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Ministry of Infrastructure and Environment
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Date
2 June 2015

Our reference
2015-TL-LTR-0100286069

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Project number
060.08196

Subject
Potential benefits of energy-efficient tyres and correct tyre pressure maintenance for the vehicle fleet of the Dutch National Road Authority (RWS), the municipal fleet of Amsterdam and the municipal fleet of Rotterdam

Dear Mr Sliggers,

This document is a collection of three studies performed by order of the Dutch Ministry of Infrastructure and Environment on the potential benefits of energy-efficient tyres and correct tyre pressure maintenance for the vehicle fleet of the Dutch National Road Authority (RWS), the municipal fleet of Amsterdam and the municipal fleet of Rotterdam.

Though each study was conducted and is published apart, the same methodology was used for all fleets with fleet-specific information on the annual mileage, fuel consumption number of vehicles. This document provides an overview of the results of all three studies in one.

Yours faithfully,

Stephan van Zyl

Memorandum

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To
Ministry of Infrastructure and Environment, the Netherlands
Attn. Johan Sliggers

From
Ryan Geerdink (TNO)
Stephan van Zyl (TNO)

Subject
Potential benefits of energy-efficient tyres and correct tyre pressure maintenance for the vehicle fleet of the Dutch National Road Authority (RWS)

Date
2 June 2015

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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 vehicle fleet of the Dutch National Road Authority (RWS). Apart from energy-efficient tyres (as indicated by the tyre label), the impact of correct tyre pressure maintenance on the RWS fleet are studied. This memo documents the order-of-magnitude fuel savings potential of both measures.

The RWS fleet consists of 1634 vehicles of which 1575 have been included in the calculations of this study. In total, these 1575 vehicles drive a cumulative annual mileage of 41 million kilometres which corresponds to an average mileage of 26000 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 RWS fleet could annually **save up to 127 thousand litres of fuel and reduce CO_2 emissions by roughly 324 ton**, an equivalent of about 5% of the annual CO_2 emissions from the vehicle fleet of RWS. Maintaining the required tyre pressure for vehicles in the RWS fleet could annually **save up to 26 thousand litres of fuel and reduce CO_2 emissions by roughly 67 ton**, an equivalent of roughly 1%. When combined the measures could annually **save up to 152 thousand litres of fuel and reduce CO_2 emissions by roughly 388 ton**, an equivalent of roughly 6% of the annual CO_2 emissions of the RWS fleet. The annual fuel cost savings from switching to energy-efficient A-label tyres would be in the order of **197 thousand Euros** and approximately **42 thousand Euros** for the maintenance of the required tyre pressure. Combining the two measures results in annual fuel costs savings of roughly **237 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 fleet of RWS. The potential benefit of the two municipalities (Amsterdam and Rotterdam) 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. Statistical adjustments are made where information on the actual tyre use is available. 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 RWS fleet is discussed. Where specific data is not available, explicit assumptions are made based on national default values.

2.1. Fleet composition

Information on the RWS fleet composition was gained directly from RWS. The database contains the following entries for each vehicle:

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

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

Table 1: RWS 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 (electric)	38	170,400	0
	Passenger cars (petrol)	401	9,013,400	6.7
	Passenger cars (diesel)	768	20,191,000	5.6
	Service delivery (diesel)	368	11,424,000	8.3

SUBTOTAL	1575	40,998,800
EXCLUDED	59	1,697,600
TOTAL	1634	42,696,400

In total, the RWS fleet consists of 1634 vehicles, of which roughly two thirds are passenger cars and one third are service delivery vans and small pickup trucks. 406 vehicles, nearly a 25% of the fleet, are younger than one year. This is due to a recent renewal of old vehicles starting from June 2014. A large share of these new vehicles are Renault Mégane Estates (114), Renault Clio Estates (106) and Isuzu D-MAX pickup vans (121). A small share of the vehicle fleet consists of electric “zero-emission” vehicles (38). 59 vehicles are excluded from further calculations because data was either not available or not applicable. This was the case for 22 lease contracts, 30 motorcycles (no tyre label required) and 7 vehicles of which the fuel consumption could not be determined. Since the fleet does not include any heavy-duty vehicles, only C1 tyres are considered in the further calculations.

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 when either the fuel consumption was negative or above 40 l/100km. In some cases values of more than a 100l/100km were recorded for passenger cars, which indicate a fault. In cases where the fuel consumption was not available for a specific vehicle or license plate the average fuel consumption of the same vehicle category or of the same vehicle type was used.

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 vehicle fleet of RWS no specific data was available on the actual shares per road type. Since the vehicles are used country-wide with no large differentiation to average vehicles, national default values were used.

2.2. Distribution of tyre labels across the fleet

The distribution of tyre labels in the RWS fleet was assumed to be the same as for the Dutch fleet, unless specific knowledge was available on the originally equipped tyre-label. The Dutch tyre label distribution was taken from [TNOa, 2014]. Specific knowledge for the vehicle models Renault Clio and Renault Mégane was used to calculate a more representative tyre label distribution for the RWS vehicle fleet.

Vehicle models can be equipped with a large range of different tyres. This depends largely on the specification of the tyre, the vehicle type (sport vs. eco), but also the demand of the customer. As a result, the tyre label for energy-efficiency can vary between A to G. Based on information from Renault, vehicle models Clio and Mégane offer a choice of labels between B to F[1]. On demand of RWS, these vehicles are equipped with the following labels (see Table 2). It can be seen that both B-labels and C-labels are offered for Clios. According to RWS, in practise B-labels are installed.

Table 2: Tyre labels offered by Renault on demand of RWS, the label (X-X-00) combines the values for fuel consumption, wet grip and noise

Vehicle brand	Tyre specs	Vehicle Model	OE brand	Tyre label
Renault	185/65 R15 88T	Clio dci Expression	Bridgestone Ecopia	B-C-69
Renault	185/65 R15 88T	Clio dci Expression	Michelin ENERGYSAVER+	C-A-68
Renault	185/60 R15 88T	Mégane dci expression	Michelin ENERGYSAVER+	B-A-70

Replacing the Dutch tyre label distribution with the specific tyre labels for Clio and Mégane yields a RWS specific distribution for passenger cars, as shown in Figure 1 and Figure 2. Figure 1 presents the distribution of C1 tyres within petrol passenger cars. Figure 2 shows the distribution of C1 tyres within diesel passenger cars. The distribution was determined by replacing 100 petrol cars (of the 399 in total) and 530 diesel cars (of the 763 in total) to be equipped with B label tyres. The tyre label distribution of other vehicle categories remain the same as for the Dutch average.

[1] As of November 2014, G-labels for energy-efficiency are no longer available.

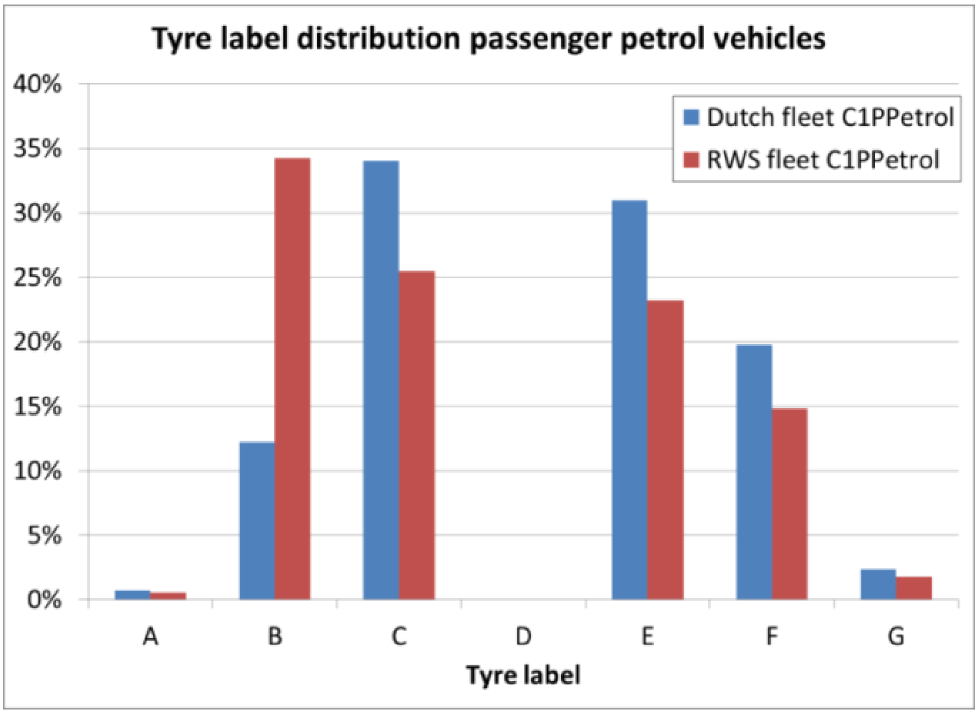

Figure 1: C1 tyre label distribution of summer tyres shown for petrol passenger cars in the RWS vehicle fleet in comparison to the Dutch average

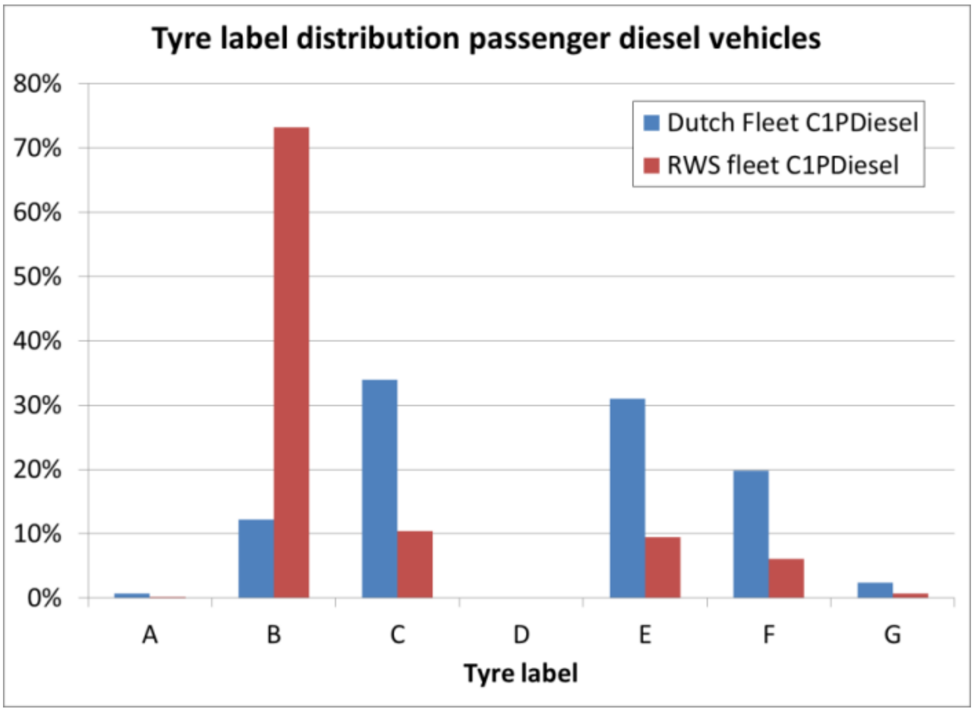

Figure 2: C1 tyre label distribution of summer tyres shown for diesel passenger cars in the RWS vehicle fleet in comparison to the Dutch average

2.3. Distribution of tyre pressure across the fleet

The distribution of tyre pressure in the RWS fleet was assumed to be the same as for the Dutch fleet, unless more specific knowledge was available. The tyre pressure distribution for Dutch passenger cars is reported in [GRRF, 2008] and shown in Figure 3 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%.

For the calculation of the tyre pressure, the distribution in the RWS fleet is assumed to be the same as the Dutch fleet for passenger cars (Figure 3). The following points have to be noted however for passenger cars and service delivery vans / small pickup trucks:

- Summer- and winter-tyres are changed twice a year. At this point, the tyre pressure is set to the recommended tyre pressure.
- 50% of all cars within the RWS fleet are person-bound, another 50% are pooling cars. It can be assumed that tyres on person-bound cars are pressurized more often than pooling cars, since pooling cars do not have an official owner who could feel responsible for the maintenance. If this is the case, the tyre distribution in the RWS fleet would be less under-inflated that on average in the Netherlands. Since no information is available on the amount of times that person-bound tyres are pressurized, this effect is not included in the calculation. It is noted though, that the savings potential is an upper-bound.
- The tyre pressure of service delivery vans and pick-up trucks in the RWS fleet are bi-weekly checked and intentionally over-pressured. It was therefore assumed that no under-inflation occurs in the RWS fleet for this vehicle category.

The adjusted distribution of the tyre pressure is shown below in Figure 3.

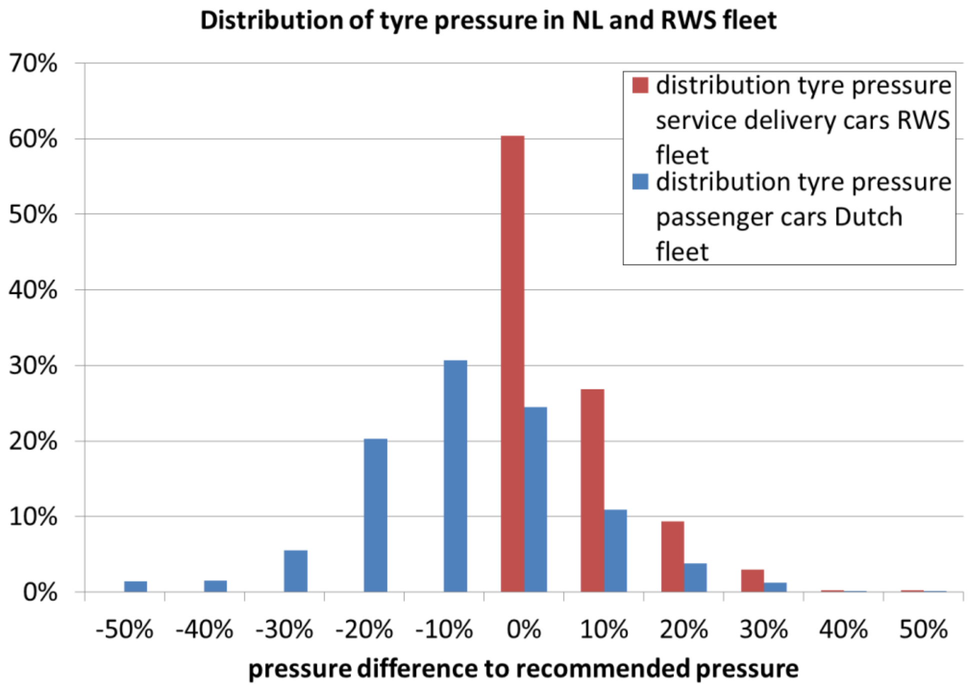

Figure 3: Distribution of tyre pressure in NL (C1 tyres only) [GRRF, 2008]

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 3: 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 (equal to Dutch average), the savings potential of switching to energy-efficient A-label tyres is recalculated for summer tyres and presented in Table 4. 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 4: Fuel savings potential of energy-efficient A-label tyres in the RWS 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)	42 / 58	3.9%	5.7%	4.8%
	Passenger cars (diesel)	33 / 67	2.6%	5.8%	4.2%
	Service delivery (diesel)	34 / 66	4.9%	5.8%	5.3%

Since the RWS fleet already has a large share of B-label summer tyres, the savings potential is lower than on average in the Netherlands. In comparison to the Dutch fleet, petrol cars in the RWS fleet save 0.4% less fuel, diesel cars save 1.2% less. Service delivery vans are not affected since the same tyre label distribution is assumed as in the Dutch average.

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 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. The resulting savings potential is shown in Table 5.

Table 5: Fuel savings potential of correct tyre pressure maintenance in the RWS 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)	42 / 58	1.5%	1.5%	1.5%
	Passenger cars (diesel)	33 / 67	1.5%	1.5%	1.5%
	Service/delivery (diesel)	34 / 66	0%	0%	0%

Since it is assumed that under-inflation does not occur for service delivery vans and pickups, the savings potential is 0%. In the RWS vehicle fleet, about 50% of the passenger cars are person-bound, i.e. registered on and used by only one specific person. The other 50% are pooling cars which means that they can be used by anyone in the organization. It is conceivable that the tyre pressure of pooling cars are less frequently maintained than person-bound cars, since the responsibility of tyre pressure maintenance for pooling cars is not clear. In the following calculations, this aspect is not taken into account.

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 6. 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 6: Fuel savings potential of energy-efficient A-label tyres and correct tyre pressure maintenance in the RWS 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)	42 / 58	5.4%	7.1%	6.3%
	Passenger cars (diesel)	33 / 67	4.1%	7.2%	5.7%
	Service/delivery (diesel)	34 / 66	4.9%	5.8%	5.3%

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 7). It is acknowledged however, that fuel costs vary over time and are currently lower than one year ago.

Table 7: 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 3.3.

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

Energy-efficient A-label tyres could save the RWS fleet up to 127 thousand litres of fuel and 324 tons of CO_2. This is equivalent to nearly 200 thousand Euros. An overview of the savings potential is shown in Table 8. This culminates to 85 litres per vehicle.

Table 8: 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)	4.8%	28,900	50,600	68
	Passenger cars (diesel)	4.2%	47,300	70,900	123
	Service delivery (diesel)	5.3%	50,600	75,900	132
		TOTAL	126,800	197,400	324

The largest savings can be achieved within the service delivery vans, although they represent the smallest number of vehicles in the RWS fleet. This is related to the fact that passenger cars have better tyre labels than service delivery vans. Service delivery vans and pick-ups also have a higher fuel consumption.

3.2. Fuel savings potential of correct tyre pressure maintenance

Correct tyre pressure maintenance could save the RWS fleet nearly 27 thousand litres of fuel and 67 tons of CO_2. This is equivalent to more than 41 thousand Euros. An overview of the savings potential is shown in Table 9. This corresponds to 18 litre of fuel per vehicle.

Table 9: 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%	9,000	15,900	21
	Passenger cars (diesel)	1.5%	17,400	26,000	45
	Service delivery (diesel)	0%	0	0	0
		TOTAL	26,400	41,900	66

The largest savings can be achieved for diesel cars. 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 RWS fleet about 150 thousand litres of fuel and 380 tons of CO_2. This is equivalent to about 240 thousand Euros. An overview of the savings potential is shown in Table 10.

Table 10: 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)	6.3%	37,500	65,700	89
	Passenger cars (diesel)	5.7%	64,000	95,900	167
	Service delivery (diesel)	5.3%	50,600	75,900	132
		TOTAL	152,100	237,500	388

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 vehicle fleet of RWS. 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 3. 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 RWS fleet
The tyre label distribution across the RWS fleet was assumed to be the same as in the Netherlands. For summer tyres, the distribution was adjusted according to specific input from RWS. The calculation of the savings potential could be further improved if more information is available on winter tyre labels.

Distribution of tyre pressure across the RWS fleet
The distribution of tyre pressures across the RWS fleet is to a large extend unknown. Therefore, the Dutch average tyre pressure distribution has been assumed based on information from [GRRF, 2008]. According to www.bandopspanning.nl, more specific data on the RWS fleet has been gathered in the past and could be used for more accuracy.

5. Acknowledgement

TNO thanks André de Boer (RWS) for the delivery of RWS-specific data on the vehicle fleet composition, fuel consumption and average vehicle mileage.

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Memorandum

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To
Ministry of Infrastructure and Environment, the Netherlands
Attn. Johan Sliggers

From
Maarten Verbeek (TNO)
Stephan van Zyl (TNO)

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

Date
2 june 2015

Our reference
2015-TL-NOT-0100285845

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Project number
060.08196

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.

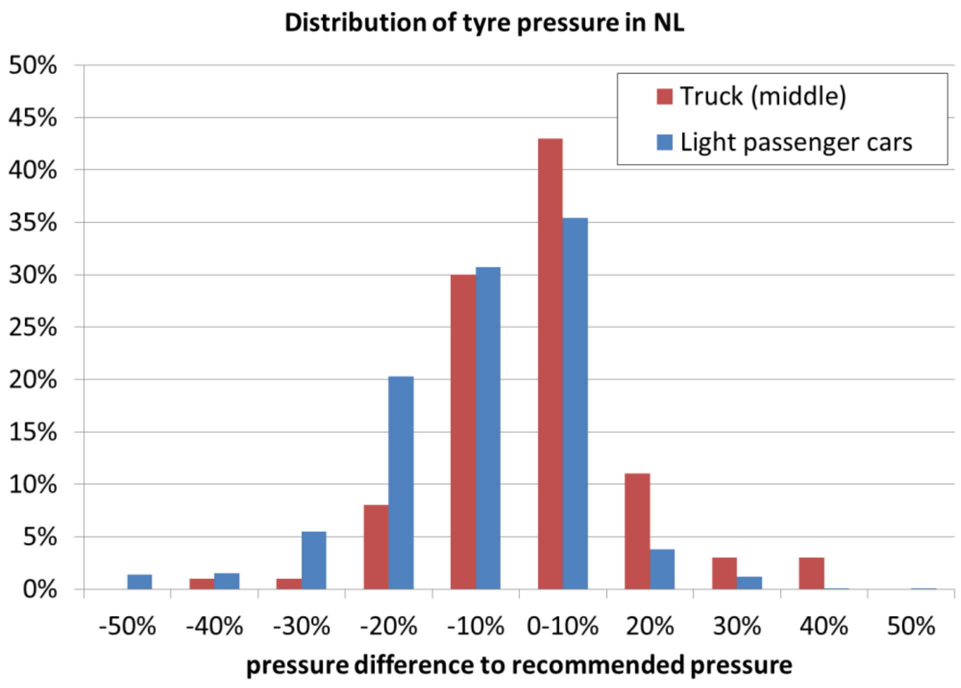

Figure 1: Distribution of tyre pressure in NL (C1 and C3 tyres) [GRRF, 2008][TPMS, 2013]

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: $\%_c = 1 – (1\text{-}\%_a)*(1\text{-}\%_b)$, 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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Memorandum

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From
Uilke Stelwagen (TNO)
Stephan van Zyl (TNO)

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

Date
2 June 2015

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Project number
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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 Rotterdam. Apart from energy-efficient tyres (as indicated by the tyre label), the impact of correct tyre pressure maintenance on the municipal fleet of Rotterdam are studied. This memo documents the order-of-magnitude fuel savings potential of both measures.

The municipal fleet of Rotterdam consists of1211 vehicles of which 1097 have been included in the calculations of this study. In total, these 1097 vehicles drive a cumulative annual mileage of 19 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 Rotterdam could annually **save about 153 thousand litres of fuel and reduce CO_2 emissions by about 396 ton**, an equivalent of about 4% of the annual CO_2 emissions of the municipal fleet of Rotterdam. Maintaining the required tyre pressure for vehicles in the Rotterdam fleet could annually **save about 45 thousand litres of fuel and reduce CO_2 emissions by about 116 ton**, an equivalent of roughly 1 %. When combined the measures could annually **save nearly 200 thousand litres of fuel and reduce CO_2 emissions by roughly 514 ton**, an equivalent of roughly 5 % of the annual CO_2 emissions of the municipal fleet of Rotterdam. The annual fuel cost savings from switching to energy-efficient A-label tyres be in the order of **234 thousand Euros** and **about 69 thousand Euros** for the maintenance of the required tyre pressure. Combining the two measures results in annual fuel costs savings of **about 304 thousand Euros**.

Given the large potential benefits of energy-efficient tyres, an accelerated market uptake could help in making road transport more environmentally friendly. 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 Rotterdam. The potential benefit of the municipality of Amsterdam 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 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 Rotterdam is discussed. Where specific data is not available, explicit assumptions are made based on national default values.

2.1. Fleet composition

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

- vehicle brand and model;
- total fuel tanked, not always accurate (Rotterdam Municipality remark);
- vehicle type/usage description;
- dashboard read vehicle total mileage and vehicle age at time of reading.

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

Table 1: Rotterdam vehicle fleet (status May 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
		[#]	[km]	[l/100 km]
C1	Passenger car (petrol)	338	5,999,500	5.8
	Passenger car (diesel)	35	1,160,100	6.4
	Service delivery (petrol)	15	144,000	6.3
	Service delivery (diesel)	503	7,387,100	8.7
C3	Heavy-duty truck (diesel)	206	4,261,100	66.8

SUBTOTAL	1097	18,951,800
EXCLUDED	114	1,144,400
TOTAL	1211	20,096,200

In total, the municipal fleet of Rotterdam fleet consists of 1211 vehicles. The largest share of vehicles are passenger cars and delivery vans (891). A smaller share of the vehicle fleet consists of medium to heavy-duty trucks (206). A total of 114 vehicles is excluded from further calculations because data was either not available or not applicable. This was the case for 58 electrical vehicles, mostly passenger cars, and 56 other vehicles. The aggregation into the indicated five general vehicle classes was done mainly on the basis of the brand and model information and for several tens of vehicles by also using the vehicle type/usage descriptions.

The annually driven kilometers per individual vehicle were estimated from the total kilometers driven and the vehicle age. From these the annual vehicle kilometers per general vehicle class were calculated by summation per class.

In a few cases, the available data on fuel consumption was conditioned to correct for faulty or lacking entries. A first estimate of the fuel consumption per individual vehicle was calculated from the total fuel tanked and the total kilometers driven. This estimate was checked against the type approval value for the vehicle, when available from the RDW database. When the estimate was lower than the type approval value or higher than one and a half times the type approval value, it was replaced by the type approval value plus a certain factor. This factor was taken to be 2 l/100km for passenger cars and service delivery vans. When no type approval values were available for a vehicle, i.e. for all trucks and older (>30 months) vans, the estimate was used as such or the value was excluded from computations. For 84 vehicles, i.e. 56 trucks and 28 excluded vehicles (as unclassifiable), with a very high estimated fuel consumption (>100 l/100km), the fuel consumption value was limited to 100 l/100km.

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 Rotterdam municipal 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.

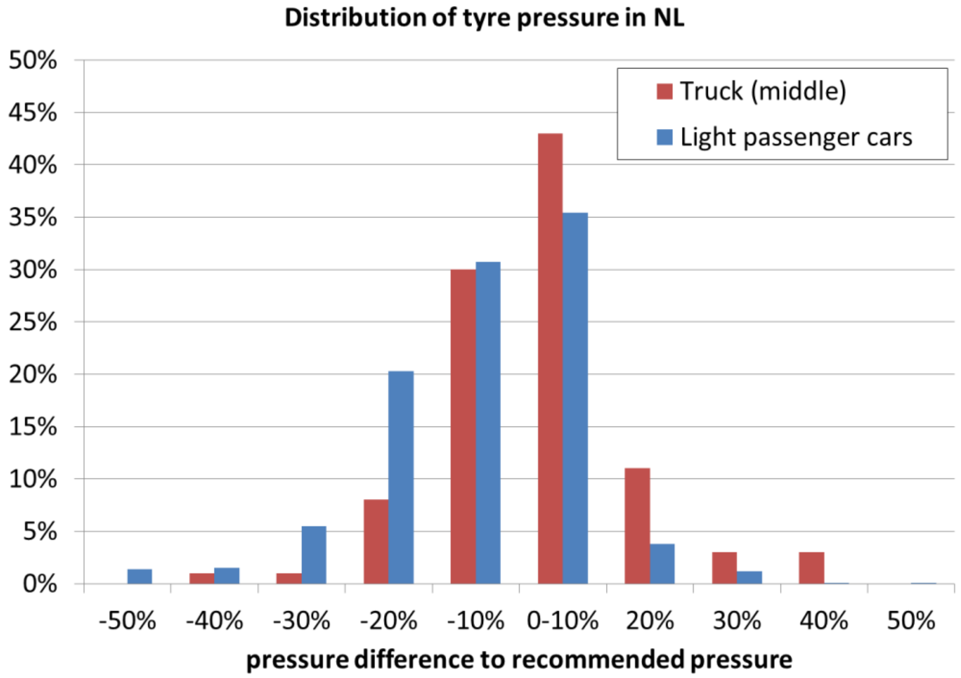

Figure 1: Distribution of tyre pressure in NL (C1 and C3 tyres) [GRRF, 2008][TPMS, 2013]

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 the 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 Rotterdam municipal fleet

Tyre class	**Vehicle category**	**Driving Pattern**	**Fuel savings potential (summer)**	**Fuel savings potential (winter)**	**Fuel savings potential (average)**
		[%] urban / [%] highway	**[%]**	**[%]**	**[%]**
C1	Passenger car (petrol)	90 / 10	4.3%	5.0%	4.7%
	Passenger car (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 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. The resulting savings potential is shown in Table 4.

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

Tyre class	Vehicle category	Driving Behaviour	Fuel savings potential (summer)	Fuel savings potential (winter)	Fuel savings potential (average)
		[%] urban / [%] highway	[%]	[%]	[%]
C1	Passenger car (petrol)	90 / 10	1.5%	1.5%	1.5%
	Passenger car (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%

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 Rotterdam municipal fleet

Tyre class	Vehicle category	Driving Behaviour	Fuel savings potential (summer)	Fuel savings potential (winter)	Fuel savings potential (average)
		[%] urban / [%] highway	[%]	[%]	[%]
C1	Passenger car (petrol)	90 / 10	5.8%	6.6%	6.2%
	Passenger car (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 or 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 0 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 Rotterdam municipal fleet about 153 thousand litres of fuel and about 396 tons of CO_2 per year. This is equivalent to an annual cost saving of about 234 thousand Euros. An overview of the savings potential is shown in Table 7.

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 car (petrol)	4.7%	16,200	28,400	38
	Passenger car (diesel)	4.7%	3,500	5,200	9
	Service delivery (petrol)	4.7%	400	700	1
	Service delivery (diesel)	4.7%	30,000	45,000	78
C3	Heavy-duty truck (diesel)	3.6%	103,100	154,600	269

TOTAL	153,200	234,000	396

The largest savings can be achieved within the trucks, although they represent a smaller part of vehicles in the Rotterdam municipal fleet. This is related to the fact that annual mileage and especially the fuel consumption of these vehicles is relatively high.

3.2. Fuel savings potential of correct tyre pressure maintenance

Correct tyre pressure maintenance could save the Rotterdam municipal fleet about 45 thousand litres of fuel and about 116 tons of CO_2. This is equivalent to an annual cost saving of about 69 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 car (petrol)	1.5%	5,300	9,200	12
	Passenger car (diesel)	1.5%	1,100	1,700	3
	Service delivery (petrol)	1.5%	100	200	0.4
	Service delivery (diesel)	1.5%	9,900	14,800	26
C3	Heavy-duty truck (diesel)	1.0%	28,500	42,700	74

TOTAL	44,900	68,700	116

The largest savings can be achieved for trucks followed by service delivery vans.

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 Rotterdam municipal fleet about 200 thousand litres of fuel and about 514 tons of CO_2. This is equivalent to about 300 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%	21,700	37,900	51
	Passenger cars (diesel)	6.2%	4,600	7,000	12
	Service delivery (petrol)	6.2%	600	1,000	2
	Service delivery (diesel)	6.2%	40,100	60,200	105
C3	Heavy-duty truck (diesel)	4.6%	132,000	198,000	345
		TOTAL	199,000	304,100	514

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 Rotterdam. 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 its 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 Rotterdam fleet
The tyre label distribution across the Rotterdam 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 the municipal fleet of Rotterdam.

Distribution of tyre pressure across the Rotterdam fleet
The distribution of tyre pressures across the Rotterdam fleet is to a large extend unknown. Therefore, the Dutch average tyre pressure distribution has been assumed based on information from [GRRF, 2008]. According to www.bandopspanning.nl, more specific data on the Rotterdam fleet has been gathered in the past and could be used for more accuracy.

5. Acknowledgement

TNO thanks René Herlaar (City of Rotterdam) for the delivery of Rotterdam-specific data on the municipal fleet composition, fuel consumption and average vehicle mileage.

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