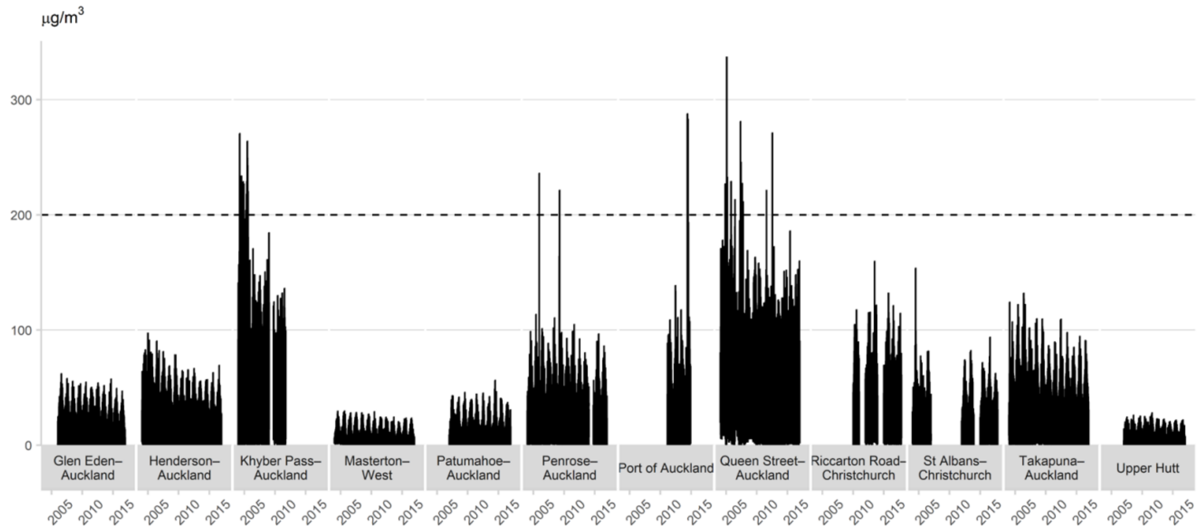


FIGURE 13. HOURLY AVERAGE NO_2 CONCENTRATIONS AT REGIONAL COUNCIL MONITORING SITES 2004-2017. SOURCE: MFE AND STATISTICS NZ, 2018

12.3 Particulate emissions ($PM_{2.5}$ and PM_{10}) – Current state

Particulate matter can be easily inhaled and the largest particles in this size fraction are deposited in the upper airways, while the smaller ones can deposit deep in the lungs. Health effects include decreased lung function or heart attack, and mortality. Children, the elderly, and people with existing heart or lung problems have a higher risk of health effects from particulate matter exposure (WHO, 2013A, 2013B).

Particulate emissions in Auckland come from a range of sources, but transport is the major year-round contributor. More PM_{10} is emitted in winter, due to home heating using solid fuels like wood and coal. PM data is derived from two different sources, emissions inventories, where proxy data sources with known relationships to PM emissions are accounted for by source; and direct monitoring of ambient air quality.

Auckland Council's emission inventory (Xie et al. 2014) found that emissions from transport make up 43% of $PM_{2.5}$ and 29% of PM_{10} and are present consistently during the whole year (Figure 14).

[9] The National Environmental Standard for Air Quality sets an Hourly average standard of 200 µg m^{-3} for NO_2. 9 breaches of the standard are allowed in a rolling 12 – month period. The same value is an Auckland Abient Air Quality Target in the Unitary Plan.

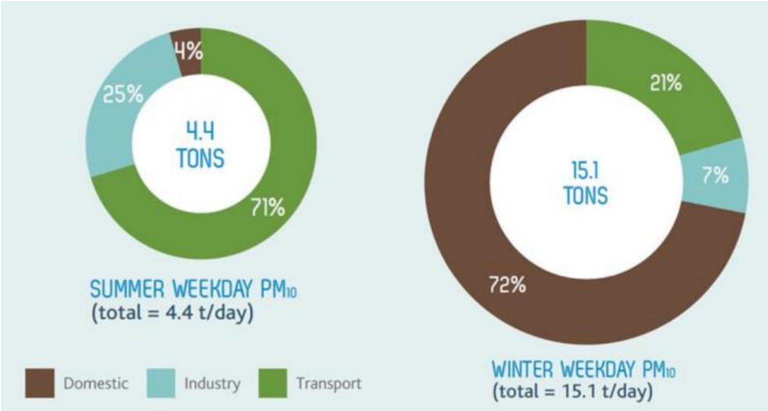


FIGURE 14 DAILY PM_{10} EMISSIONS IN SUMMER AND WINTER (XIE ET AL., 2014)

Auckland Council's source apportionment monitoring programme further classifies sources, using monitoring data from approximately 5 representative sites across the region. 43% of $PM_{2.5}$, and 29% of PM_{10} is emitted by motor vehicles (all fuels). Vehicles, though emission of NO_x and SO_2 also contribute to total PM concentrations as through photochemistry (Figure 10) and secondary sulphate (Figure 15).

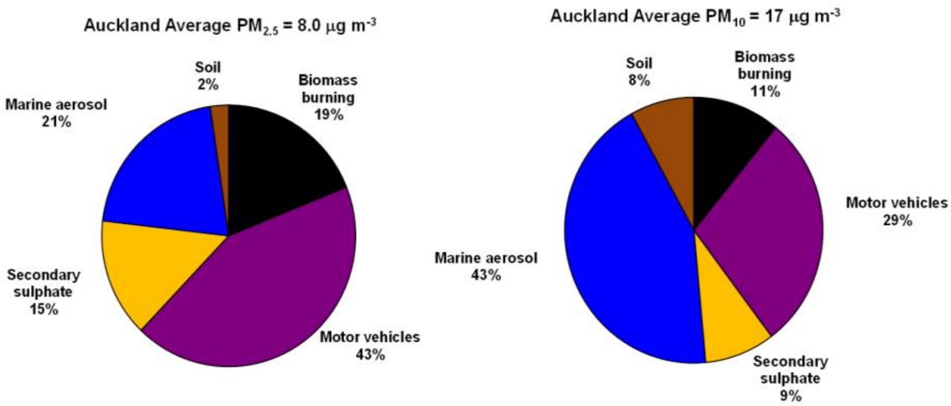


FIGURE 15 SOURCE CONTRIBUTION FOR PM2.5 (LEFT) AND PM10 (RIGHT) PARTICULATE (DAVY ET AL., 2017)

PM_{10} emissions are forecast to decrease to 2040 (Figure 16). The bulk of this reduction is expected to be driven by improvements in diesel emissions, in both light and heavy diesel vehicles. The forecast improvement in emissions is projected despite increased VKT (Sridhar and Metcalfe, 2019), and is driven by improvements in emissions in most vehicle classes, and increasing proportions of hybrid and electric vehicles.

$PM_{2.5}$ concentrations from diesel sources are declining at monitored sites (Davy et al., 2014) (Figure 17). This suggests that the forecast declines are possible. These declines are most evident at sites with a larger traffic influence.

Analysis of $PM_{2.5}$ and PM_{10} data between 2006 and 2015 (Talbot et al. 2017) found that annual average concentrations were declining across the region, reporting statistically significant trends at the majority of sites. Peak sites, especially Takapuna and Khyber Pass, declined rapidly to 2011 and then have stabilised. As well as declines in concentrations, the frequency of exceedances of the National Environmental Standard for Air Quality[10] has declined, with no exceedances of the PM_{10} standard since 2013. The Auckland Urban Airshed is now considered ‘non-polluted’ (with regard to the PM_{10} 24hr-average standard in the NES-AQ. (MfE, 2014). $PM_{2.5}$ from transport may be a more significant issue for air quality in Auckland and is not currently regulated nationally.

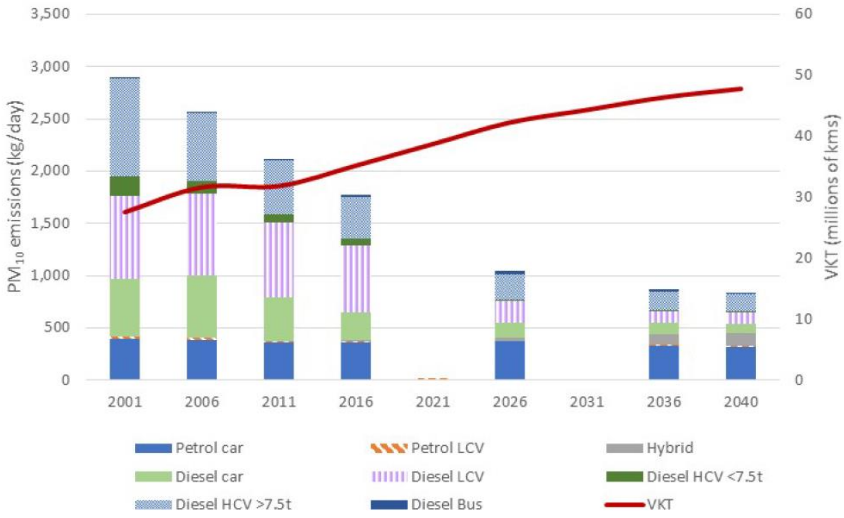


FIGURE 16 PM_{10} EMISSION ESTIMATES FROM 2001 TO 2016 AND EMISSION PROJECTIONS TO 2040 BY VEHICLE TYPE AND TOTAL VKT. SOURCE: SRIDHAR AND METCALFE, 2019.

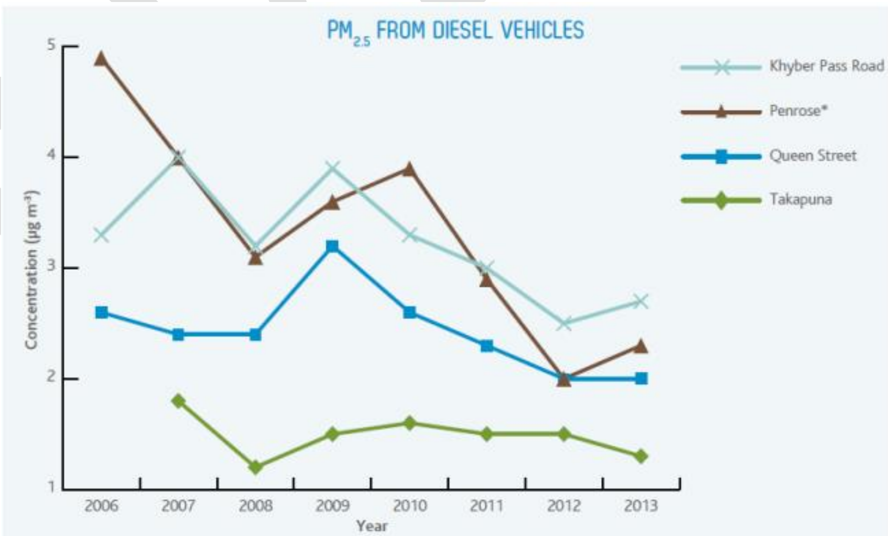


FIGURE 17 TREND OF PM2.5 FROM DIESEL VEHICLES (DAVY ET AL., 2014). (SOURCE: AUCKLAND COUNCIL, 2015)

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[10] https://www.mfe.govt.nz/air/air-regulations/national-environmental-standards-air-quality/about-nes

12.4 Black carbon (BC) – Current state

Historically, BC as a pollutant has been known, but difficult to quantify efficiently. However, recent advances in monitoring techniques and understanding of health impacts have resulted in more widespread monitoring. In Auckland, this has been accomplished through new monitoring and re-analysis of historic samples (Davy and Trompetter, 2018).

BC is a major component of soot and in the transport sector is emitted from incomplete combustion, particularly from light and heavy diesel vehicles. BC is an important contributor to both ambient air quality and climate change. BC has a short lifespan in the atmosphere, so reductions in BC could help make quick gains for climate change. Both the Climate and Clean Air Coalition and Intergovernmental Panel on Climate Change (IPCC) have indicated BC as one of their respective priorities (Davy and Trompetter, 2018).

While most aerosols in the atmosphere scatter incoming solar radiation, resulting in a net cooling effect on the atmosphere, BC absorbs significantly more light than it reflects, resulting in a net warming effect. Light absorbing particles radiate long-wave energy that heats the surrounding air. BC has been estimated to be the 2nd highest contributor to warming (next to CO_2) (Bond et al. 2013). BC also has implications for human health. Where $PM_{2.5}$ and PM_{10} have impacts, BC is likely also having an impact. Over shorter timeframes, BC is likely to be a better indicator of health impacts, especially from transport sources (WHO, 2012)

In Auckland, diesel vehicles are the main contributor to ambient BC(Figure 18) (Davy and Trompetter, 2018). Elsewhere in New Zealand, biomass burning (e.g. wood and coal burning fires for domestic heating) dominate. The study also found that BC concentrations in New Zealand, and especially Auckland where generally high when compared to overseas examples:

> *"Black carbon concentrations at New Zealand urban locations were generally higher than those found in Western European and United States cities. This is most likely due to the time lag for motor vehicle engine emissions technology improvements to enter the New Zealand vehicle fleet and the prevalence of biomass combustion for residential heating during winter"*

At Auckland transport emissions dominated sites, annual average concentrations are elevated when compared to overseas sites. At Khyber Pass, annual averages range between 4.1 – 4.7 µg m^{-3}, and at Penrose and Takapuna these are around 3 µg m^{-3}. Overseas, urban sites are around 1-2 µg m^{-3} (Davy and Trompetter, 2018).

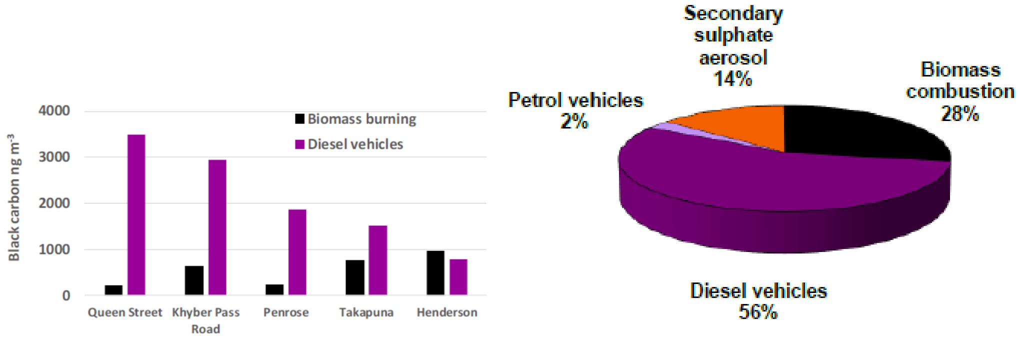

FIGURE 18 AVERAGE BLACK CARBON CONCENTRATIONS BY SOURCE AT AUCKLAND MONITORING SITES (LEFT) AND AMBIENT BC SOURCES AT TAKAPUNA. SOURCE: DAVY AND TROMPETTER, 2018.

12.5 Volatile organic compounds (VOCs) – Current state

Volatile organic compounds (VOCs) are organic chemical compounds that vaporise under normal ambient conditions to enter the atmosphere as gases. Many VOCs are hazardous to human health (especially benzene and 1,3 butadiene). Health effects are broad, ranging from dizziness and unconsciousness from short-term exposure to cancer from long-term exposure (group one carcinogen). 52% of VOC in ambient air in Auckland are from transport emissions, particularly from petrol vehicles (Stevenson and Narsey, 1998). Results reported in 2009 by ARC (Smith et al., 2009), confirmed significantly elevated levels of benzene at the two Khyber Pass sites.

VOC concentrations have declined in Auckland since the early 2000's, and have generally stabilised close to guideline values, especially since on-going revision of national fuel specifications, removing lead and then benzene, (which was initially added for smoother running of unleaded fuel. Data reported in 2014 (Reid, 2014) confirmed a decline to end of 2013. For benzene, concentrations have stabilised close to relevant standards and guidelines (Figure 19).

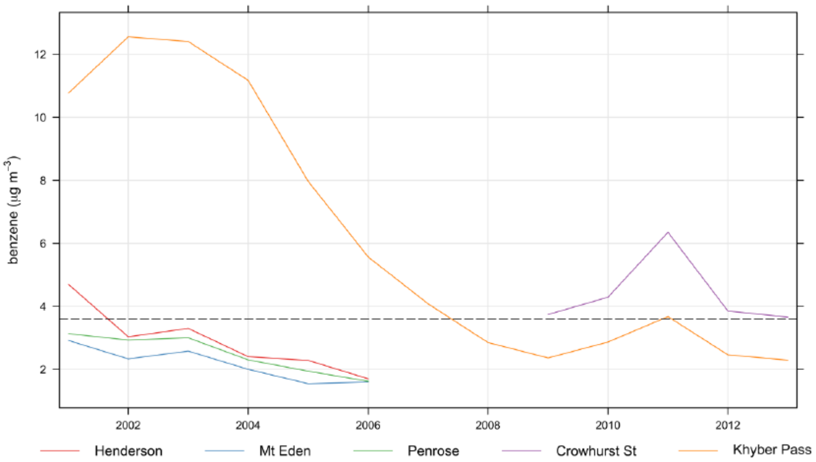

FIGURE 19. ANNUAL AVERAGE PASSIVE BENZENE, 2001-2013. THE DASHED LINE IS THE MFE GUIDELINE VALUE. SOURCE: REID (2014).

12.6 Changes to emission distribution

Pollutants in Auckland tend to follow distinct patterns. Emissions from transport greatly influence this pattern. Generally, transport related emissions rise to an early morning spike, associated with the morning travel period (Figure 20). During the middle of the day, concentrations decline, before rising to an early evening peak, which, in winter is exacerbated by home heating emissions. Emissions are highest during the week, with low concentrations during the weekend. If congestion pricing was implemented, and people made decisions to shift their travel patterns and times, this pattern could change, in that the observed trough between peaks may shift, so that the trough between peaks is less pronounced.

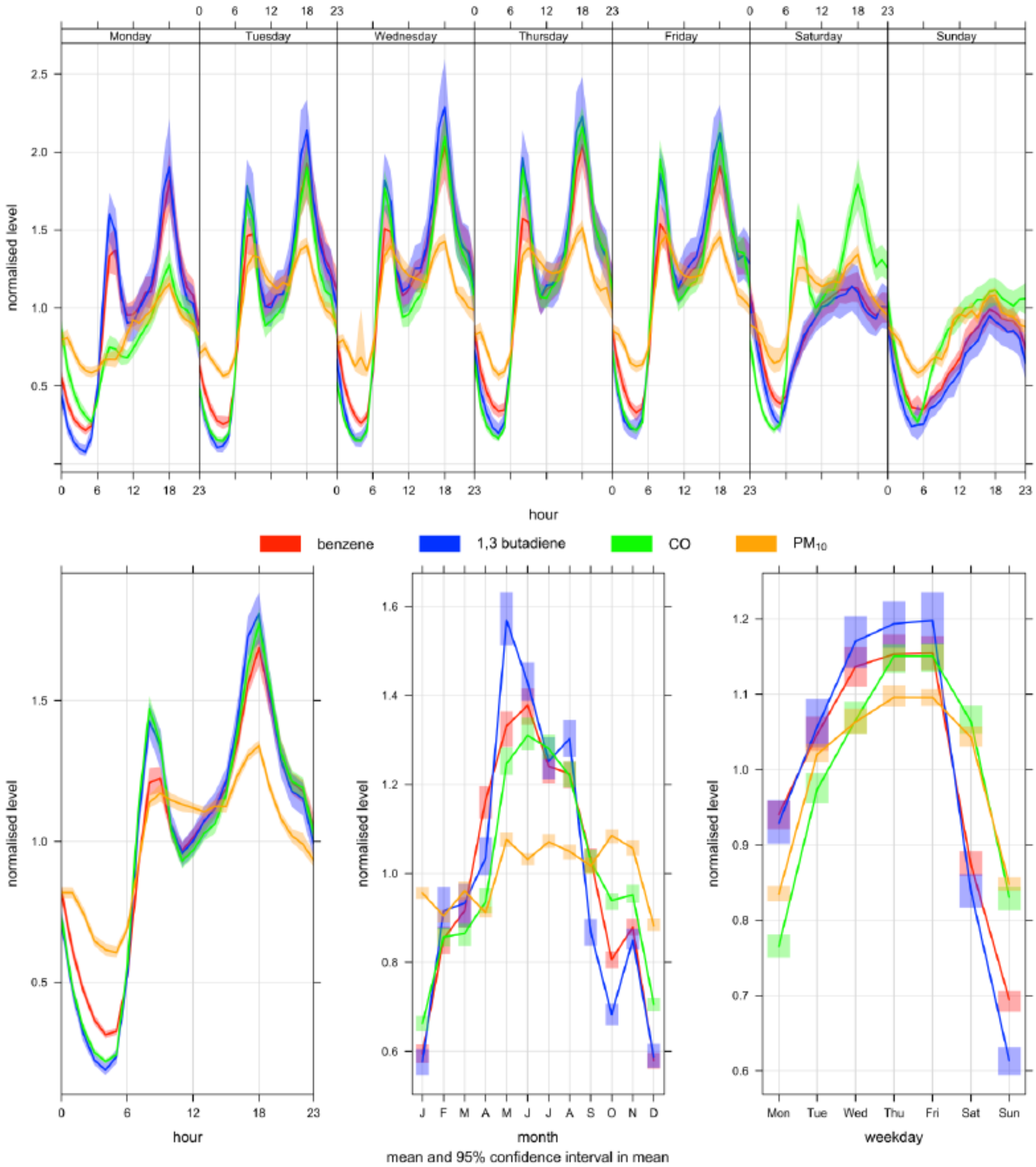

FIGURE 20. TEMPORAL TREND (NORMALISED) FOR CONTINUOUS BENZENE, 1,3 BUTADIENE, CO AND PM_{10} AT KHYBER PASS, 2005 – 2013. SOURCE: REID, 2014.

12.7 Improvement in run off from roads

Auckland's road network makes up a significant proportion of total land use in the region. Run off from sealed roads is generally quick because efficient removal of stormwater is essential for safety. A range of contaminants are present in road run off, including fuels, additives, oil and brake and tyre residues. These contain a range of toxic pollutants including heavy metals (Gardiner et al. 2016). Run off from roads makes a significant contribution to reduced water quality in Auckland.

Freshwater quality across Auckland ranges from excellent in catchments with predominantly native vegetation cover, good or fair in those with exotic forest and rural land use, and is generally poor in urban catchments (Auckland Council, 2015; Hamil & Lockie; 2015; Holland et al., 2016). Results for 2015 classified only 4 of the 36 sites as having 'excellent' water quality. Nine sites were classified as 'good' and the remainder were 'fair' and 'poor' (Holland et al., 2016). In 2017, only 1 site (West Hoe Stream, west of Orewa) was classified as having excellent water quality, and more streams shifted into the "poor" classification (Buckthought, 2017).

Heavy metals in Auckland streams frequently exceed protection guidelines (e.g. Australian and New Zealand Guidelines for Freshwater and Marine Water Quality (ANZECC)) (Gadd et al. 2019). At these concentrations there are impacts on in-stream ecology (including macro-invertebrates and fish). Gadd et al. (2019) found that between 2005 and 2014 the ANZECC 80% protection level for soluble copper in urban streams was exceeded by 10% of samples, and the 90% level by 30% of the samples (Figure 21). These contaminants eventually end up in harbours where they accumulate and can continue to have ecological impacts.

In the absence of strict source control (e.g. mandatory ceramic brake pads, or zinc free roofing) a reduction in VKT could have an impact on heavy metal concentrations.

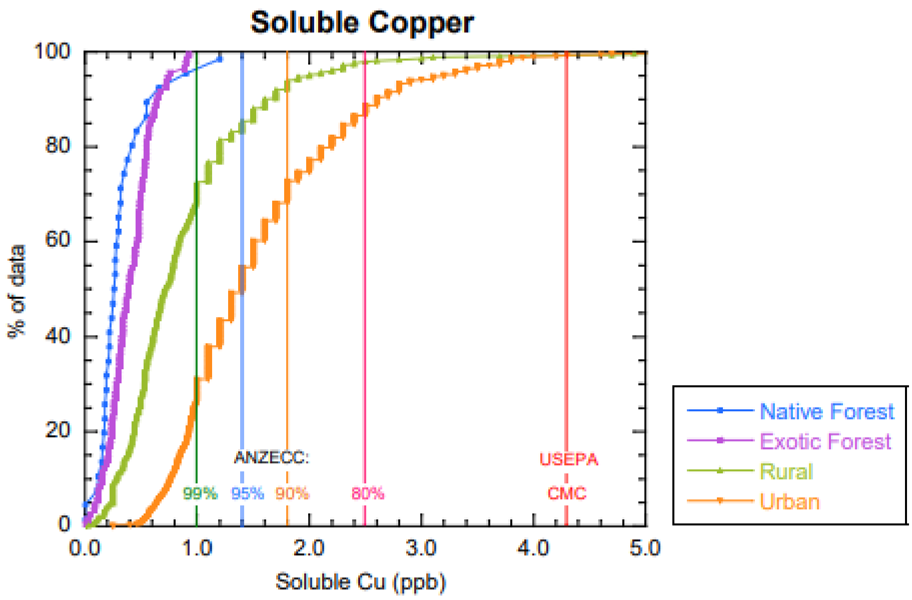

FIGURE 21. PROBABILITY PLOT FOR SOLUBLE COPPER. SOURCE: GADD ET AL, 2019).

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