Carbon monoxide changes in Auckland - the effects of government legislation

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Abstract

The main sources of carbon monoxide (CO) in New Zealand are motor vehicle exhaust emissions and domestic home heating. In Auckland the 2011 emissions inventory (Sridhar et al., 2014a) showed that 88-89% of annual CO emissions were attributable to petrol motor vehicles. Atmospheric CO concentrations were measured at a roadside monitoring site in central Auckland, New Zealand (Khyber Pass Road) from 1996 to 2015. Data collected at this site show a steady decline through 1996 to 2011; between 2011 and 2015 the declining trend slowed and became reasonably flat. This downward trend is consistent with observations made at several other urban sites, in New Zealand, the United Kingdom and other overseas countries. Causes of the decline include changes in vehicle and fuel technology, changes in the vehicle fleet, and most importantly, government legislation to set minimum standards for vehicle exhaust emissions and incentives for households to switch to more efficient and cleaner home heating options.

1. Introduction: why care about CO?

Carbon monoxide (CO) is a colourless, odourless gas found at trace levels, typically between 0.01-0.23 mg/m^3, in the New Zealand atmosphere. Natural sources are volcanoes, fires and metabolism of organisms. Anthropogenic sources include incomplete combustion of fossil fuels, such as petrol in internal combustion engines, wood and coal burned for home heating, and burning of crop and forest residue after harvest. Small amounts arise from certain industrial and biological processes.

CO has an indirect radiative forcing effect by elevating concentrations of methane (CH_4) and ozone (O_3) through chemical reaction with other atmospheric constituents e.g. the hydroxyl radical (OH) (Riedal, 2008). Most of the trace gases found in the atmosphere are oxidised by OH into water-soluble products that are washed out by rain and snow. CO is the major reactant with OH, accounting for about 75% of OH destruction, with most of the remainder destroyed by CH4 (methane) oxidation.

$CO + OH \rightarrow CO_2 + H$ (hydrogen)

CO molecules can remain in the atmosphere for up to three months before being chemically transformed (via interaction with the OH radical) into CO_2, and is included in the amount of greenhouse gas emitted from motor transport.

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High CO levels can be a localised problem alongside busy and congested roadways and an urban/regional problem when calm stable weather conditions trap the polluted air near ground level.

CO, which is readily absorbed from the lungs into the blood stream, interferes with the blood's ability to carry oxygen through the formation of carboxyhaemoglobin (COHb) (Blumenthal, 2001). Low level exposure causes dizziness, weakness, nausea, confusion and disorientation. At higher levels, it can be fatal. It can take the human body between 2 and 6.6 hours to metabolise half of any concentration of CO that is absorbed.

Health impairments can be experienced by the general population when the COHb levels in the body go above 2.3%, although more sensitive people can be affected by lower levels (WHO 1999).

The World Health Organisation has recommended guidelines to keep the COHb level below 2.5%. These guidelines are average exposures and cover short term exposure (100mg/m^3 for 15 minutes) to longer term exposures (30mg/m3 for 1 hour and 10mg/m^3 for an 8-hour average) (WHO 1999).

The Health and Air Pollution in New Zealand (HaPiNZ) report in 2007 found that the health effects associated with CO exposure showed a significant level of premature mortality (178 cases per year) and illness (2247 extra hospital admissions). The total economic costs of air pollution in New Zealand for both premature death and adverse health impacts were estimated at $1.14 billion per year (based on the 2001 population) (Fisher et al., 2007). In 2012 the HaPiNZ model had updates to some sections, basing the new assessment on PM10; this does not mean that all health effects are attributed to PM10 alone as urban air pollution is a complex mixture of gases and particles. The summary report stated that the total social cost (in June 2010 dollars) associated with anthropogenic air pollution in New Zealand was estimated to be $4.28 billion per year. The contribution from motor vehicles was 22% and domestic fires was 56% (Kuschel et al., 2012).

In the Auckland context (based mainly on PM10 concentrations), air pollution causes approximately 300 premature deaths, and results in an increased number of reduced activity days and hospital visits, and higher usage of medications. It is estimated that the social cost from air pollution in Auckland is $1.07 billion per year (ARC, 2012).

2. The national context and the Auckland monitoring

New Zealand has National Environment Standards (NES) for five air contaminants, which includes an 8-hour moving average (10mg/m^3) for CO (MfE, 2004). These standards, which came into force in September 2005, are concentration limits set to protect people's health and follow the WHO guidelines. It is permissible to have one exceedance of the 8-hour standard per year. Even though the CO NES only came into effect in September 2005, the same value had been a national guideline since 1994. There is also a national guideline for the 1-hour average of 30mg/m^3.

The main sources of CO in New Zealand are domestic home heating and motor vehicle emissions, with traffic being a more dominant source during the summer months. Winter months are the only time domestic home heating fires contribute significantly to pollution. A winter peak in CO occurs due to an increase of emissions but is also related to poorer dispersion conditions. Under certain meteorological conditions e.g. during intense anticyclonic conditions when light winds and near-surface temperature inversions occur, the ability for pollution to be dispersed is restricted, which can create locally elevated CO levels.

In Auckland, the 2004 emissions inventory showed that during an average winter weekday, 83% of the CO emissions were attributable to motor vehicles and were predominantly petrol engines. This increased to 94% during the summer (ARC, 2004). The 2006 emissions inventory showed that, on an annual basis, transport was responsible for 86% of the CO emissions with domestic sources being 12% and industry 2% (Xie, 2014). The 2011 emissions inventory (Sridhar, 2014a) showed that while emissions from petrol vehicles had dropped 42% from 2001-2011, petrol cars still contributed 88-89% of annual CO emissions.

From 1996 to 2015, CO was monitored for the Auckland Council at the corner of Khyber Pass and Mountain Roads in the central Auckland suburb of Newmarket (close to the Central Business District). Khyber Pass Road is oriented WNW-ESE and slopes down to the east, resulting in atmospheric effects similar to those experienced in valleys and canyons.

The location is dominated by traffic, with over 27000 vehicles passing each day. There is a major intersection controlled by traffic lights adjacent to the site which results in frequent queues of idling vehicles alongside the analyser intakes. The original measurement site, from October 1996 to January 2009, had the intake 12.5m east of the road intersection. The measurement site was relocated by September 2009 with the intake now 28m from the intersection. Both sites were on the same downhill side of the road. Co-located measurements were not possible due to site access issues.

The monitoring of CO at the Khyber Pass Road site was undertaken using an API M300 GFC-IR absorption analyser, in accordance with the Australian Standard AS 3580.7.1 which is the method mandated by the Ministry for the Environment (MfE, 2009).

3. Synopsis of results

Since 1998 there has been an overall downward trend in the 8-hour moving average of CO concentrations in Khyber Pass Road air (Figure 1). The percentage of

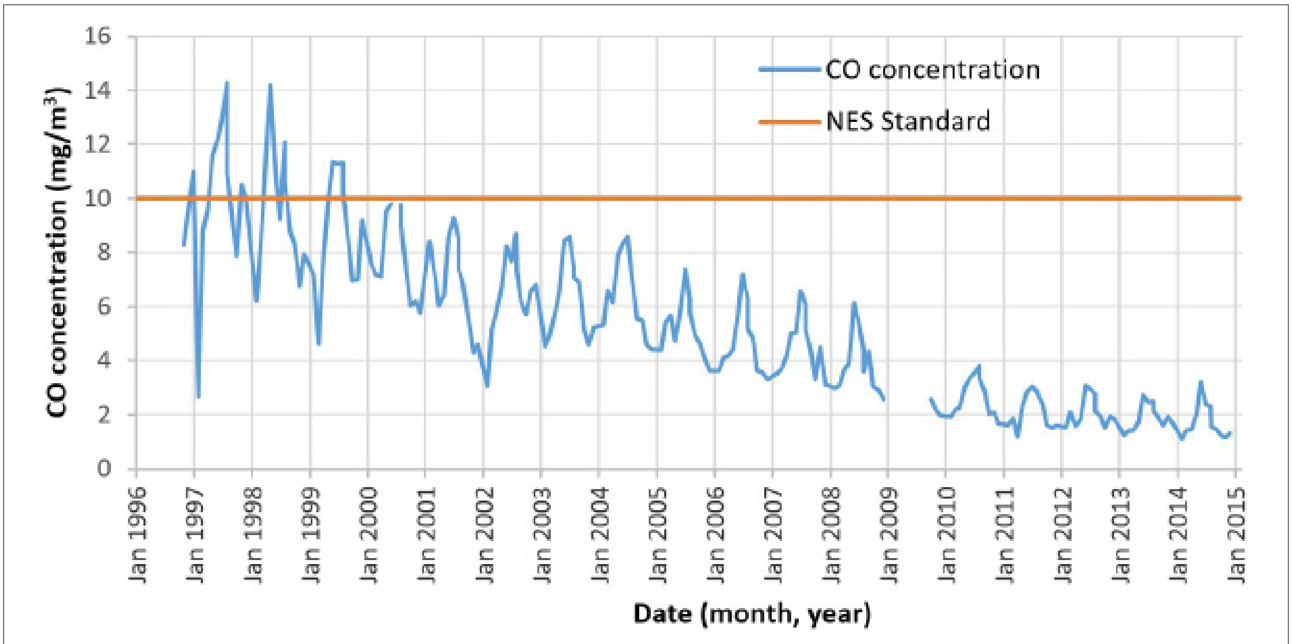

Figure 1: Khyber Pass Road: maximum 8-hour moving average CO. The red line indicates the 8-hour NES concentration. NB there was a site change in September 2009.

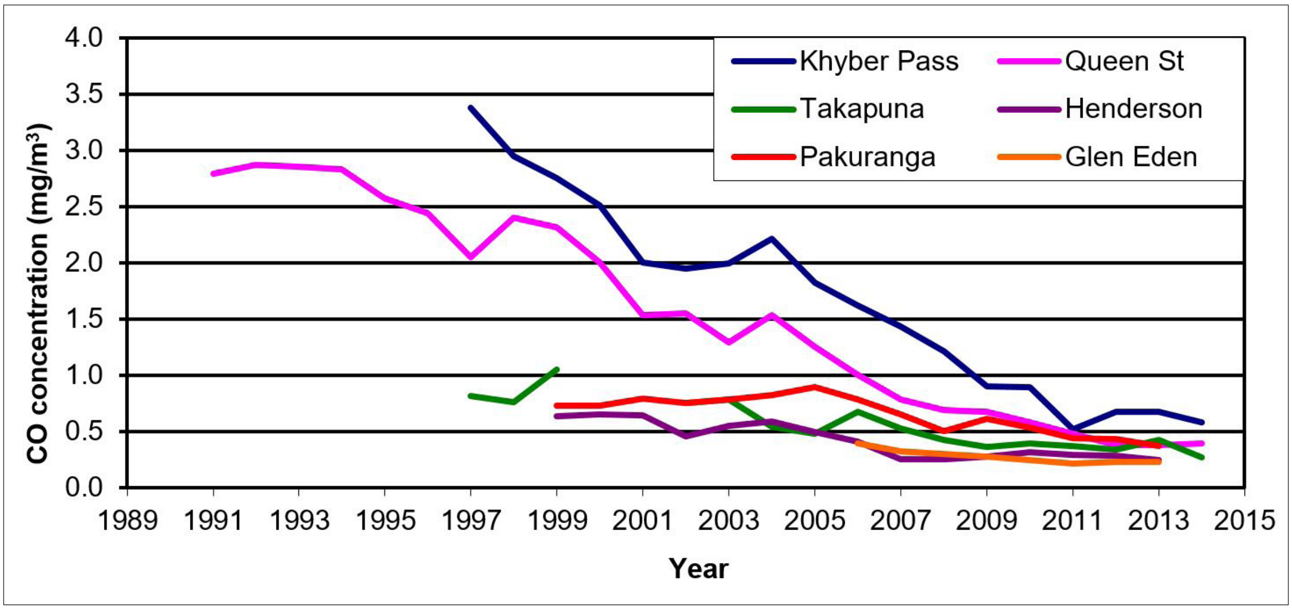

Figure 2: All Auckland CO monitoring sites - annual average.

the year where measurements were above the 8-hour standard fell from 2.3% in 1997 to 0.6% in 1999. The last exceedance occurred in August 1999. In all these years the exceedances mainly occurred in June and July, with the highest monthly percentage being 9.3% during June 1997. A seasonal cycle with a winter maximum is clearly visible in the data plot. This results from a combination of additional CO from domestic home heating fires (around 15% of total emissions) and poor dispersion associated with meteorological conditions described earlier. In February 2015, CO monitoring at Khyber Pass Road was discontinued.

Auckland Council also undertook CO monitoring at several other sites around Auckland. Annual averages from all the Auckland monitoring sites show a similar downward trend in CO over the observation period (Figure 2). Khyber Pass Road and Queen Street have the highest CO concentrations, being more traffic dominated and heavily influenced by the street canyon effect and large buildings which restrict dispersion. The other sites were in more open topography. CO monitoring stopped in Auckland during 2016 at all sites.

CO has also been monitored at other locations in New Zealand. Continuous data are mainly available from the larger towns and cities including Rotorua, Wellington and the Canterbury region. The annual maximum 8-hour moving average data is shown in Figure 3 and the annual average in Figure 4.

The data shows the highest maximum 8-hour concentration occurred at the Christchurch site of St Albans whereas the annual data plot up to 2014 shows the highest annual concentration is at the Auckland site of Khyber Pass. The reason for this difference is primarily related to the location of the sites. In these two figures, the Khyber Pass, Takapuna, Wellington Central and Queen St sites are all traffic dominated whereas the remainder are urban sites. A traffic dominated site will have higher concentrations over the entire year whereas an urban site will have higher concentrations during winter but lower concentrations in summer. All of these sites are in locations reflecting where many people live or work and are potentially exposed to pollutants. Both the 8-hour moving averages and the annual average figures show that other locations in New Zealand also have a downward trend between the 1990s and early 2000s followed by a

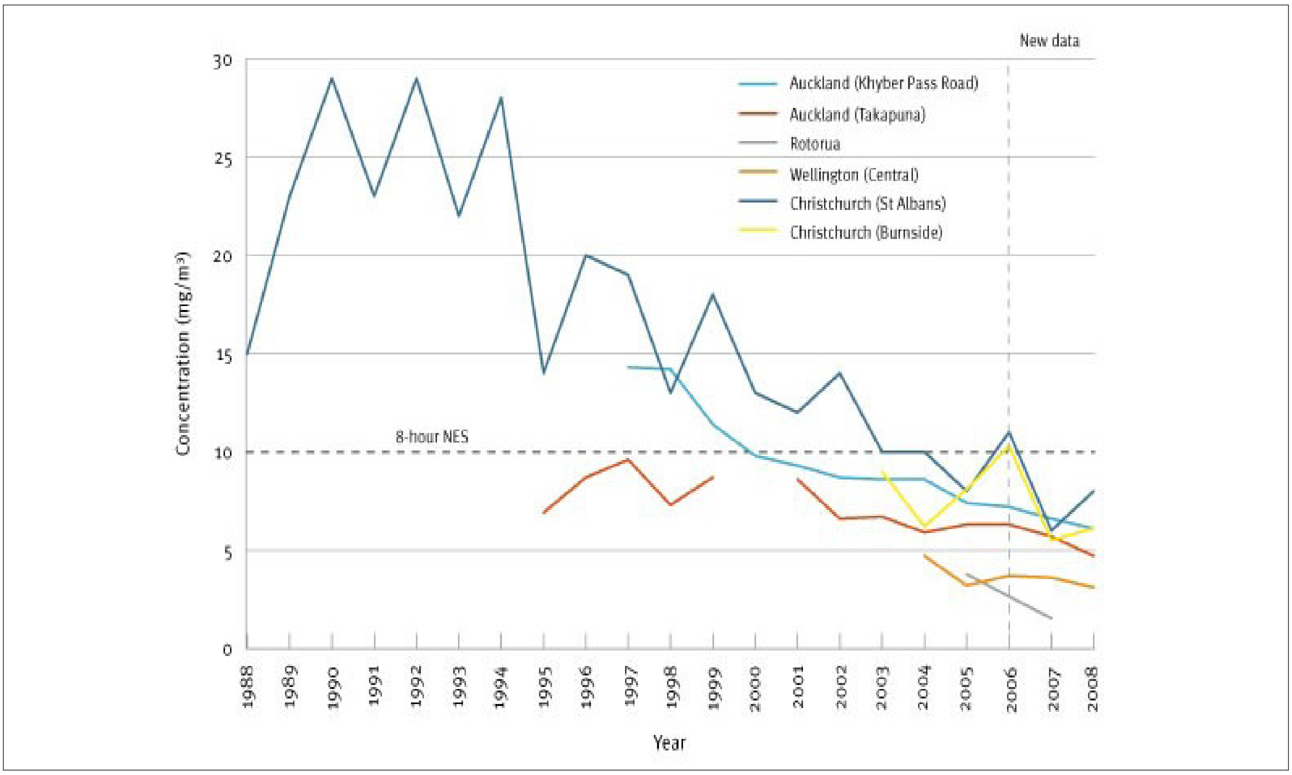

Figure 3: Annual maximum 8-hour moving average of CO for various New Zealand sites. (Graph courtesy of MfE).

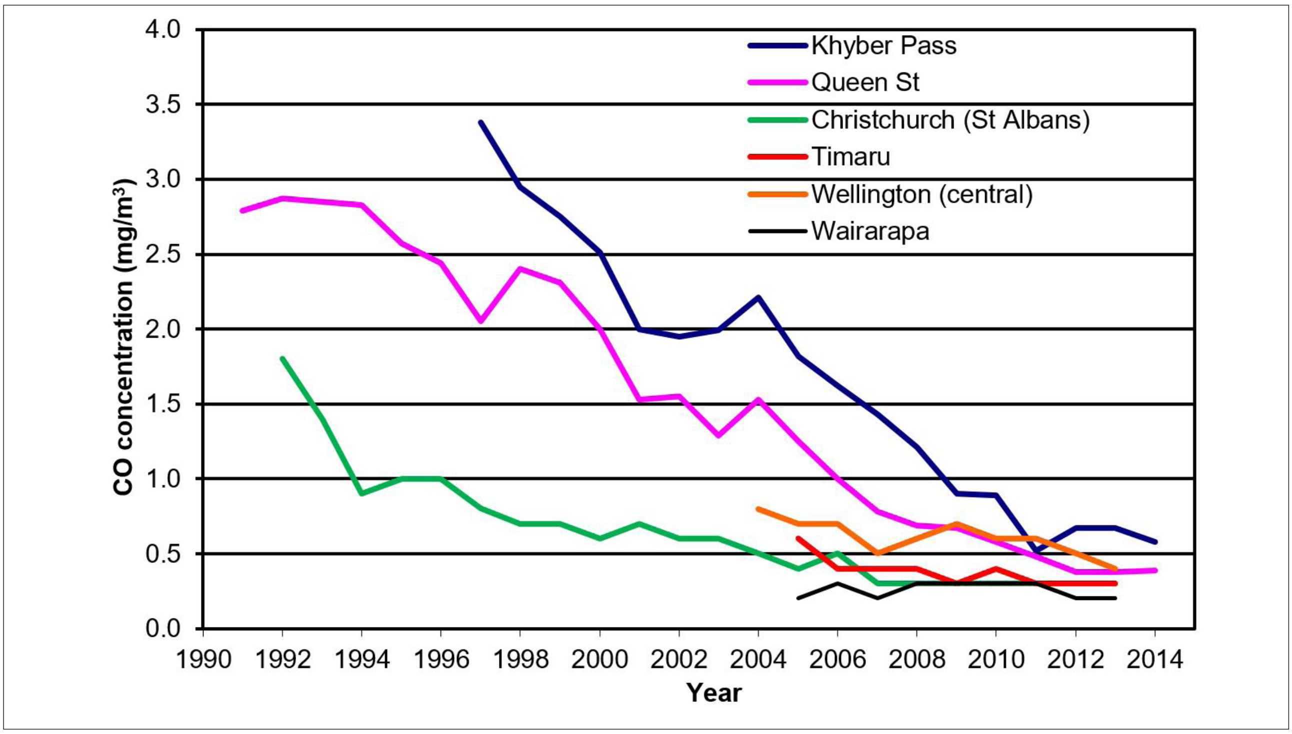

Figure 4: Annual average of CO for various New Zealand sites.

Since 2000 Christchurch has been the only location to have recorded exceedances of the 8-hour NES. This is most likely due to the effects of the local winter meteorology inhibiting the dispersal of the emissions coupled with a greater number of woodfires used for home heating in Christchurch. There have been no exceedances of the 8-hour NES in New Zealand since 2006.

4. What impacts concentrations of CO

4.1 Vehicle Exhaust Emission Rules

Through the 1990s, used imported vehicles had better exhaust emission control technology than the same model vehicles manufactured new in New Zealand; the imports were manufactured to comply with more rigorous standards that applied in their home country than the standards required in New Zealand. In the late 1990's a voluntary agreement between the government and New Zealand car manufacturers resulted in some New Zealand-new vehicles being fitted with emission control technology. The 2003 Vehicle Emission Rule (MoT, 2003) was the first requirement in New Zealand for vehicles to have a recognised emission standard: new vehicles had to be built to a minimum standard and imported used vehicles to a recognised standard.

In 2007 the Rule was changed (MoT, 2007) so that all vehicles entering the New Zealand fleet had to meet minimum standards. If an emission standard changed in a country of vehicle origin, then that standard would apply to imported new vehicles into New Zealand two years later. For used imported vehicles there was a longer lag, e.g. the Japan 2005 Standard applied to vehicles imported into New Zealand from Japan from 2012.

4.2 Changes in the vehicle fleet

In 1998 import tariffs imposed by the government were removed, making it cheaper to import vehicles. This resulted in an influx of cheaper second-hand vehicles from overseas, mainly from Japan. A large number of these imports had been manufactured in the 1995-1997 period and these imports were built to more rigorous emission control standards than New Zealand manufactured vehicles. As the number of imported vehicles increased, the overall CO emissions started decreasing. A second peak of imported used vehicles manufactured in the years 2005-2008 is now becoming evident (MoT 2016), which is partly caused by another change in the required vehicle standard (Figure 5).

Real time emissions monitoring of motor vehicles has been done in New Zealand on a campaign basis over a number of years for the New Zealand Transport Agency and Auckland Council (ARC, 2012). During the 2009 campaign, the 1995-1997 vehicle peak translated to an average vehicle age of 12-14 years. The emissions from the Japanese imports were still lower than those for a New Zealand new vehicle. It is only for vehicles manufactured since 2000 (age groups up to 8-10 years) that CO emissions from New Zealand new and Japanese used vehicles became similar and the benefit, emission-wise, from Japanese imports became less significant (Figure 6).

4.3 Catalytic converters

Catalytic converters are devices that are fitted to the exhaust system of a motor vehicle. They use chemical catalysts to convert some pollutants, including CO, into less toxic forms, such as carbon dioxide, nitrogen and water. Over the average lifetime of a vehicle a catalytic converter can reduce total emissions of CO by up to 80% (Modhavadiya et al., 2015).

Until the 2007 Vehicle Exhaust Emission Rule, there was no legislation to prevent tampering with emission systems (MoT, 2007). The earlier Japanese imports were built with emission control systems that included catalytic converters. In many cases these were removed from the

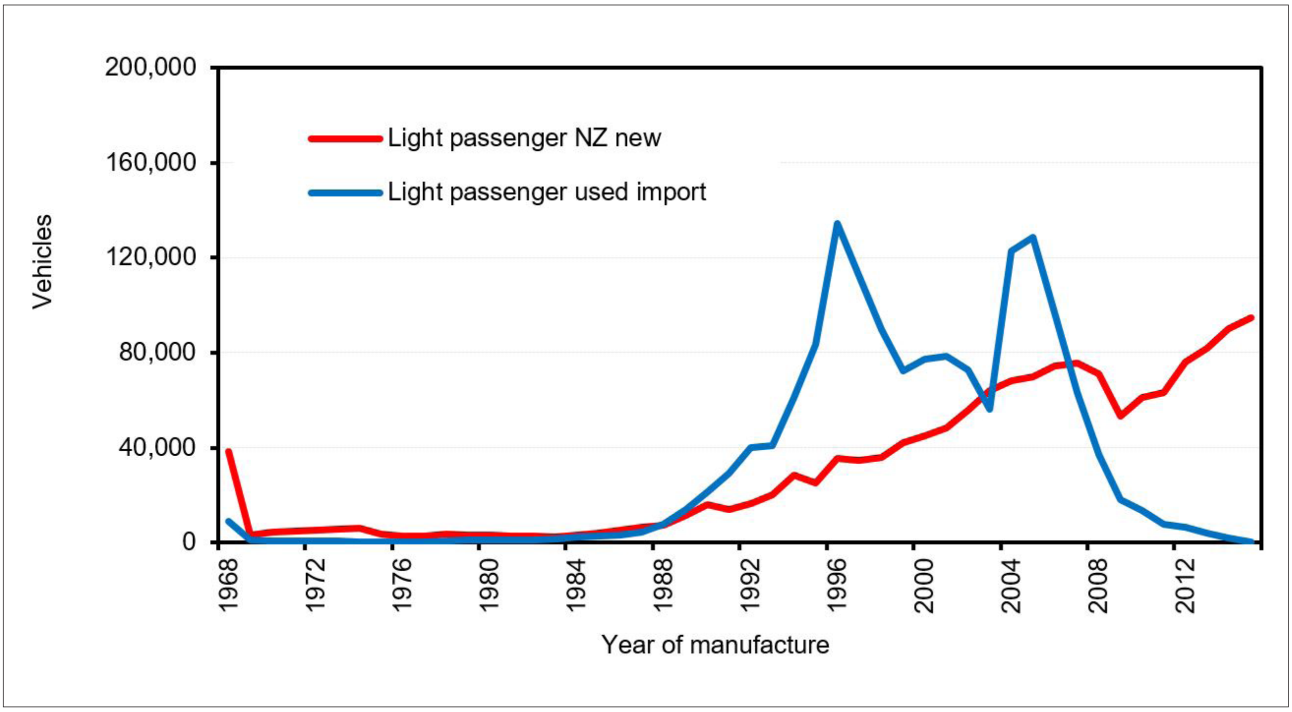

Figure 5: New Zealand vehicle fleet as at December 2015. NB The 1968 data are for years up to and including 1968.

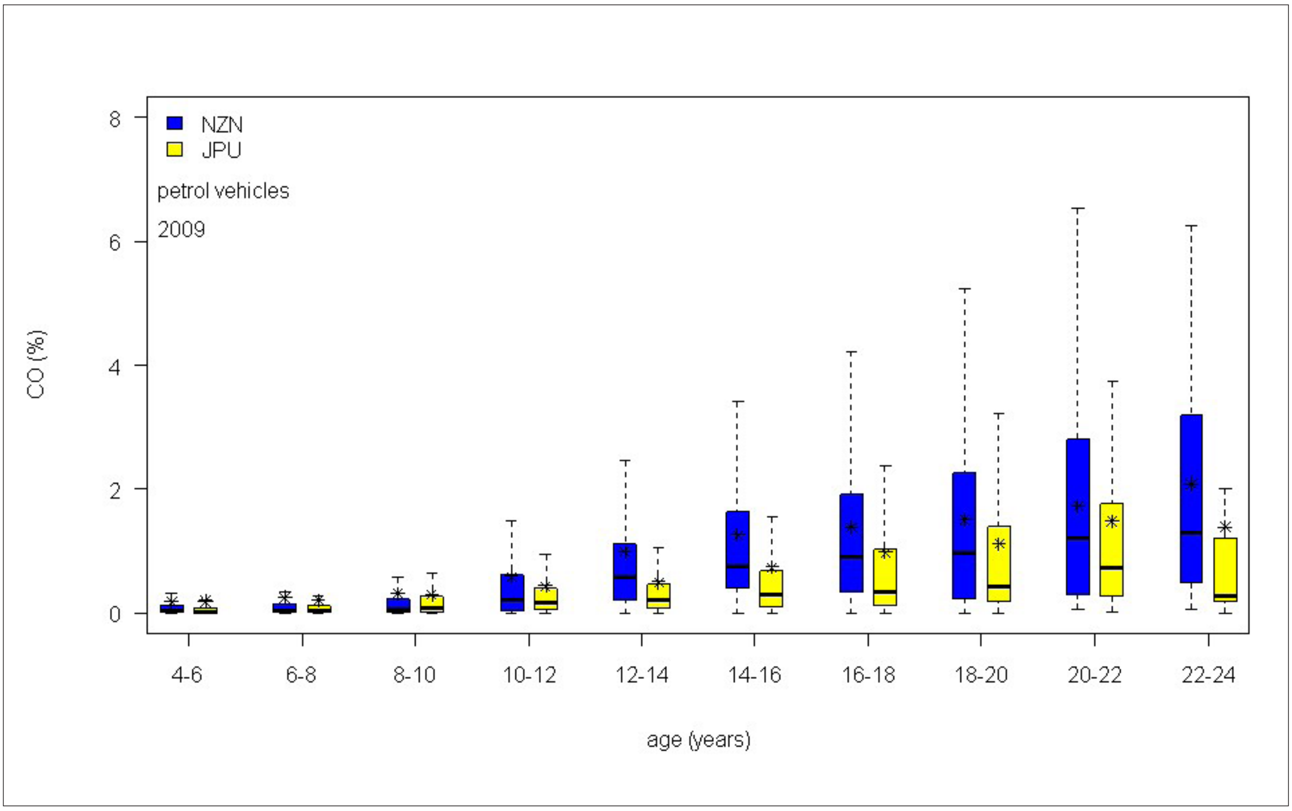

Figure 6: Vehicle age and CO emissions for Japanese used and New Zealand new petrol vehicles from the 2009 emission monitoring campaign.

vehicles as soon as they arrived in the country. This was particularly prevalent when leaded petrol was still being used. The main reason for the removal of the converter was that New Zealand drivers believed it tended to reduce the power output of the motor, and this was not popular with the New Zealand buyer (UUC, 2017).

4.4 Vehicle travel

The Vehicle Kilometres Travelled (VKT) by the New Zealand light vehicle fleet is expected to increase as the population of New Zealand increases (MfE 2009b). There was a steadying off in the late 2000s as a result of economic decline, but this has now increased again with a 5% increase in the light fleet in 2015, and a 40% overall increase since 2000 (MoT, 2016). This increase in distance travelled could lead to an increase in vehicle emissions, but improvements to engine technology, a consumer demand for lighter, smaller and more efficient vehicles, and a growing number of electric cars should result in continued low levels of ambient CO. A review of the Auckland fleet (Sridhar et al., 2014b) showed that from 2001 until 2011, even though the VKT had increased, the total CO emissions have decreased but the proportion attributed to petrol cars has remained consistent (Figure 7).

4.5 Home heating

Government incentive programmes such as "Warm Up New Zealand" (EECA, 2009), which provided subsidies for residential property owners to remove inefficient heating and replace it with cleaner more efficient options (such as electric heat-pumps and woodfires designed to burn solid fuel more efficiently) encouraged over 6000 households to take advantage of the offer during the first year in 2009. It is expected that up to 80,000 homes across New Zealand will be heated more efficiently and cleanly as a result of

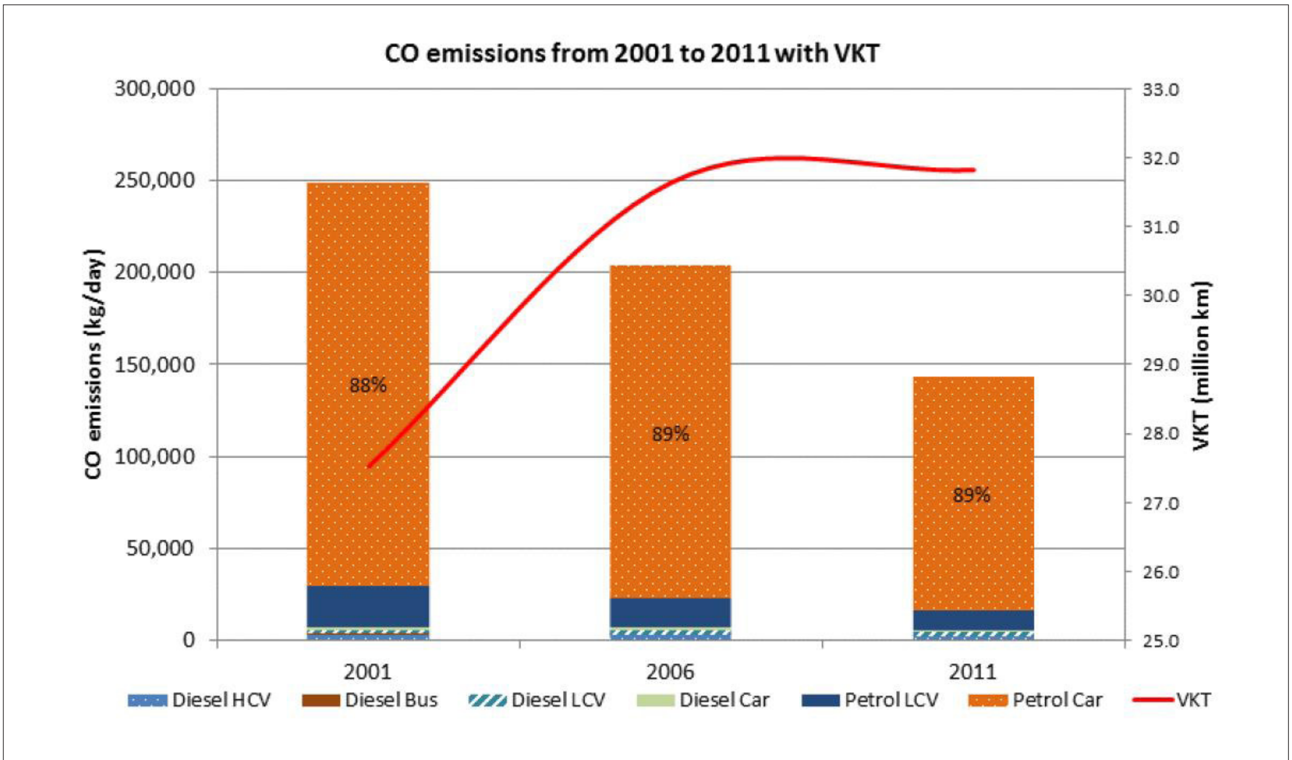

Figure 7: Vehicle age and CO emissions for Japanese used and New Zealand new petrol vehicles from the 2009 emission monitoring campaign in Auckland. Source: Sridhar et al., (2014a).

this programme (EECA, unpublished). Removing old inefficient wood-burners and open fires reduces emission of CO into the atmosphere. The reduction in CO will be more significant in more southern areas of New Zealand where winter home heating is needed more than in Auckland because of colder winter temperatures. The weather conditions in some of these cooler towns such as Christchurch, Masterton and Alexandra are also more suitable to the development of inversions which can trap and contain pollutants near ground level.

Local government programmes involving subsidies and regulations to incentivise householders to switch from solid fuels to more clean heat, especially those introduced by Environment Canterbury and Nelson City Council, have also had a large impact on improving air quality. These measures targeting domestic home heating, although successful in reducing emissions of CO, have had a relatively minor role overall compared to other measures aimed at vehicle emissions.

5. International CO decline

Overseas data have also shown that many countries have experienced a similar decline in ambient CO to that described for Auckland (Lowry et al., 2016). Figure 8 shows the Auckland Queen Street annual average CO concentrations compared to concentrations measured in London (Marylebone and North Kensington), Cardiff, and Belfast in Northern Ireland.

The Marylebone and Queen Street data track downwards at a remarkably similar rate. Marylebone Road is a very busy urban street canyon on the northern edge of the inner London congestion charge area; the sustained decline in average CO implies strict controls on vehicle emissions introduced by the UK government (the 1991 Road Vehicles Regulations, the 1997 National Air Quality Strategy and other measures such as the London congestion charge in 2003) have been effective in reducing vehicle emissions (Lowry et al., 2016).

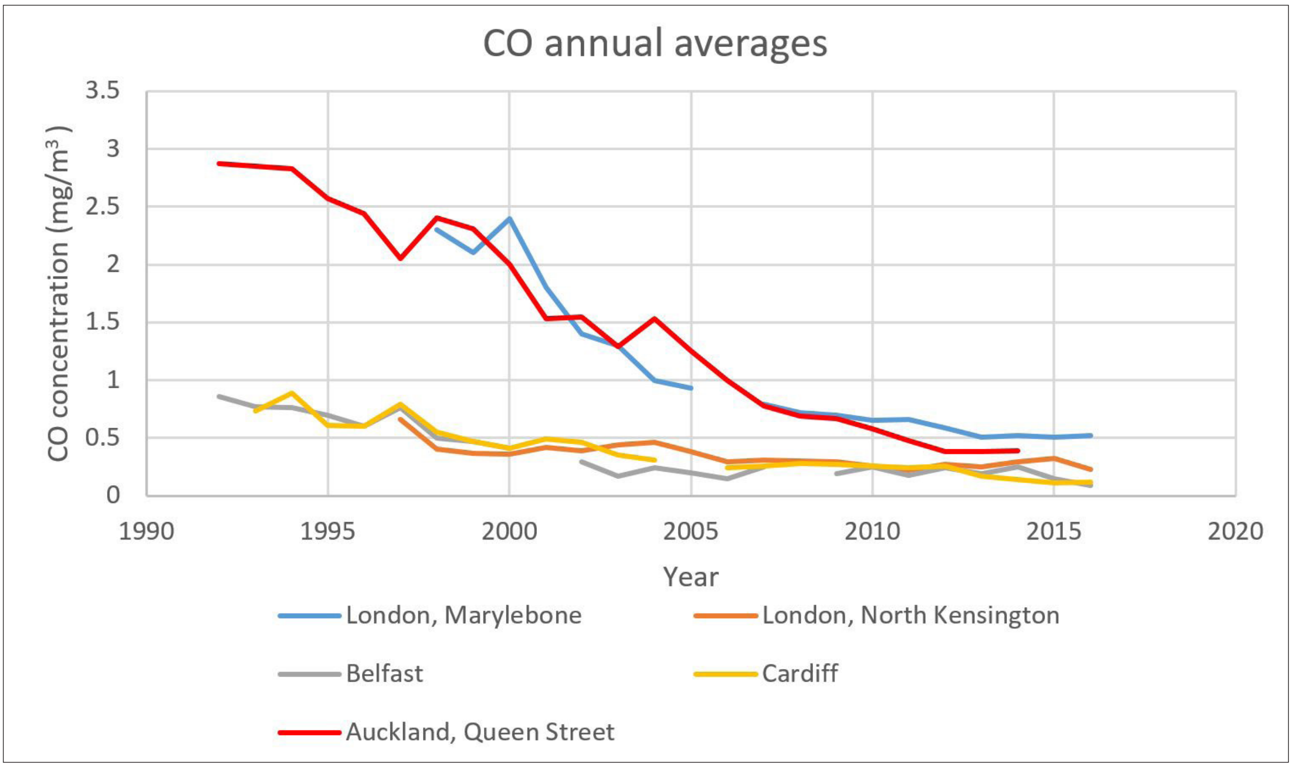

Figure 8: CO annual average concentrations in London, Cardiff, and Belfast compared to Queen Street, Auckland concentrations.

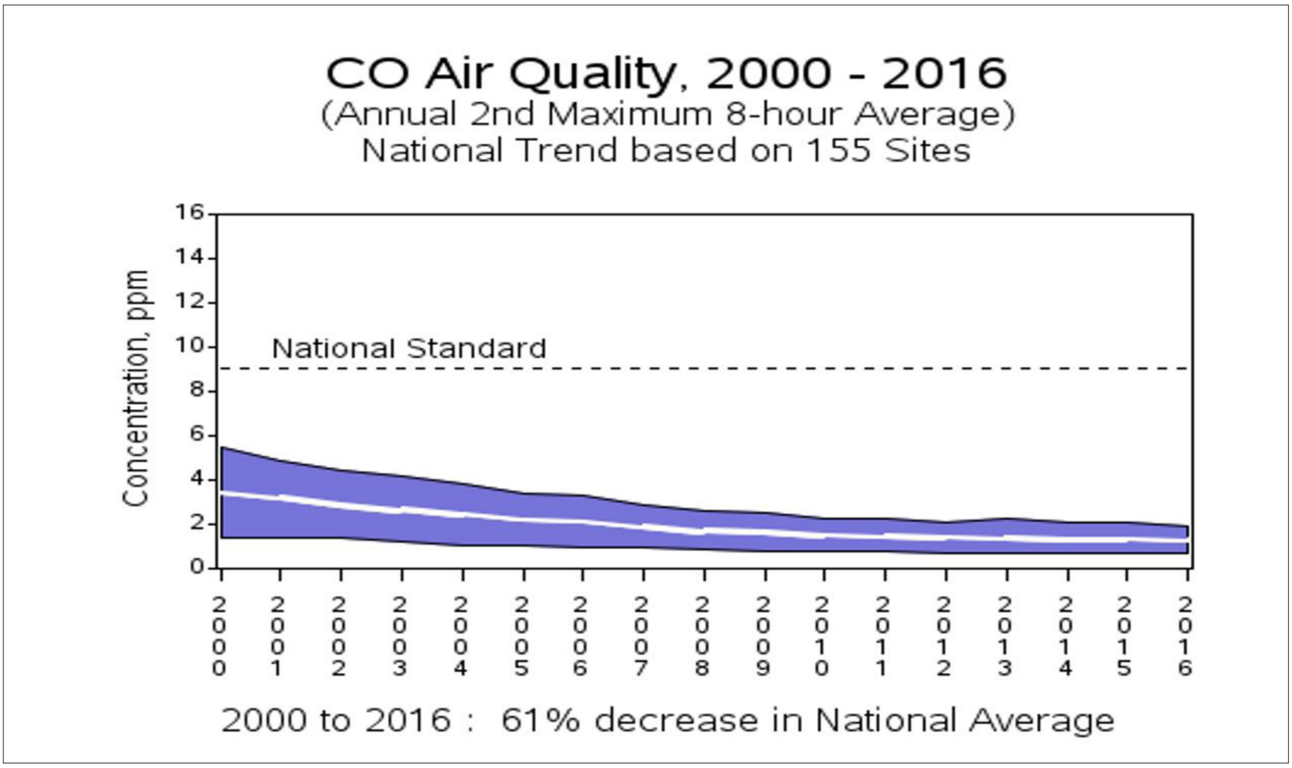

Figure 9: Ambient CO decrease in the USA. Source: EPA, 2017.

CO concentrations in major urban areas in Korea have decreased from 2001 in similar fashion (Kim et al., 2015). This rather abrupt reduction is attributed to a combination of technological improvements and government emission mitigation strategies, as well as a shift away from coal and oil burning to alternative energy fuels.

In the USA, the National Ambient Air Quality Strategy for CO, implemented in 1971, and reviewed in 1994 and 2011, has resulted in a 61% decrease in the national maximum 8-hour average concentration between 2000 and 2016 (Figure 9) (EPA, 2017).

6. Summary

The monitoring at Khyber Pass Road showed a general long-term decrease in CO concentrations. The maximum 8-hour moving average concentration dropped from 14mg/m^3 in 1997 to around 3mg/m3 in 2014 when monitoring ended. The last exceedance of the 8-hour NES was in 1999. The annual average dropped from 3.4mg/m^3 to 0.6mg/m^3 during the same time frame. This downward trend is also evident at other sites around Auckland and in other localities in New Zealand.

The decrease is largely due to changes in the vehicle fleet as a result of government legislation and international trends in improving emissions controls. In 1998 import tariffs were removed, resulting in a large number of used Japanese vehicles entering the New Zealand vehicle fleet; at this time, these imported vehicles had been built to a much more rigorous emission control standard than their New Zealand-built equivalent. Exhaust emission rules were introduced in 2003 with a later update in 2007, when all vehicles, entering the New Zealand fleet both new and used, had to meet minimum standards.

The “Environment Aotearoa” report (MfE, 2015) found that CO emissions in New Zealand from transport had declined by 46% since 2001, due to improvements to fuel and stricter emission limits on new vehicles.

The vehicle kilometres travelled (VKT) by the New Zealand light vehicle fleet is expected to increase as the population of New Zealand increases. This could lead to an increase in vehicle emissions for some contaminants, but improvements to engine technology, a consumer demand for lighter, smaller and more efficient vehicles, and a growing number of electric cars should result in continued low values of ambient CO.

Government incentive programmes to encourage households to replace inefficient solid fuel heaters with cleaner technology such as heat pumps or modern cleaner-burning woodfires, has also been a factor in the overall reduction of CO, especially during the colder winter months.

Decreases in the level of CO pollution will continue to benefit the health of the New Zealand public and reduce the level of premature mortality and hospital admissions that are directly related to the inhalation of CO. Reducing CO levels will also assist New Zealand to achieve its greenhouse reduction targets under the Paris Agreement.

Although CO is only a very weak direct greenhouse gas, it has important indirect effects on global warming. CO reacts with hydroxyl (OH) radicals in the atmosphere, reducing their abundance. As OH radicals help to reduce the lifetimes of the stronger greenhouse gases, such as methane, CO indirectly increases these gases.

The large decrease in New Zealand's ambient CO levels has occurred in a relatively short time, just over a decade, through strong targeted government legislation backed by effective scientific monitoring and advice.

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