Memorandum

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Subject
Potential benefits of energy-efficient tyres and correct tyre pressure maintenance for the municipal fleet of Amsterdam

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Summary

In two previous studies performed by TNO and M+P, it has been shown that energy-efficient tyres can have a large effect on the fuel consumption of Dutch and EU road transport. In this study, the specific fuel savings potential is calculated for the municipal fleet of Amsterdam. Apart from energy-efficient tyres (as indicated by the tyre label), the impact of correct tyre pressure maintenance on the municipal fleet of Amsterdam are studied. This memo documents the order-of-magnitude fuel savings potential of both measures.

The municipal fleet of Amsterdam consists of 908 vehicles of which 781 have been included in the calculations of this study. In total, these 781 vehicles drive a cumulative annual mileage of 13 million kilometres which corresponds to an average mileage of 17200 kilometres per year per vehicle.

The results show that energy-efficient tyres and tyre pressure have a large impact on fuel consumption. The use of energy-efficient tyres in the municipal fleet of Amsterdam could annually **save up to 113 thousand litres of fuel and reduce CO_2 emissions by roughly 291 ton**, an equivalent of about 4% of the annual CO_2 emissions from the municipal fleet of Amsterdam. Maintaining the required tyre pressure for vehicles in the Amsterdam fleet could annually **save up to 33 thousand litres of fuel and reduce CO_2 emissions by roughly 86 ton**, an equivalent of about 1%. When combined the measures could annually **save up to 147 thousand litres of fuel and reduce CO_2 emissions by roughly 379 ton**, an equivalent of roughly 5% of the annual CO_2 emissions of the municipal fleet of Amsterdam. The annual fuel cost savings from switching to energy-efficient A-label tyres would be in the order of **173 thousand Euros** and approximately **51 thousand Euros** for the maintenance of the required tyre pressure. Combining the two measures results in annual fuel costs savings of roughly **224 thousand Euros**.

Given the large potential benefits of energy-efficient tyres, an accelerated market uptake could help in making road transport more environmentally friendly, safer and quieter. Whether the full potential can be realized in practice largely depends

on the vehicle's driving behaviour and the degree to which advertised tyre label values comply with EU-mandated values. The calculated savings potential of energy-efficient tyres is in the same order-of-magnitude of on-road measurements performed by TNO for light-duty and heavy-duty vehicles.

1. Introduction

In two previous studies performed by TNO and M+P it was determined that large cost savings and CO_2 reductions can be achieved in the Netherlands and in the EU by switching to energy-efficient tyres [TNOa, 2014][TNOb, 2014]. Apart from the choice of the tyre, correct tyre pressure maintenance plays a significant role for optimized fuel consumption. The Dutch government has a clear vision for sustainable transport in 2020 and 2030 [BSV, 2015]. Energy-efficient tyres as well as correct tyre pressure maintenance can contribute to this vision and are considered low hanging fruit with little extra costs and large impact. Based on these insights, a number of governmental and municipal fleet owners have shown interest in the implementation of tyre-related measures.

Aim and scope
This report is part of a study where the potential benefits of energy-efficient tyres and correct tyre pressure maintenance are quantified for three specific vehicle fleets:

- the vehicle fleet of the Dutch National Road Authority (RWS);
- the municipal fleet of Amsterdam;
- the municipal fleet of Rotterdam.

This memorandum solely reports the potential benefit for the municipal fleet of Amsterdam. The potential benefit of the municipality of Rotterdam and RWS are documented and published separately.

Benefits are calculated for the following measures:

- Switching from average (D-label) tyres to energy-efficient A-label tyres;
- Correct tyre pressure maintenance.

Benefits are expressed in terms of fuel savings: reduced fuel consumption (in litres), fuel cost savings for the end-user (in Euros) and CO_2 reduction (in tons).

Approach
The savings potential of energy-efficient A-labelled tyres is determined based on the average distribution of tyre labels in the Netherlands as determined in the previous Triple-A studies. The savings potential of correct tyre pressure maintenance is determined based on the average tyre pressure distribution of vehicles on Dutch and European roads.

Structure
This report is structured in the following way: In chapter 2, an overview is given of the methodology and assumptions that are used in order to determine the savings potential. Results are displayed and discussed in chapter 3. Items for conclusion, discussion and recommendations are documented in the final chapter 4. A short note of acknowledgements is added in chapter 5.

2. Methodology and assumptions

This chapter describes the methodology and assumptions used for the calculation of the savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance.

The fuel savings of energy-efficient tyres and correct tyre pressure maintenance are calculated separately and in combination. Apart from the knowledge of the impact of tyre choice and tyre pressure (as determined in the previous chapter), the following knowledge is required:

- fleet composition (annual mileage, average fuel consumption)
- distribution of tyre labels across the fleet;
- distribution of tyre pressure across the fleet;
- savings potential of energy-efficient A-label tyres;
- savings potential of correct tyre pressure maintenance;
- combined savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance;
- fuel costs.

Below, the available information on the municipal fleet of Amsterdam is discussed. Where specific data is not available, explicit assumptions are made based on national default values.

2.1. Fleet composition

Information on the Amsterdam municipal fleet composition was gained directly from Amsterdam Municipality. The database contains the following entries:

- vehicle brand and model;
- real world fuel consumption;
- expected and actual yearly mileage;
- start and end date of leasing.

An overview of the Amsterdam vehicle fleet is provided in Table 1.

Table 1: Amsterdam vehicle fleet (status March 2015) aggregated per general vehicle category: Number of vehicles, (summed) annual mileage, average fuel consumption

Tyre class	Vehicle Category	Number of vehicles	Annual mileage	Average fuel consumption
		[#]	[kms]	[l/100 km]
C1	Passenger cars (petrol)	234	4,048,000	6.7
	Passenger cars (diesel)	13	408,700	6.2
	Service delivery (petrol)	24	297,400	11.1
	Service delivery (diesel)	365	5,026,400	10.7
C3	Heavy-duty truck (diesel)	145	3,616,400	55.2

SUBTOTAL	781	13,396,900
EXCLUDED	127	n/a
TOTAL	908	13,396,900

In total, the municipal fleet of Amsterdam fleet consists of 908 vehicles. The largest share of vehicles are cars and vans. A small share of the vehicle fleet consists of heavy-duty trucks. 127 vehicles are excluded from further calculations because data was either not available or not applicable. This was the case for 77 cleaning vehicles and 50 mopeds.

In a few cases, the available data on fuel consumption was conditioned to correct for faulty or lacking entries. Fuel consumption entries in the database were considered faulty if the fuel consumption was lower than the type approval value or higher than one and a half times the type approval value plus a certain factor. This factor was taken to be 2 l/100km for passenger cars and 1.5 l/100km for service delivery vans. For trucks the faulty value was replaced by the value of a similar vehicle which had a realistic real world fuel consumption.

The reduction potential of energy efficient tyres and correct tyre pressure maintenance also depend on the driving behaviour. This is expressed in terms of the share of kilometres driven on urban and highway roads. For the municipal fleet of Amsterdam no specific data was available on the actual shares per road type. However, since these vehicles are mainly used within the city, it is assumed for all vehicle categories that 90% of the kilometres are driven in urban areas and 10% on highways.

2.2. Distribution of tyre labels across the fleet

The distribution of tyre labels was assumed to be the same as in [TNOa, 2014].

2.3. Distribution of tyre pressure across the fleet

The distribution of tyre pressure in the Amsterdam fleet was assumed to be the same as for the Dutch fleet (light duty) and EU fleet (heavy duty), unless more specific knowledge was available. The tyre pressure distribution for Dutch passenger cars is reported in [GRRF, 2008] and shown in Figure 1 as a function of the difference between recorded pressure and recommended pressure. Based on this data, approximately 30% of the cars on the road drive with an under-inflation of up to 10%. The tyre pressure distribution heavy duty trucks was assumed to be the same as reported in [TPMS, 2013] and is also shown in Figure 1.

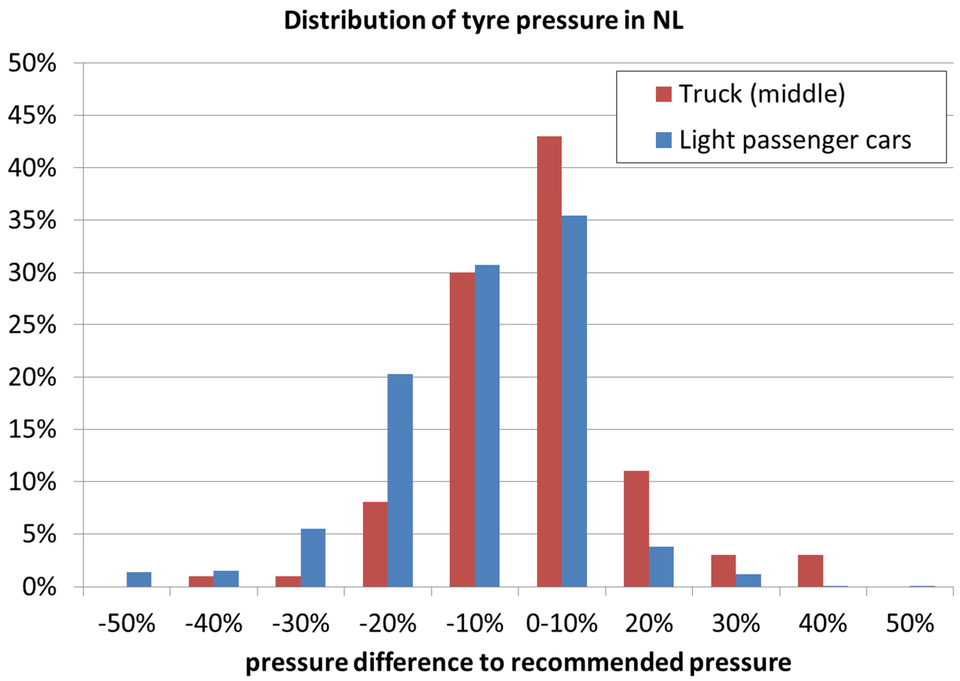

Figure 1: Distribution of tyre pressure in NL (C1 and C3 tyres) [GRRF, 2008][TPMS, 2013]

2.4. Saving potentials of energy efficient A-label tyres

The fuel savings potential of energy-efficient A-label tyres is determined by using the same methodology as in [TNOa, 2014]. The basis of all calculations is the coefficient of rolling resistance (RRC) as documented in regulation EC 1222 [EC1222, 2009] and UNECE R117. The table below documents the range of rolling resistances of each tyre class and different vehicle categories.

Table 2: Coefficient of rolling resistance (RRC) in kilograms per ton in % [EC1222, 2009]

Tyre label	Coefficient of rolling resistance (RRC) [in kilograms per ton in %]		
	C1 (Passenger car)	C2 (Light Truck)	C3 (Heavy truck & bus)
A	RRC ≤ 6.5	RRC ≤ 5.5	RRC ≤ 4.0
B	6.6 ≤ RRC ≤ 7.7	5.6 ≤ RRC ≤ 6.7	4.1 ≤ RRC ≤ 5.0
C	7.8 ≤ RRC ≤ 9.0	6.8 ≤ RRC ≤ 8.0	5.1 ≤ RRC ≤ 6.0
D	None	None	6.1 ≤ RRC ≤ 7.0
E	9.1 ≤ RRC ≤ 10.5	8.1 ≤ RRC ≤ 9.2	7.1 ≤ RRC ≤ 8.0
F	10.6 ≤ RRC ≤ 12.0	9.3 ≤ RRC ≤ 10.5	RRC ≥ 8.1
G	None	None	None

The fuel savings potential is calculated by multiplication of the difference in RRC (due to a switch from tyre label B, C D, E or F to tyre label A) with the share of rolling resistance in the overall driving resistances (as a function of the driving behaviour). Based on fleet-specific shares of the driving pattern, the savings potential of switching to energy-efficient A-label tyres is recalculated and presented in Table 3. In analogy to [TNOa, 2014], it is assumed that summer and winter tyres are replaced by energy-efficient A-label tyres and that the tyres are changed twice a year, from winter to summer and back. It is assumed that tyres are replaced at the end of their lifetime and at the moment of new vehicle purchase. The presented savings potential is therefore not instantly achieved for the entire fleet.

Table 3: Fuel savings potential of energy-efficient A-label tyres in the Amsterdam fleet

Tyre class	Vehicle category	Driving Pattern	Fuel savings potential (summer)	Fuel savings potential (winter)	Fuel savings potential (average)
		[%] urban / [%] highway	[%]	[%]	[%]
C1	Passenger cars (petrol)	90 / 10	4.3%	5.0%	4.7%
	Passenger cars (diesel)	90 / 10	4.3%	5.0%	4.7%
	Service delivery (petrol)	90 / 10	4.3%	5.0%	4.7%
	Service delivery (diesel)	90 / 10	4.3%	5.0%	4.7%
C3	Heavy-duty truck (diesel)	90 / 10	3.2%	4.0%	3.6%

2.5. Savings potential of correct tyre pressure maintenance

For the calculation of the impact of correct tyre pressure maintenance, the relation between tyre pressure and rolling resistance is required. This relation has been extensively studied by several tyre manufacturers and is described by [Exxon, 2008]:

$$RR \sim (p_{reference}/p_{test})^{0.5\text{-}0.7}$$

The effect of tyre pressure on RRC is thus equal for all vehicles for the same relative difference from the recommended tyre pressure. The resulting savings potential is shown in Table 4.

Table 4: Fuel savings potential of correct tyre pressure maintenance in the Amsterdam fleet

Tyre class	Vehicle category	Driving Behaviour	Fuel savings potential (summer)	Fuel savings potential (winter)	Fuel savings potential (average)
		[%] urban / [%] highway	[%]	[%]	[%]
C1	Passenger cars (petrol)	90 / 10	1.5%	1.5%	1.5%
	Passenger cars (diesel)	90 / 10	1.5%	1.5%	1.5%
	Service delivery (petrol)	90 / 10	1.5%	1.5%	1.5%
	Service delivery (diesel)	90 / 10	1.5%	1.5%	1.5%
C3	Heavy-duty truck (diesel)	90 / 10	1.0%	1.0%	1.0%

The savings potential of correct tyre pressure maintenance is determined by reducing all under-inflation to zero. It is assumed that over-inflation remains unchanged with correct tyre pressure maintenance.

2.6. Combined savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance

The combined savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance is shown in Table 5. It is determined through multiplication of the savings potentials in the following way: $\%_c = 1 - (1-\%_a)*(1-\%_b)$, where $\%_a$, $\%_b$ and $\%_c$ represent the savings potentials of measures A and B and the combined savings potential of measure C.

Table 5: Fuel savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance in the Amsterdam fleet

Tyre class	Vehicle category	Driving Behaviour	Fuel savings potential (summer)	Fuel savings potential (winter)	Fuel savings potential (average)
		[%] urban / [%] highway	[%]	[%]	[%]
C1	Passenger cars (petrol)	90 / 10	5.8%	6.6%	6.2%
	Passenger cars (diesel)	90 / 10	5.9%	6.6%	6.2%
	Service delivery (petrol)	90 / 10	5.9%	6.6%	6.2%
	Service delivery (diesel)	90 / 10	5.9%	6.6%	6.2%
C3	Heavy-duty truck (diesel)	90 / 10	4.2%	5.0%	4.6%

2.7. Fuel costs

Fuel cost savings are calculated from an end-user perspective. For reasons of consistency, the same fuel costs are used as in the Triple-A tyre study for the Netherlands (see Table 6). It is acknowledged however, that fuel costs vary over time and are currently lower than one year ago.

Table 6: Average fuel prices used in the calculation of end-user cost savings [BSP, 2014].

	Fuel price, end-user perspective (incl. excise duty, incl. VAT)	Fuel price, societal perspective (excl. excise duty, excl. VAT)
	[€/l]	[€/l]
Petrol	1.75	0.68
Diesel	1.50	0.76

Additional investment costs and operational costs of energy-efficient A-label tyres and correct tyre pressure maintenance have been assumed to be zero. In [Geluid, 2015], it was determined that high-performance tyres do not necessarily cost more than standard tyres. In fact, there seems to be little of no correlation between additional costs and high-performance tyres. This is of course only applicable, if the appropriate tyres are chosen at the point of new vehicle sales or effectively when the tyre need to be replaced because they have reached the end of their lifetime. Additionally, large vehicle fleets often have their own pumping station or maintenance costs are included in the lease contract. Extra pumping costs are therefore excluded.

3. Results

In this chapter, the savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance are presented, separately in section 3.1and section 3.2 as well as in combination in section 0.

3.1. Fuel savings potential of energy-efficient A-label tyres

Energy-efficient A-label tyres could save the Amsterdam fleet up to 113 thousand litres of fuel and 291 tons of CO_2 per year. This is equivalent to nearly 173 thousand Euros. An overview of the savings potential is shown in Table 7.

The largest savings can be achieved for trucks, although they represent the smallest number of vehicles in the Amsterdam municipal fleet. This is related to the fact that annual mileage and especially the fuel consumption of these vehicles is relatively high.

Table 7: Fuel savings potential, annual fuel savings, cost savings and CO_2 reduction of energy-efficient A-label

Tyre class	**Vehicle category**	**Fuel savings potential (average)**	**Annual fuel savings**	**Annual cost savings**	**Annual CO_2 reduction**
	[]	**[%]**	**[l]**	**[€]**	**[tCO_2]**
C1	Passenger cars (petrol)	4.7%	12,700	22,300	30
	Passenger cars (diesel)	4.7%	1,200	1,800	3
	Service delivery (petrol)	4.7%	1,500	2,700	4
	Service delivery (diesel)	4.7%	25,000	37,500	65
C3	Heavy-duty truck (diesel)	3.6%	72,300	108,500	189
		TOTAL	112,700	172,700	291

3.2. Fuel savings potential of correct tyre pressure maintenance

Correct tyre pressure maintenance could save the Amsterdam fleet nearly 33 thousand litres of fuel and 86 tons of CO_2. This is equivalent to more than 51 thousand Euros. An overview of the savings potential is shown in Table 8.

Table 8: Fuel savings potential, annual fuel savings, cost savings and CO_2 reduction of correct tyre pressure maintenance

Tyre class	Vehicle category	Fuel savings potential (average)	Annual fuel savings	Annual cost savings	Annual CO_2 reduction
	[]	[%]	[l]	[€]	[tCO_2]
C1	Passenger cars (petrol)	1.5%	4,100	7,200	10
	Passenger cars (diesel)	1.5%	400	600	1
	Service delivery (petrol)	1.5%	500	900	1
	Service delivery (diesel)	1.5%	8,200	12,300	21
C3	Heavy-duty truck (diesel)	1.0%	20,000	30,000	52
		TOTAL	33,200	51,000	86

The largest savings can be achieved for trucks. Service delivery vans have no savings potential, since tyre pressures are already maintained at set pressure.

3.3. Combined fuel savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance

In combination, energy-efficient A-label tyres and correct tyre pressure maintenance could save the Amsterdam fleet about 147 thousand litres of fuel and 379 tons of CO_2. This is equivalent to about 225 thousand Euros. An overview of the savings potential is shown in Table 9.

Table 9: Fuel savings potential, annual fuel savings, cost savings and CO_2 reduction of energy-efficient A-label tyres and correct tyre pressure maintenance

Tyre class	Vehicle category	Fuel savings potential (average)	Annual fuel savings	Annual cost savings	Annual CO_2 reduction
	[]	[%]	[l]	[€]	[tCO_2]
C1	Passenger cars (petrol)	6.2%	17,000	29,700	40
	Passenger cars (diesel)	6.2%	1,600	2,400	4
	Service delivery (petrol)	6.2%	2,100	3,700	5
	Service delivery (diesel)	6.2%	33,400	50,100	87
C3	Heavy-duty truck (diesel)	4.6%	92,600	138,900	242
		TOTAL	146,700	224,800	379

4. Discussion and Recommendation

In above chapters the fuel savings potential of energy-efficient tyres and correct tyre pressure maintenance are quantified and discussed for the municipal fleet of Amsterdam. It is concluded that both measures have a large potential and come at little or no costs. It is therefore advisable to apply both measures, for as far as this is practical.

Below several notes are made on the accuracy and specific boundary conditions of the above calculation. Furthermore, recommendations for improvement are made.

Tested tyre label values and real-world performance
Tyre label values for fuel-efficiency refer to a specific rolling resistance value that has been measured using the harmonized testing method UNECE R117.02, referring to ISO standard 28580. The measured value is corrected according to the alignment procedure as described by EU regulation 1235/2001, amending EU Regulation 1222/2009 [ETRMA, 2012].

It is acknowledged that several sources indicate an incoherence between the labelled performance and the measured performance of tyres ([IN2, 2013][ADAC, 2015]). In both [IN2, 2013] and [ADAC, 2015] on average a clear correlation is observed between rolling resistance (RRC) and the tyre label, however the variance of the measured rolling resistance is large within one label. As a result, there is overlap between RRC and label values. In [ADAC, 2015], B label tyres perform best on average, A label tyres have not been tested. Except for two outliers in the measurement (Pirelli Cinturato P1 Verde and Nokian Line), a downward trend is observed towards reduced RRC with improved tyre label. From the test specifications defined in [ADAC, 2015], it remains unclear what the reasons are for this deviation. Fuel consumption is measured at a constant speed of 100 km/h over a distance of 2 km and measurements are repeated at least three times. At this test condition, the external influences of wind and other must not be neglected.

Generally, stakeholders have questioned the accuracy of the tyre RRC test. Tyre manufacturers have shown that the R117 test is reproducible and repeatable across the different laboratories with an accuracy which is much higher than the width of a tyre label class as described in Table 2. The relevance of the test for on-road performances of tyres is as yet an open question. The test is performed on a smooth steel drum (unlike the noise test) at a fixed velocity, and tyre manufacturers suggest that the additional rolling resistance due to the radius of the drum is about 10%-20% which should be comparable to a 10%-20% increase from the road surface texture. This would make the R117 absolute value relevant for on-road performances. Aspects at turning, toe-in and road undulation are not covered by this tests. Alternative test procedures may produce a large variation in test results, which may however, lie outside the control of the tyre manufacturer. The test procedure R117 is designed to provide a standard value, which may have is drawbacks but is the best available, comparable and relevant number at present.

TNO tests of low-rolling resistance tyres have shown on light-duty as well as heavy-duty vehicles that fuel savings in the order of 3 to 4 % can be achieved [TvdT, 2013][WLTP, 2014]. Such evaluation requires large monitoring programs. On road testing is affected by many external circumstances for which must be corrected, and the tests must be performed with exact identical vehicle state, to exclude unwanted variations. Two aspects in particular are important. First, the warm tyre pressure is the result of the conditioning due to driving, this varies greatly from tests to test, by up to 12% variation in warm tyre pressure. Secondly, wind will affect the results, and is almost impossible to correct for as wind gustiness may vary from location to location, and time to time.

Availability of energy-efficient A-label winter tyres
While there is a large abundance of energy-efficient A-label summer tyres, the choice for winter tyres is limited. In practise, this could result in a lower savings potential for winter tyres simply because the end-user cannot buy the tyre of choice.

Tyre conditioning
It is known that the rolling resistance of a tyre depends on its stiffness. Since the stiffness of rubber is to a large degree dependent on the tyre temperature, the rolling resistance changes over the drive time and generally leads to a lower rolling resistance after a few minutes of driving. Once the tyre is conditioned, the rolling resistance does not decrease any further. In this study, the hysteresis of tyre stiffness is not taken into account, thus calculations are based on a warm conditioned tyre. The different hysteresis of tyres and tyre labels can be relevant if an existential share of the fleet only travel very short distances.

Emissions of particulate matter (PM)
Several sources are of influence to emissions of particulate matter (PM): the engine, after-treatment technologies, abrasive wear of brakes and abrasive wear of tyres. Tyre wear is not part of the tyre label and yet little research has been done to document the difference in PM emissions between tyre labels. In [ADAC, 2015], tyre wear has been quantified with a grade however no numbers of particulate numbers, nor amount of grams, have been published. In order to compare the different performance of tyres on particulate matter emissions, it is recommended to perform further research.

Distribution of tyre labels across the Amsterdam fleet
The tyre label distribution across the Amsterdam fleet was assumed to be the same as in the Netherlands. The calculation of the savings potential could be further improved if more information is available on the specific tyre labels distribution within Amsterdam.

Distribution of tyre pressure across the Amsterdam fleet

The distribution of tyre pressures across the Amsterdam fleet is to a large extend unknown. Therefore, the Dutch average tyre pressure distribution has been assumed based on information from [GRRF, 2008] and [TPMS, 2013].

5. Acknowledgement

TNO thanks Carlo Schoonebeek and Hans de Booij (City of Amsterdam) for the delivery of Amsterdam-specific data on the municipal fleet composition, fuel consumption and average vehicle mileage.

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