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Estimating Emissions from Tyre Tread Wear of Motor Vehicles in New Zealand

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Abstract

Over 5.6 million road vehicles are registered in New Zealand, with a wide range of contaminants released as a result of their operation. The material wearing out from tyre tread has previously been identified as a contaminant of potential concern (COPC) in New Zealand, but its amount has not been quantified. Numerous studies confirm that the wear rate of a tyre depends on multiple factors and can vary significantly, even for the same type of vehicle with the same tyres installed. Such factors have already been classified and weighted; therefore, they were not the subject of the current research. The aim of this study is to estimate the total amount of material released into the environment in New Zealand due to the tread wear of tyres.

In this research, the New Zealand motor vehicle fleet was divided into categories according to the available statistical data. The estimation of the amount of the tyre material released into the environment was done separately in each category of vehicle, using the three-point method (Low, Medium and High). The calculation was performed using the statistical average annual distances driven by vehicles, and the tyre abrasion rates, also called emission factors (mg/km). The emission factors were adopted through a thorough review of the available studies of tyre abrasion rates in different countries.

The three-point estimate shows that every year roughly 6.5 to 15.5 thousand tonnes of material from tyre tread wear is released into the environment in New Zealand, which gives between 1.26 and 2.97 kg when converted per capita. Such quantification is an important step in understanding the impacts of this contaminant on New Zealand ecosystems. Further research of tyre tread wear material is needed with regard to its emission factors; deposition, migration and concentrations in environmental compartments; accumulation and degradation paths; effects on living organisms and human health.

Background

The amount of tyre wear particles (TWP) generated on roads can be quantified using four different methods. The first, most widely used, approach is based on the tyre abrasion rates, also called emission factors (EFs) (mg/km), combined with the statistical mileage of vehicles in a particular country or region. The tyre abrasion rates are either measured as a part of the research itself or, in most cases, are adopted from previous/existing studies. The second popular method is to calculate the volumetric difference between a new and an old tyre, together with an assumption of its mileage or lifespan and the total number of vehicles. The third approach takes into account the number and the total mass of tyres disposed of every year in a region/country, with an assumption about the percentage of the mass loss for a tyre during its on-road use. Finally, some estimations of TWP amounts are based on the dynamic probabilistic material flow modelling analysis (DPMFA) – the method that quantifies flows and stocks of materials/substances in a well-defined system, considering both temporal dynamics and parameter uncertainty.

Wagner et al. (2018) quantified TWP emissions for the European Union, Germany and the USA, using the tyre abrasion rates and the statistical mileage of vehicles. According to this research, the annual amount of TWP for the EU was 1.327 million tonnes in 2014; for Germany, 133,000 tonnes in the same year; and 1.120 million tonnes for the USA in the year 2010. The study considered either the number of registered cars (for the EU), or total travelled distances (for Germany and the USA). It was based on tyre abrasion rates, established for different categories of vehicles by Hillenbrand et al. (2005). For example, the median TWP rate for passenger cars was 90 mg/km (with a range of 53–200 mg/km), for trucks 700 mg/km (with a range of 105–1700 mg/km) and for trailer trucks 1200 mg/km (with a range of 1000–1500 mg/km). Kole et al. (2015), using tyre abrasion rates established by Deltares and TNO (2016), calculated the annual TWP generated in 2012 in the Netherlands at 15,030 tonnes/year. The same approach was used by Magnusson et al. (2016) to estimate the amount of tyre wear material in Sweden in 2016 at approximately 7674 tonnes/year. In this case, the tyre abrasion rates were adopted from the work of Gustavsson (2001). Kole et al. (2017) reviewed the available studies, collating the national estimates of the amount of tyre wear material released into the environment in different

countries and presenting the results per capita. The estimated emissions were between 0.23 kg/year for India and 4.7 kg/year for the USA, with the global average of 0.81 kg/year.

In Japan, the annual volume of rubber released into the environment from tyre wear was estimated at over 1.7 million cubic metres (Yamashita & Yamanaka, 2013). The study considered the total number of automobiles in the country (79 million), with the calculation performed in five different categories (based on Japanese classification): light automobiles, normal vehicles, trucks, buses and trailers. The calculation of tyre dust amount was based on the volumetric difference between a new and a completely worn tyre. It was a simple and straightforward quantification; however, the approach used in this study lacked important details (for example, the tyre tread void, the actual tread width and the annual mileage for different categories of vehicles were apparently not considered). Also, there was no practical validation on the proposed volumetric calculation method. These factors, together with the assumption that each category of vehicles would use just one 'standard-sized' tyre and all would have a lifespan of five years, led to a rather rough estimate, which probably satisfied the purpose of the research.

The United Kingdom Environment Agency (1998) calculated the amount of TWP using the number and mass of tyres disposed annually (37 million and 380,00 tonnes respectively), together with the assumed 10–20% of mass loss for a tyre during its road use. The result of the estimate was between 38,000 and 76,000 tonnes of TWP per year.

A research team from Empa-Swiss Federal Laboratories for Materials Science and Technology (Sieber et al., 2020), using DPMFA, estimated that around 10,600 tonnes of tyre abrasion particles were generated in Switzerland in 2018, making it the largest source of rubber released into the environment. Three vehicle categories were considered in this research: passenger cars, light-duty vehicles (vans) and heavy-duty vehicles (trucks), with the assumed tyre lifespan of four years. The same team has also calculated that, over the last 30 years, from 1988 to 2018, around 200,000 tonnes of micro-rubber (97% coming from tyre dust) have accumulated in the environment in Switzerland (Sieber et al., 2020). Material flow modelling is an advanced scientific method to predict and quantify the flows of materials into the environment. However, the results obtained using this approach could be challenging for understanding and verification by engineers and practical specialists from the transportation industry, who are not familiar with DPMFA.

One of the most comprehensive literature reviews, regarding TWP emissions, was funded by the German Federal Ministry of Transport and Digital Infrastructure, and conducted by Baensch-Baltruschat et al. (2020). They found that the available studies of tyre abrasion rates often do not provide sufficient information about the origin of data and the applied measurement methods, which raised the question about the validity of all those results. The authors' compilation of published TWP emissions for different countries showed the range from 0.2 to 5.5 kg/per capita, with the global estimation at almost 6 million tonnes.

In New Zealand, the emission of TWP began to gain interest from the scientific community in the 1990s. Cenek et al. (1997) conducted a research project considering the methods to determine the pavement surface

abrasiveness characteristics of New Zealand roads. Measurements of tyre rubber loss were attempted, but the obtained results were deemed to be insufficient to derive conclusions. A previous study of tyre wear on New Zealand roads (Cenek et al., 1993) included the driving test of one car (a 1985 Nissan Pulsar) on two routes of different severity (Aotea Quay, Wellington, to Palmerston North and Haywards, Wellington, to Featherston). The reported tread wear rate for a tyre was 4.0–5.6 mg/km for the first, low-severity, route, and between 19.9 and 38.4 mg/km for the second, high-severity, route (Cenek et al., 1993, as cited in Kennedy et al., 2002). The tread wear rate of under 6 mg/km is around ten times lower when compared to other studies. Unfortunately, this report is not available to review the research methods and to further comment on the results.

Carpenter and Cenek (1998) proposed a method to calculate the increased tyre wear in congested traffic conditions (frequent starts and stops) for the existing Highway Development and Management Model (HDM-4). Using this method, the volumetric tread wear rates for a tyre were calculated at 32 cm^3/1000 km for a medium car, 48 cm^3/1000 km for a motorcycle and 111 cm^3/1000 km for a heavy truck. This allowed tyre lifespan estimates of 12,000 km for a motorcycle, 47,000 km for a medium car, and 119,000 km for a heavy truck. Although the tyre lifespan values for a motorcycle and a heavy truck were not obtained by direct measurements, the authors claimed that their estimates were confirmed by New Zealand motor-industry representatives.

Tyre tread wear, as one of the emission factors from motor vehicles, was included in a report prepared for the New Zealand Ministry of Transport by Kennedy et al. (2002). A detailed analysis of available studies and their results from New Zealand and abroad was performed. It was summarised, for example, that different routes and driving styles can change the wear rate for the same tyres by a factor of ten. The authors also reported the average mass-loss for a tyre during its complete lifespan on New Zealand roads: 1.1 kg for a car, 1.8 kg for a light truck and 7.5 kg for a heavy truck. It was stated that these values were identified in collaboration with industry, but, unfortunately, no other details (sources, data collection and processing methods, etc.) were provided in the report.

New Zealand's National Institute of Water and Atmospheric Research (NIWA) conducted a detailed literature analysis on non-exhaust emissions (NEE), including particulate matter from brakes, tyres and road-surface wear (Semadeni-Davies et al., 2021). The goal of this study (called Stage 1) was to review the existing NEE data, identifying the knowledge gaps and developing recommendations to address those gaps at the next stage, so no attempts were made to measure EFs or to calculate the total tyre wear emissions in New Zealand.

A critical review of the literature has not found any estimates of the total amount of tyre wear material emitted by motor vehicles in New Zealand, which allows this to be established as a research aim for the current study.

Research Methods

To calculate the amount of tyre wear material emitted by fleet of motor vehicles in New Zealand, the first method discussed in the previous section was selected, which requires the application of tyre abrasion rates, also called emission factors (EFs) (mg/km), and the average annual distance driven by a vehicle. The tyre abrasion rate depends on multiple factors; the most important are the route and style of driving, road surface, seasonal influences, vehicle characteristics, and tyre size and quality. Despite the seeming abundance of available studies regarding EFs, critical analysis of the literature shows that the majority of these are just some form of review or application of data/results available from other studies, and not the EF parameters measured during the research itself. Mennekes and Nowack (2022) conducted a systematic and comprehensive literature review that resulted in publishing the research paper with the self-explanatory title "Tire wear particle emissions: Measurement data where are you?" They found that out of 63 studies, which were used/referenced to calculate tyre wear particle (TWP) emissions in different countries since the year 2000, only nine studies measured tyre abrasion rates and none of them were peer reviewed. In New Zealand, researchers from NIWA (Semadeni-Davies et al., 2021) came to a similar conclusion, stating that most of the data about non-exhaust emissions (including tyre wear) are derived from studies conducted in Europe between the 1990s and 2000s, so the resulting emission factors may have limited validity for the current New Zealand fleet.

Tyre emission factors adopted for the current research are based on the following five studies (Table 1), which were selected through a thorough literature review, using two criteria:

1. The study had to be relatively new, accommodating the most significant changes in tyre technology (for example, the introduction of radial tyres and important developments in tread-compound composition).
2. The preference is given to emission factors being obtained through direct, multiple experiments by driving a fleet of vehicles on general roads and measuring/weighing the tyres periodically.

Table 1. Studies selected for sourcing tyre emission factors.

Study	Categories of vehicles	Region and driving conditions	Research methods	Emission factors per vehicle, mg/km min–max (average)	Additional information	Limitations
Gebbe & Hartung, 1997 (as cited in Baensch-Baltruschat et al., 2020)	a) Passenger cars b) Vans c) Buses d) Trucks e) Lorries	Germany Urban roads	Real driving conditions. Tyre tread loss was measured, re-calculated into mass loss and related to the mileage of the tyre.	a) (53) b) (107) c) (344) d) (1092) e) (539)	Large number (around 350) of vehicles tested.	Considered to be one of the most reputed studies of tyre EFs. However, the report could not be found. The request was made through libraries participating in OCLC WorldShare and directly with the institute that made the report.
Luhana et al., 2004	Passenger cars	Sweden Mixed urban, rural areas and motorways	Regular driving on the road for one year, covering between 16,000 and 48,000 km. The tyre mass loss was directly measured every two months.	56–193 (97)	For FWD cars, the average wear rate of the front tyres was significantly higher (up to 5.5 times) than wear rate of the rear tyres.	Small sample size. On-rim weighing with no pressure check mentioned.
ADAC, 2022	Passenger cars	Germany Test circuit (60% urban and suburban traffic, 40% motorway)	Direct, multiple measurements every 2,500 km of tyres' mass and tread loss during 15,000 km of convoy driving.	59–171 (120)	Almost 100 different tyres (summer, winter and all-season) from 15 manufacturers tested. Winter tyres showed significantly higher abrasion rates than summer tyres.	Press release only – full article with all data and details was not available. Only good-quality tyres from reputable brands were tested.
Hillenbrand et al., 2005	a) Passenger cars b) Vans and trucks c) Trailer trucks d) Buses	N/A	Literature review	a) 53–200 (90) b) 107–1500 (700) c) 1000–1500 (1200) d) (700)	–	Widely cited research, but the EFs are based on review and analysis of other studies.
Deltares and TNO, 2016	a) Passenger cars b) Vans c) Buses d) Trucks e) Lorries f) Motorcycles g) Mopeds	N/A	Literature review	a) 90–140 (100) b) 108–170 (140) c) 300–440 (360) d) 580–900 (600) e) 450–700 (495) f) 40–65 (50) g) 10–14	Maximum and minimum values refer to EFs on urban roads and rural roads respectively. The values represent the total emissions (coarse and airborne dust).	Recognised research in tyre wear emissions; however, the EFs are based on the review and analysis of other studies that cannot be retrieved.

The estimation of emissions from tyre tread wear of motor vehicles in New Zealand was performed in the following steps:

1. The New Zealand motor vehicle fleet was divided into categories according to available statistical data from the Ministry of Transport (2020a; 2020b).
   a. Light passenger vehicles (LPVs) – this category includes all passenger cars/vans with the GVM up to 3500 kg.
   b. Light commercial vehicles (LCVs) – covers goods vans/trucks/utility vehicles/motor caravans and buses with the GVM up to 3500 kg. It was divided into two sub-categories, representing the majority of LCVs in New Zealand – utility vehicles and goods vans.
   c. Trucks – this category includes the following types of vehicles with the GVM over 3500 kg: passenger car/van, goods van/truck/utility, and motor caravan.
   d. Buses – covers buses and minibuses with the GVM over 3500 kg.
   e. Motorcycles – includes two- and three-wheelers with engine capacity over 50 cc. All-terrain vehicles (ATVs) and mopeds were not considered.
   f. Trailers – includes full-, semi-, simple- and pole-trailers with the GVM over 3500 kg and the number of axles between two and eight.
2. The number of vehicles in New Zealand and in Auckland for each category was retrieved from the Motor Vehicle Register (Waka Kotahi New Zealand Transport Agency, 2023).

3. Tyre emission factors (EFs) per vehicle were adopted from the sources explained in Table 1. The chosen 'High' and 'Low' EFs do not represent the extreme values observed, but rather the typical high and low EFs confirmed across multiple selected studies. For example, the maximum EFs for passenger cars from Table 1 were 193, 171, 200 and 140 mg/km. So 160 mg/km was adopted as the typical high but not an extreme value for the current estimate. The 'Medium' EFs were derived from the above-mentioned studies, where they are called either 'average' or 'median'.
4. The average annual distance driven by a vehicle is calculated by dividing the annual vehicle-kilometres travelled by the number of registered vehicles in New Zealand from the Annual Motor Vehicle Fleet Statistics (Ministry of Transport, 2020a). It is based on data prior to Covid-19 lockdowns, and the results applied are the same for New Zealand and Auckland estimations. Data about the annual mileage for trailers could not be found, so were taken the same as for trucks.
5. The total emission of tyre material is considered without subdividing it into emission groups (coarse particles, airborne particles, gaseous emissions).
6. The factors affecting tyre wear emission rates were not considered directly, but accounted for by using Low, Medium and High tyre emission factors.

Results and Discussion

Table 2. Estimation of tyre tread wear emissions of motor vehicles in New Zealand, including Auckland.

Vehicle category		Number of registerd vehicles, NZ	Average annual distance driven by a vehicle	Tyre material emission factors per vehicle			Tyre material emissions per vehicle annually			Tyre material emissions per fleet annually, New Zealand		
		–	*km × 10³*	*mg / km*			*kg / year*			*t / year*		
		–	–	Low	Medium	High	Low	Medium	High	Low	Medium	High
		VN_{NZ}	AD	VEF^{low}	VEF^{md}	VEF^{high}	VEA^{low}	VEA^{md}	VEA^{high}	–	–	–
		–	–	see Table 1			$VEF^{low} \times 10^{-3} \times AD$	$VEF^{md} \times 10^{-3} \times AD$	$VEF^{high} \times 10^{-3} \times AD$	$VEA^{low} \times 10^{-3} \times VN_{NZ}$	$VEA^{md} \times 10^{-3} \times VN_{NZ}$	$VEA^{high} \times 10^{-3} \times VN_{NZ}$
Light passenger		3,592,000	11.7	70	120	160	0.819	1.404	1.872	2942	5043	6724
Light commercial	utility	550,300	15.2	70	120	160	1.064	1.824	2.432	585	1003	1338
	goods vans	203,500		90	140	180	1.368	2.128	2.736	278	433	557
Trucks		175,000	20.7	600	1000	1500	12.420	20.700	31.050	2174	3622	5434
Trailers		40,000	20.7	600	1000	1500	12.420	20.700	31.050	497	828	1242
Buses		11,700	28.0	300	450	600	8.400	12.600	16.800	98	147	197
Motorcycles		146,000	3.0	45	50	65	0.135	0.150	0.195	19	22	28
Total:										**6593**	**11,098**	**15,520**

Table 3. Estimation of tyre tread wear emissions of motor vehicles in Auckland.

Vehicle category		Number of registerd vehicles, Auckland	Average annual distance drivenby a vehicle	Tyre material emission factors per vehicle			Tyre material emissions per vehicle annually			Tyre material emissions per fleet annually, Auckland		
		-	*km x 10 ³*	*mg / km*			*kg / year*			*t / year*		
		–	–	Low	Medium	High	Low	Medium	High	Low	Medium	High
		VN_{AKL}	AD	VEF^{low}	VEF^{md}	VEF^{high}	VEA^{low}	VEA^{md}	VEA^{high}	–	–	–
		–	–	see Table 1			$VEF^{low} \times 10^{-3} \times AD$	$VEF^{md} \times 10^{-3} \times AD$	$VEF^{high} \times 10^{-3} \times AD$	$VEA^{low} \times 10^{-3} \times VN_{AKL}$	$VEA^{md} \times 10^{-3} \times VN_{AKL}$	$VEA^{high} \times 10^{-3} \times VN_{AKL}$
Light passenger		1,191,800	11.7	70	120	160	0.819	1.404	1.872	976	1673	2231
Light commercial	utility	132,100	15.2	70	120	160	1.064	1.824	2.432	140	241	321
	goods vans	48,900		90	140	180	1.368	2.128	2.736	67	104	134
Trucks		50,000	20.7	600	1000	1500	12.420	20.700	31.050	621	1035	1552
Trailers		9300	20.7	600	1000	1500	12.420	20.700	31.050	115	193	289
Buses		2450	28.0	300	450	600	8.400	12.600	16.800	21	31	41
Motorcycles		34,500	3.0	45	50	65	0.135	0.150	0.195	4	5	7
Total:										1944	3282	4575

The three-point estimate shows that, every year, roughly 6.5 to 15.5 thousand tonnes of material as tyre tread wear is released into the environment in New Zealand, with light passenger vehicles contributing around 45% to the total amount (Figure 1). The bulk of the tyre tread wear material would be emitted as coarse particulate matter, 10 to 350 µm in diameter (Kreider et al., 2010). Together with the material worn out of the road surface, this creates compounds known as tyre and road-wear particles (TRWP), which are mainly released into soils near roads and into aquatic compartments. The mechanism through which TRWP are further transported from freshwater into the marine environment, and the impacts on ecosystems, are still unclear (Baensch-Baltruschat et al., 2020) and will be of a particular interest for New Zealand.

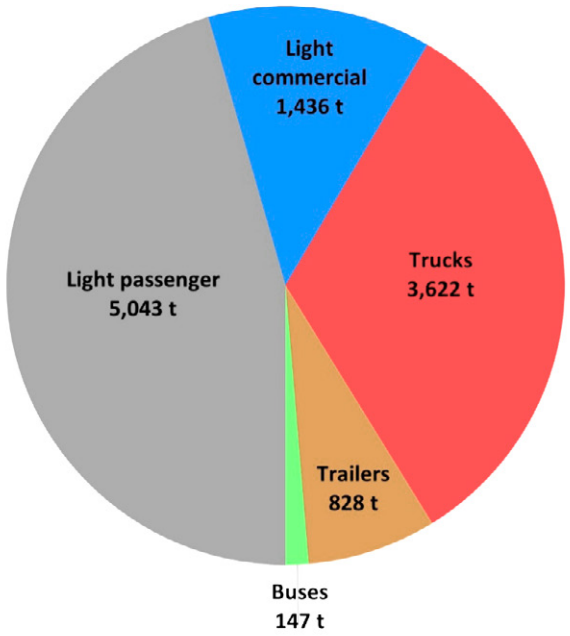

Figure 1. Annual emissions of tyre tread wear by different categories of vehicles in New Zealand (medium estimate).

The tyre wear particles that stay airborne and would be respirable (smaller than 10 µm in diameter) account for up to 10% by mass of total tyre wear emissions (Panko et al., 2013), so the estimate for New Zealand is between 650 and 1,550 tonnes of respirable TWP yearly. According to Baensch-Baltruschat et al. (2020), the risk for human health via inhalation of such particles is considered low; however, the information regarding the long-term effects on health caused by intake via the food chain is not available.

Expressing emissions of tyre tread wear per capita (kg per person per year) allows comparison for different countries. The performed estimate gives between 1.24 and 2.97 kg (2.12 kg medium, Figure 2) for New Zealand, which is close to the results for Japan (Kole et al., 2017). The per capita values for tyre tread emissions are influenced by many factors, and the most important are the level of automobilisation, distances travelled, availability and use of public transport and other modes of goods/cargo transportation (railways, marine, aviation).

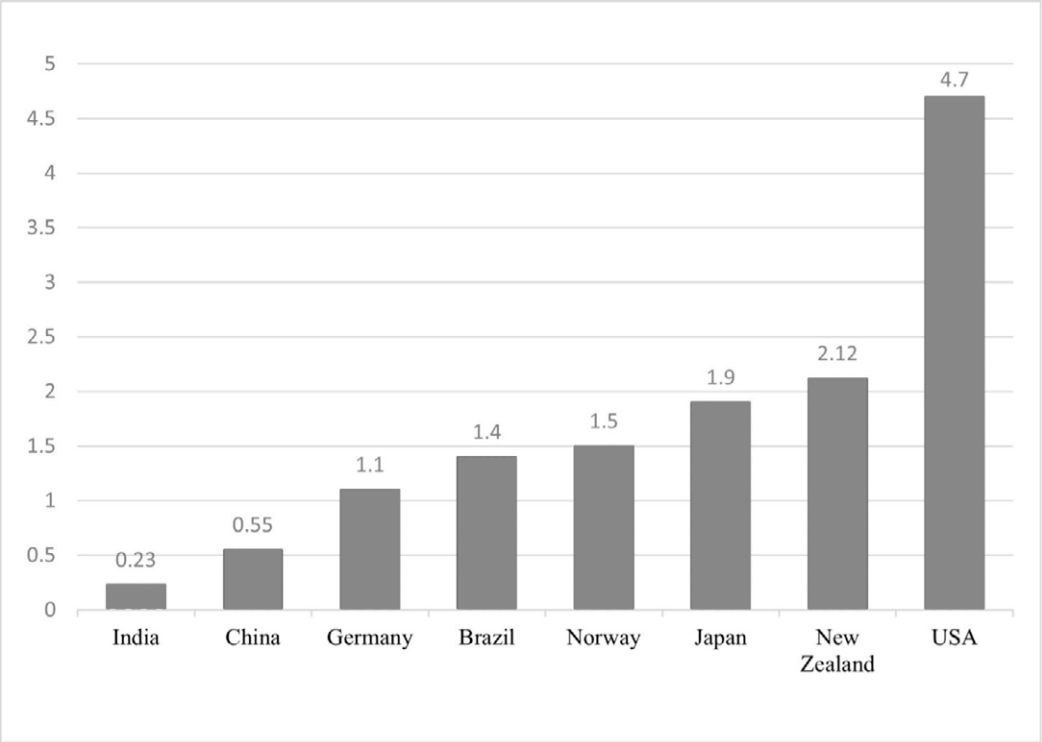

Figure 2. Tyre tread emissions per capita, kg/person/year (data for other countries adopted from Kole et al., 2017).

The tyre emission factors (EFs) adopted for the current research were selected from the available and widely cited studies completed in other countries. However, such studies are scarce, their methods are rather unclear, and the results are often hard to verify. Also, the EFs established in other countries may not accurately represent the actual situation in New Zealand regarding its road surfaces, climate, terrain and other conditions that would influence tyre abrasion rates. To reduce this uncertainty and to provide a more precise estimate, a study of the real-world emission factors for tyres in New Zealand is required.

Conclusion

The estimation of the amount of tyre wear material emitted on New Zealand roads was performed using the statistical average annual distances driven by vehicles, and the emission factors (mg/km). The EFs were adopted via thorough analysis of the available studies of tyre abrasion rates. The three-point estimate shows that every year roughly 6.5–15.5 thousand tonnes of material as tyre tread wear is released into the environment in New Zealand, and around 10% of that amount would be airborne particulate matter. The tyre emission factors are characterised by a high degree of uncertainty – the available data are very limited (especially for heavy vehicles), most of the studies are over 20 years old and were conducted on European roads. Establishing the real-world emission factors for tyres in New Zealand, as the next possible stage for this research, would allow the current estimate to be narrowed.

LIST OF ABBREVIATIONS AND ACRONYMS

ATV	All-terrain vehicle
COPC	Contaminant of potential concern
DPMFA	Dynamic probabilistic material flow modelling analysis
EF	Emission factor
GVM	Gross vehicle mass
HDM	Highway Development and Management Model
LCV	Light commercial vehicle
LPV	Light passenger vehicle
NIWA	National Institute of Water and Atmospheric Research
NEE	Non-exhaust emission
TRWP	Tyre and road wear particles
TWP	Tyre wear particles

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