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LEON-T

Low particle Emissions and lOw Noise Tyres

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Revision history

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V2	19/12/2024	Input from WPs	all
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V5	10/1/2015	Final	B. Giechaskiel (JRC)

Contents

Abbreviations

4VCH	4-vinylcyclohexene
ACEA	European automobile manufacturers' association
ALI	Air–liquid interface
BaP	Benzo(a)pyrene
CL	Cathodoluminescence
CPX	Close proximity
D	Deliverable
DNA	Deoxyribonucleic Acid
DP	Dipentene
DSN	Driving severity number
DTG	Derivative thermogravimetry
ECHA	European Chemicals Agency
EDX	Energy-dispersive x-ray spectroscopy
END	Environmental noise Directive
EPREL	European product registry for energy labelling
ERTRAC	European road transport research advisory council
ETRMA	European tyre & rubber manufacturers association
ETRTO	European tyre and rim technical organisation
EU	European Union
GCMS	Gas Chromatography-Mass Spectrometry
GRBP	Working party on noise and tyres
GRPE	Working party on pollution and energy
HDV	Heavy-duty vehicle
LCV	Light commercial vehicle
M+S	Mud and snow
MP	Microplastic
NR	Natural rubber
NRM	Nuclear magnetic resonance

OP	Oxidative potential
PAH	Polycyclic aromatic hydrocarbon
PC	Passenger car
PLC	Polymer of low concern
PM	Particulate matter
PMP	Particle measurement programme
PN	Particle number
POP	Persistent organic pollutant
REACH	Registration, evaluation, authorisation and restriction of chemicals
RR	Rolling resistance
SB	Cyclohexenylbenzene
SBR	Styrene-butadiene rubber
SEM	Scanning electron microscopy
SPT	Sodium polytungstate
SVHC	Substance of very high concern
TED	Thermal Extraction and Desorption
TFTA	Task Force on Tyre Abrasion
TGA	Thermo-gravimetric analysis
TRWP	Tyre-road wear particle
TWP	Tyre wear particle
UNECE	United Nations Economic Commission for Europe
UTQG	Uniform tire quality grading
UV	Ultraviolet
VACES	Versatile aerosol concentration enrichment system
WFD	Water Framework Directive
WG	Wet grip
WP	Work Package

The following section refer often to deliverables of the project (with abbreviation D). The deliverables are public, unless specified otherwise and can be found at https://www.leont-project.eu/deliverables/

- D2.1 (FORD) Detailed design of research procedures and methods, including approaches and tools for sampling and characterisation of tyre particles (confidential)
- D2.2 (FORD) Final results from the assessment and characterisation of tyre particle emissions (confidential)
- D2.3 (TNO) Results from chemical transformations of tyre organic compounds and volatiles and health hazard potential classification
- D.2.4 (JRC) Results from the comparison of tyre tread wear and related particle emissions
- D3.1 (TNO) Improved sample pre-treatment, thermo-analytical and microscopic methods for determination of TWP in environmental matrices
- D3.2 (TNO) Results from monitoring TWP (results from selective field measurements) in different environmental compartments
- D3.3 (TNO) Results from degradation testing of TWP
- D3.4 (RIVM) Updated emission model for local and EU scale scenario's
- D3.5 (RIVM) Quantification of TWP in environmental compartments and comparison to other MPs
- D4.1 (INSA) Definition of the acoustic perceptual space of tyre noise and creation and synthesis of tyre sound stimuli for health studies.
- D4.2 (INSA) Results on perceptual and physiological response to selected tyre sound stimuli
- D4.3 (UGOT) Results on sleep disturbance and cardiovascular risk to different tyre noise psychoacoustic parameters
- D5.1 (VTI) Airless tyres – A State of-the-Art report
- D5.2 (Euroturbine) Two Composite Wheel airless tyre prototypes
- D5.3 (IDIADA) Technical performance of the tyre prototypes (confidential)
- D5.4 (AUDI) Demonstration, seminar and final report of WP5 (confidential)
- D6.1 (JRC) Evaluation of future new policies and mitigation strategies on tyre wear particle emissions
- D6.2 (JRC) Evaluation of future new policies and mitigation strategies on microplastic emissions
- D6.3 (IDIADA) Evaluation of future new policies on noise emissions
- D6.4 (BAX) Policy recommendations executive summary

1. Introduction

Microplastics (synthetic polymer particles below five millimetres that are organic, insoluble and resist degradation) are often added to products such as the granular infill material used on artificial sport surfaces, cosmetics, medicines, and detergents; they are also used in packaging. Microplastics can pass unchanged through waterways into the oceans. Tyre wear contributes significantly to unintentional release of microplastics to the environment. Various policies address directly or indirectly tyres, and will be discussed in this Chapter. First an overview of EU policies on microplastics will be given. The next chapter will summarise the work at Leon-T and future policy recommendations.

1.1. EU policies and microplastics

The Zero Pollution Action Plan set a 30% reduction target for microplastics release. This can be achieved by: (i) reducing plastic pollution (as these degrade into microplastics); (ii) restricting the use of intentionally added microplastics to products; (iii) reducing unintentional microplastics release.

There is currently no EU law in place applying to microplastics in a comprehensive manner. Indirectly, they are addressed in:

- Marine Strategy Framework Directive
- Fertilising Products Regulation
- REACH which addresses intentionally added microplastics
- Proposal for a Regulation on preventing pellet losses

Unintentionally formed microplastics (i.e. when larger plastics break down) are addressed by:

- Plastics strategy
- Waste Framework Directive
- Marine Strategy Framework Directive

EU laws affecting the production of microplastics, or their release into the environment, both directly and indirectly, include:

- Ecodesign Directive
- Waste Framework Directive
- Urban Waste Water Treatment Directive
- Sewage Sludge Directive
- Directive on air quality
- Industrial Emissions Directive

- Regulation on tyre labelling
- Regulation on motor vehicle type approval

More info at the respective web pages[1]. Recently, Commission Regulation (EU) 2023/2055 amended the REACH Regulation to prohibit the sale of microplastics and products to which microplastics have been added. Materials subject to the restriction must not contain microplastic particles in concentrations greater than 0.01% by weight. Some of the industries affected by the ban on intentionally added microplastics include sports, beauty, health, agriculture, and construction materials. The first measures, including a ban on loose glitter and microbeads, entered into force on the 17th of October 2023. Other sales bans will come into force gradually to give companies the time to react and switch to alternatives.

All EU countries have to comply with the EU Water Framework Directive (WFD), 2000/60/EC, which aims achieve 'good status' for all of Europe's surface waters and groundwater by 2015 or 2027 at the latest, i.e. to reduce levels of pollutants to levels that pose no negative impact on the aquatic environment. The WFD implies that member states must identify first the problems and then the solutions. A compilation of current legislation for stormwater management from four countries; Sweden, Norway, Germany Austria and Switzerland can be found elsewhere[2]. In 2024, the European Council and European Parliament reached a provisional political agreement on a proposal to review the urban wastewater treatment directive, which describes among others:

- Urban wastewater collecting systems should be extended to all agglomerations of 1,000 population equivalent (p.e.) or more by 2035.
- Secondary treatment (i.e. the removal of biodegradable organic matter) should be applied to urban wastewater before it is discharged into the environment to all agglomerations of 1,000 p.e. or more by 2035.
- Integrated urban wastewater management plan should be established to agglomerations of over 100,000 p.e. by 2033, and at-risk agglomerations between 10,000 and 100,000 p.e. by 2039.
- Tertiary and quaternary treatment should be applied in larger plants of 150,000 p.e. and above by 2039 and 2045, respectively.
- Producers of pharmaceuticals and cosmetics leading to urban wastewater pollution by micropollutants would need to contribute a minimum of 80% of the costs of this additional treatment.

[1] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_4581

https://www.consilium.europa.eu/en/press/press-releases/2024/01/29/urban-wastewater-council-and-parliament-reach-a-deal-on-new-rules-for-more-efficient-treatment-and-monitoring/

https://environment.ec.europa.eu/topics/plastics/microplastics_en

[2] Andersson, J.; Mácsik, J.; van der Nat, D.; Norström, A.; Albinsson, M.; Åkerman, S.; Hernefeldt, P.; Jönsson, R. Reducing Highway Runoff Pollution (REHIRUP). Sustainable Design and Maintenance of Stormwater Treatment Facilities.; Trafikverket: Sweden, 2018

1.2. EU policies and tyres

Various regulations cover the lifespan of tyres, i.e., from raw materials and production to use, end-of-life, and repurposing. Different materials are used to produce a tyre. During the use of tyres, various compounds (PM, metals, volatile organic compounds, etc.) are emitted to the environment. Worn tyres are recirculated back as end-of-life tyres through different recycling management systems in the EU. Recycling is the preferred option, either as material recovery (for artificial turfs, rubber modified asphalt, etc.) or de-vulcanisation (to obtain rubber for new tyres). Retreading (removing the old tread and applying a new one) truck tyres is also common. UNECE Regulations 108 and 109, which are compulsory in the EU, deal with retreaded tyres.

Table 1 summarises the European Union’s regulations regarding tyres. Until recently, none directly targeted the contribution of tyre particles and their chemical constituents to the environment.

Euro 7 regulation includes limits on the tyre abrasion rate for light-duty and heavy-duty vehicle tyres; however, the limit values are yet to be defined. The corresponding testing methodology was developed by the UNECE task force on tyre abrasion (TFTA) under the working parties on noise and tyres (GRBP) and pollution and energy (GRPE). It is included in United Nations regulation 117. The suggested methodology is based on the mass loss of the tyres (thus determining only tyre abrasion) after on-road driving under typical urban, rural, and highway driving conditions. The option using the drum method with a pre-determined vertical load and lateral and longitudinal force profiles is also included. Currently a market assessment for the determination of an appropriate level for a tyre abrasion rate limit is ongoing.

Regulation EU 2020/740 on tyre labelling includes a provision to include information for tyre abrasion and service life (durability) on the tyre label as soon as appropriate methods to test and measure tyre abrasion and mileage will be available for use by European or international standardisation organisations. The proposal is to use tread depth measurements during tyre abrasion rate tests, and projections will provide indications of the tyre’s service life. A similar method exists for the treadwear index in the United States.

Table 1 : Existing European Union (EU) regulation relative to the various life cycle stages of tyres (given as titles in bold).

Raw materials	
EC Critical Raw Materials Act	Refers to critical raw material supply disruption and vulnerabilities. Natural rubber is recognised as a critical raw material
Production of synthetic rubber and tyres	
Dir. 2010/75/EU	Industrial Emissions Directive: polymers are considered PLCs
Reg. 1907/2006 (European chemical legislation REACH)	Manufacturers and importers must register substances of REACH list (PLCs are exempted). SVHCs with concentration > 0.1%, quantity > 1 t/year are registered to ECHA [1]
Dir. 2005/69/EC	Max 1 mg/kg BaP or 10 mg/kg of the sum of the 8 listed PAHs
Use	
Reg. EU 2019/214	General safety of motor vehicles
Dir. 2004/107/EC	BaP in air < 1 ng/m3 in PM10 averaged over a year
Dir. 2008/50/EC	National Emissions reduction Commitments (NEC) emission reduction commitments for Member States and EU for $PM_{2.5}$ [2]
Reg. EU 2019/214	Tyre pressure monitoring systems (TPMSs) have been mandatory since 2012
Dir. 2014/45/EU	Wheel alignment control is part of regular vehicle inspections
Reg. EU 2020/740	Tyre labelling on fuel efficiency (rolling resistance), safety (wet grip), and noise reduction
Dir. 2000/60/EC	Water Frame Directive priority list (tyre substances such as 6-PPD, aniline, and benzothiazole are not included)
End of life and repurposing	
Dir. 1999/31/EC	Prohibits landfilling waste tyres
Dir. 2000/53/EC	Prevents waste from vehicles and their components (including tyres) [3]
Decis 2000/532/EC	Rubber waste is non-hazardous
Reg. EC 1907/2006	<20 mg/kg PAHs in granules used as infill

[1] a ban of microplastics used as infill material on artificial turf pitches was recommended.
[2] information also for PM_{10}; heavy metals; PAHs should be provided. In 2024, the European Council formally adopted a directive setting updated air quality standards across the EU. Although this does not directly impact tyre emissions, Member States exceeding the limits should take actions to reduce PM[3].
[3] under the Green Deal and the new Circular Economy Action Plan (CEAP), the legislation on end-of-life vehicles was reviewed.
BaP=Benzo(a)pyrene; ECHA=European Chemicals Agency; PAHs=polycyclic aromatic hydrocarbons; PLC=polymer of low concern; PM=particulate matter; REACH=registration, evaluation, authorisation and restriction of chemicals; SVHC=substance of very high concern.

[3] https://www.consilium.europa.eu/en/press/press-releases/2024/10/14/air-quality-council-gives-final-green-light-to-strengthen-standards-in-the-eu/?utm_source=brevo&utm_campaign=AUTOMATED%20-%20Alert%20-%20Newsletter%20from%20TST&utm_medium=email&utm_id=3318

Regulation EU 858/2018 introduced the mandatory compliance verification of motor vehicles, components and separate systems for both Member States and the European Commission. Regulations relevant to tyres under the framework set out by Regulation EU 858/2018 are mentioned below. The safety and environmental performance of tyres are regulated by Regulation (EU) 2019/2144 to guarantee minimum performances of tyres of cars, vans, trucks, buses, and trailers. The regulation refers to the following:

- UNECE Regulations 30 and 54 regarding pneumatic tyres on passenger cars, light commercial vehicles, and their trailers, respectively.
- UNECE Regulation 117 regarding rolling sound emissions, adhesion on wet surfaces, and rolling resistance.
- Regulation EU 2020/740 on tyre labelling.
- UNECE Regulation 142 on the installation of tyres on cars, vans, trucks, buses, and trailers.
- Directive 2005/64/EC on the type-approval of motor vehicles with regard to their reusability, recyclability, and recoverability implements the end-of-life vehicle directive (Directive 2000/53/EC).

For more details see elsewhere[4].

[4] Giechaskiel B, Grigoratos T, Mathissen M, Quik J, Tromp P, Gustafsson M, Franco V, Dilara P. Contribution of Road Vehicle Tyre Wear to Microplastics and Ambient Air Pollution. Sustainability. 2024; 16(2):522. https://doi.org/10.3390/su16020522

2. Tyre wear and emissions (WP2)

The main goal of work package 2 (WP2) was to identify, measure, characterise and compare, through both in-laboratory and on-road experiments, the particle emissions from both light-duty and heavy-duty vehicle tyres under different driving conditions. Moreover, this WP also aimed at assessing the potential chemical transformation of the emitted particles in the air and analysing health hazard of the transformed species. Finally, this WP aimed at creating the necessary research procedures and methods to allow for reliable and repeatable measurement and comparison of tyre emissions, particularly to develop a standardisable cost-effective tyre abrasion rate measurement methodology that enables the prediction of airborne particle emissions generated. The following deliverables were produced:

- D2.1: Detailed design of research procedures and methods, including approaches and tools for sampling and characterisation of tyre particles (Confidential).
- D2.2: Final results from the assessment and characterisation of tyre particle emissions (Confidential).
- D2.3: Results from chemical transformations of tyre organic compounds and volatiles and health hazard potential classification (Public).
- D2.4: Results from the comparison of tyre tread wear and related particle emissions (Public).

The results of the chemical characterisation of tyre particles are publicly available (D2.3). The methodology of on-board vehicle particle sampling, the physical characterisation of particles on-road and in the lab have been described in two confidential deliverables (D2.1 and D2.2). Two key elements impacted the outcomes of D2.4: (i) During the project it was made clear that the vehicle on-board measurement of tyres is extremely difficult and uncertain for regulatory purposes; (ii) the activities at UNECE level defined a regulatory methodology for measurement of tyre abrasion.

2.1 Design of research methods for sampling and characterization of tyre particles (D2.1)

This deliverable summarized the plan and status for all WP2 related work streams. Within Task 2.1, two vehicle-based measurement approaches were developed to measure tyre wear particles directly at the vehicle. The light-duty vehicles approach was an enclosed sampling approach while the heavy-duty vehicles approach is based on an open sampling system. In addition to the vehicle-based systems, a laboratory-based measurement method was deployed.

2.2. Assessment and characterization of tyre particle emissions (D2.2)

Tyre wear particle emissions were investigated in the laboratory environment and in the field (open roads and test tracks). Two vehicle-based measurement approaches were developed for a light-duty vehicle and a heavy-duty vehicle, respectively.

For the light-duty vehicle measurements, various configurations and driving manoeuvres were tested on a closed track. The study found high variability in aspiration efficiency influenced by factors like driving direction and abrasion of inlet tubing. Particle measurements indicated significant emissions due to the presence of brushes at the wheel housing edge and contamination from resuspended road dust. The complexity of measuring particle emissions accurately due to variables such as vehicle dynamics, road surface conditions, and sampling system design was highlighted. Future work should focus on improving sampling system durability and efficiency, particularly in addressing road surface contact and resuspended road dust. Quantifying tyre wear's contribution to total aspirated dust using a tracer-dotted tyre was also suggested.

For heavy-duty vehicles, tyre particle measurability was investigated under various driving cycles. The study found a dependency of particle number on driving severity and events like sharp cornering and braking. Initial sensitivity tests established good conditions for sampling and particle measurement, confirming that measured particles originated from vehicle tyres. Emission behaviour varied significantly with driving cycles and strain collectives, with increased driving severity shifting emitted particle sizes towards 2-5 µm.

In a laboratory setting, tests were conducted to study how tyre characteristics and ambient conditions affect tyre wear using a road simulator. Five different tyres were tested under various conditions, including different temperatures and wet surfaces. Results showed lower wear rates than literature, possibly due to soft and sticky tyre surfaces attracting road dust. Softer tyres caused higher particle concentrations, especially at increased temperatures. Wet conditions decreased wear rates and evened out differences between tyres. No tyre outperformed others in particle concentration and mass loss.

2.3. Chemical transformations of tyre organic compounds and volatiles and health hazard potential classification (D2.3)

The aim of the toxicity experiments was to investigate the hazard of tyre particles, generated by artificially wearing various tyres in a road simulator, using an in vitro model of human lung cells. Data on toxicity can then be combined with physicochemical data into an assessment of the health hazard potential of tyre emissions. During the sampling campaign at the road simulator facility, concentrations of emitted particles proved to be substantially lower than expected. Though low emissions are obviously beneficial with respect to potential health risks of tyre emissions, this meant that the yield of PM for toxicity testing was lower than expected and that it was not feasible to conduct the toxicity experiments as initially envisaged. It was intended to perform air-liquid interface exposures of human epithelial airway cells co-cultured with macrophages, and to characterize the toxicity using a large set of readout parameters. However, because of the low PM yield, the testing strategy had to be reconsidered and a slightly less sophisticated cell model (mono- rather than co-culture) and mode of exposure (quasi- air–liquid interface ALI) was selected to investigate the toxicity using a limited set of readout parameters. The limited availability of test material, which is often an issue in toxicity testing of various emissions, is an important factor to take into account for future campaigns. Direct on-site ALI exposure to emissions may be a promising – albeit technically and logistically challenging – alternative, which also eliminates the need for PM collection and extraction procedures.

It is recommended to confirm these findings using a larger set of tyres, which may be tested up to higher dose levels and using additional parameters (e.g. oxidative stress, DNA damage, omics analysis) to characterize the toxicity. Also, more complex cell models (e.g. co-cultures of – possibly primary – epithelial cells and macrophages) and mode of exposure (e.g. air liquid interface exposure) may be applied. Based on the present in vitro experiments, which had to be redesigned due to the limited amount of test material available, it is difficult to conclude on the health hazard potential of tyre emissions.

2.4. Comparison of tyre tread wear and related particle emissions (D2.4)

The methodology of on-board vehicle particle sampling, the physical characterisation of particles on-road and in the laboratory was described in two confidential deliverables (D2.1 and D2.2). D2.4 summarised results from the comparison of tyre tread wear and related particle emissions. Two key elements impacted the outcomes of D2.4: (i) During the project it was made clear that the vehicle on-board measurement of tyres is extremely difficult and uncertain for regulatory purposes; (ii) the activities at UNECE level defined a regulatory methodology for measurement of tyre abrasion. Furthermore, in the European Union, there is an interest to include a ‘durability’ index at the tyre labelling. The tread depth reduction during the tyre abrasion test could be a possible approach.

In order to assess mass loss and tread depth reduction various tests were conducted. IDIADA tested five tyres on the proving ground with an accelerated wear method. The vehicle was front-wheel driven with a weight of 1650 kg. One of the tyres (from LingLong) was also tested on the road under normal driving conditions at both IDIADA and LINGLONG. Under the PM/PN testing, VTI (at a road simulator) and FORD (at a handling road) measured mass loss and tread depth with a different set of five tyres.

The results demonstrated a clear impact of the ambient temperature and tyre load on the abrasion rate. For the summer and M+S tyres the mass loss increase was 30% per 10° increase of ambient temperature. For the winter tyre the increase was 55%. The mass loss was almost linear to the load increase (for the same tyre). No correlation was found between mass loss and the tyre hardness. Other factors, like differences in tread pattern contact area, might have masked any relation. All the tyres started with a higher shore A hardness and stabilised during the abrasion tests.

The accelerated wear method resulted in wear rates of 600-1500 mg/km (vehicle, sum of four tyres) and 0.5-0.6 mm per 1000 km (average per tyre), more than 10 times higher than the on-road tests. Urban driving had up to 5 times higher wear than rural and motorway driving. However, part of this difference was likely due to the different road surface. The DSN (driving severity number) on its own could not fully justify the differences between proving ground and on-road tests. For the front-wheel driven vehicle of this study the front tyres contributed 65-85% of the total wear.

The on-road tests with one of the tyres had abrasion rates of 20-120 mg/km[5]. The urban part had higher wear 2-5 times compared to total and motorway parts. The abrasion rates had some correlation with wear indices reported in consumers' web sites. The tyre life estimated from the accelerated method did not have any correlation with the treadwear Uniform Tire Quality Grading (UTQG) used in the United States. More studies are needed to investigate if such correlation exists with the final regulated on-road protocol. The abrasion rates of this study had some correlation with the tyre wear rate published on the internet.

The tread depth measurement was found to have high uncertainty compared to the mass measurement. Different locations of the tyre can also have different tread depth reductions. Even though there is a correlation between tread wear reduction and mass loss, this was different for the front and rear tyres and the different tyre manufacturers. Values of 306 g/mm for the front tyres and 198 g/mm for the rear tyres were calculated.

Finally, measurements with a 6×2 truck (6 wheels) and low payload (34% of maximum weight capacity, but 61% for the front tyres and 25% for the rear tyres) were carried out. The abrasion rates were 100 mg/km (highway), 540 mg/km (real-driving), 2,000 mg/km (delivery), but 6,000 mg/km around airfield roads with dynamic driving.

[5] Giechaskiel, B.; Grigoratos, T.; Li, L.; Zang, S.; Lu, B.; Lopez, D.; García, J.J. Tyre Wear under Urban, Rural, and Motorway Driving Conditions at Two Locations in Spain and China. Lubricants 2024, 12, 338, doi:10.3390/lubricants12100338.

3. Microplastics (WP3)

This work package was dedicated to the quantification and tracing of tyre particles in different environmental compartments (i.e. air, waterbodies, soil and sediments). It resulted in a better understanding of their fate after emission, such as the degree of persistence of tyre particles in soil/sediments, and their potential for long range transport, e.g. to the marine environment, leading to a better insight of environmental concentrations in Europe. It also assessed tyre particles contribution to the microplastic pollution in different compartments at local, national and continental scale. To achieve this objective, a multimedia fate model was applied where the estimated aggregate emission of TWP from transport to the environment was used to trace concentrations of TWP in different environmental compartments. To improve existing tyre particles estimates, emissions factors (WP2), collected field data (Task 3.1), kinetics of degradation processes (Task 3.2) and local scale deposition measurements (Task 3.3) were implemented in the model. The acquired knowledge was used for generating potential mitigation scenarios in WP6.

3.1. Improved sample pre-treatment, thermo-analytical and microscopic methods for tyre particles (D3.1)

The aim of this deliverable was to optimise pre-treatment and analysis methods for tyre-road wear particles (TRWPs) in environmental samples and developing them beyond the state-of-the-art. Our novel approach is summarized in the figure below (*Figure 1*) and identifies the measurement campaign for the execution of this deliverable. Environmental samples were collected using air, deposition water and soil/sediment samplers. Depending on the collected sample matrix, different pre-treatment methods were employed. Air samples do not require any pre-treatment and were analysed directly. Water samples were first freeze-dried and then worked up as a dry powder simulating soil/sediment samples. To remove organic components, a digestion can be used. We have investigated three oxidation-based digestions using H_2O_2, Fenton's reagent and NaClO. NaClO was shown to be unsuitable due to low selectivity towards environmental matter and strong attack towards rubber, particularly synthetic rubber. While H_2O_2 did not digest TRWPs, it was also not so active against environmental matter. Fenton's reagent was shown to be the optimal digestion reagent as it had high activity against matrix matter whilst also not reacting with TRWPs. While the separation method has been optimised so far as recovery of the sample is concerned, further optimisation of the solution density is required. Whilst 2.4 g/ml seemed a logical choice based on literature values for the densities of TRWPs and soil components, our results suggest that this solution is too heavy. Investigation into the optimal solution densities should be conducted with a focus on investigating sodium polytungstate (SPT) solutions with densities of 1.7 – 2.2 g/ml. Sample analysis will be performed in two ways: bulk analysis for information on environmental TRWP concentrations with a coarse size indication and single particle analysis for detailed information on the particle size distribution and particle morphology. For bulk analysis, a novel thermal extraction and desorption combined with gas chromatography-mass spectrometry (TED-GCMS) method has been developed on the basis of the largest tyre pyrolysis dataset to date. A survey of current literature methods was performed and it was determined that the current downfalls are due to insufficient datasets on which to based quantify styrene-butadiene rubber (SBR) and natural rubber (NR) from rubber markers and poor assumptions in conversion factors for indirect TRWP determination from SBR and NR concentration. With a wide-reaching dataset of 74 tyres from literature and our own experiments, spanning three countries, ten years and both cars and trucks we determined what we believe are the most accurate conversion factors to date. TWP concentration is also directly calculated from marker concentrations, avoiding the uncertainty of a second conversion factor. 4-vinylcyclohexene (4VCH) was chosen as the optimal marker for quantification, as opposed to the commonly used cyclohexenylbenzene (SB) and dipentene (DP), as it showed the lowest variation between samples, leading to the most reliable quantification. We have also shown that the variation in tyre composition at any one time is far larger than the variation in tyres across different years, seasons and vehicle types, demonstrating the reliability of these conversions across different times and locations. Finally, a comparison of calibration methods and use of standards has shown that our combination of external calibration and internal standard gives a concentration comparable to that with standard addition but with a lower variance. To add coarse size information to the bulk analysis, a sequential filtration system was investigated. Initial studies showed that this system fractionated model nanoplastics, relevantly sized environmental components, and simulated TRWPs successfully. However, when untreated environmental samples were tested it was shown that many small particles were retained with the larger fractions meaning the use of such a system is limited. Work to optimise the filtration set-up is recommended. If an optimal solution is found before the measurement campaign, this will also be applied. Finally, single particle analysis is carried out using scanning electron microscopy with energy-dispersive x-ray spectroscopy and cathodoluminescence (SEM-EDX-CL). While this is a very powerful technique due to the detailed physicochemical information that can be gathered, it suffers in that analysis of statistically relevant numbers of particles is slow and often impractical in samples with a large contribution from matrix particles. In order to address these problems, we developed an automated analysis procedure which could positively classify and measure TRWPs in environmental matrices. The automated analyses were assessed for accuracy in recognition and measurement through comparison with manual measurements and for classification by comparison with TED-GCMS measurements. Recognition, measurement and classification were all deemed to be suitable for the implementation of this method for the automated analysis of environmental samples.

As a result of the pre-treatment methodology for TRWP designed by TNO in this deliverable deemed recognizable in the measurement and classification to be suitable for the implementation of this method for the automated analysis of environmental samples.

This methodology was used in following TRWP physico-chemical analysis in the project Leon-T.

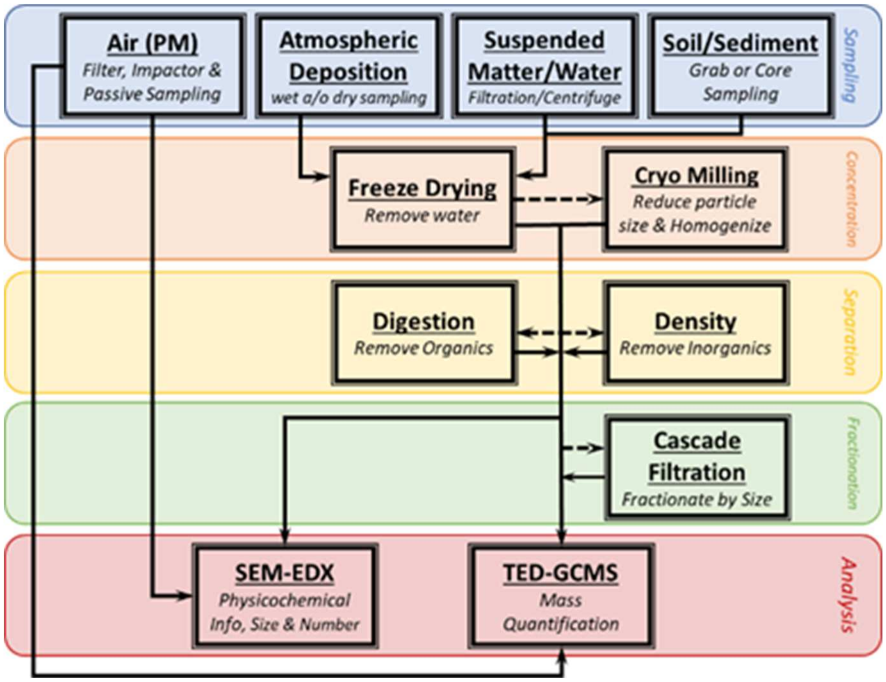


Figure 1 : Approach of D3.1.

3.2. Tyre particles in different environmental compartments (D3.2)

An in-lab test campaign at VTI's road simulator facilities was organised, to conduct abrasion experiments with different types of tyres and from different market segments, to chemically and toxicologically characterise the emitted particles and volatiles and identify potential chemical transformation processes with the objective to evaluate their associated health hazard. Gas and size-selective particle sampling techniques and a versatile aerosol concentration enrichment system (VACES) BioSampler was used to collect volatile organic compounds and particles on filter and in liquid suspensions which allows for direct in-vitro toxicity testing. The sampled particles on filter were subjected to an accelerated ultraviolet (UV)-ageing program to simulate the short-term (~2 weeks) UV exposure of particles. Both freshly generated particles and UV-aged TRWP as well as emitted volatiles were analysed on their organic composition using several target and non-target analytical techniques. Toxicity experiments were performed using an in vitro model of human lung cells and additional oxidative potential analysis.

The chemical characterisation of tyres represents minor differences in the organic composition of the additives between the winter tyre and summer tyres. The most pronounced difference are the share of carboxylic acids (two times more acids in summer tyres) and amines (70% more amines in winter tyres; although differences in chemical compounds can also be the result of differences between brands (Continental, GoodYear, Ling Long). All tested tyres show a similar composition: 47 - 52% rubber, 9 - 12% organic additives and 37 - 42 % filler. Regarding the chemical characterisation and transformation total Tyre wear particle (TWP) concentrations were low (0.9 – 4.4 µg/m^3) compared to total PM (36 – 71 µg/m^3), with decreasing concentrations in the smaller particulate size fractions (PM_{10}: 0.3 – 3.4 µg/m^3, $PM_{2.5}$: 0.2 – 2.3 µg/m^3 and PM_1: 0.1 – 0.9 µg/m^3). The winter tyre produced 5 – 10 times more TWP than the summer and all season tyres. For the winter tyre also the particle size distribution of TWP was different with the largest share in the size fraction 1 – 2.5 µm, while the summer and all-season tyres produced more coarse material (> 2.5µm). In contrast with the low TWP concentrations, organic carbon concentrations were quite high (20 - 25 µg/m^3), with the majority in the smallest size fraction PM_1 (ca. 14 µg/m^3). This can partly be explained by volatilization of semi-volatile additives in the tyres during the road simulator tests. A portion of these organic vapours eventually will condensate and form small aerosols or adsorb on other (small) particles From these experiments it can be concluded that besides emitted TWP (0.9 – 4.4 µg/m^3) from abrasion processes, emitted tyre-related organic chemicals from volatilization (10 - 45 µg/m^3) and subsequent condensation/adsorption processes (3 – 6 µg/m^3) can contribute to a large extend to the total tyre emissions. Even though the tested tyres have been broken in, they are quite new, which means that volatile and semi-volatile organic compounds emissions will be lower in real-life as car tyres age. Finally in the toxicological examination it is recommended to confirm these findings using a larger set of tyres, which may be tested up to higher dose levels and using additional parameters (e.g. oxidative stress, DNA damage, omics analysis) to characterise the toxicity. Also, more complex cell models (e.g. co-cultures of – possibly primary – epithelial cells and macrophages) and mode of exposure (e.g. air liquid interface exposure) may be applied. Based on the present in vitro experiments, which had to be redesigned due to the limited amount of test material available, it is difficult to conclude on the health hazard potential of tyre emissions. The results showed an increased oxidative potential (OP) of PM when compared to vehicle controls – without any obvious differences between the various types of tyres – indicating that oxidative stress may play a role in possible tyre PM-induced toxicity. This is in agreement with the chemical composition of PM samples, which show no clear differences between the tested tyres. In addition, OP analysis was also performed on TSP subjected to accelerated UV-aging, as well as on non-aged TSP collected on filters. Interestingly, while only marginal oxidation of phospholipids was induced by non-aged TSP samples, oxidative potential was significantly enhanced after aging. These findings can be explained by the difference in chemical composition of the non-aged and aged PM samples. The aged PM contains more oxygenated species, mainly aldehydes, but also carboxylic acids and carboxylic esters. These oxygenated species are more OP-active which provoke more oxidative stress responses in the human body. Oxidative stress plays an important initial role in the development of negative health effects (e.g. respiratory and cardiopulmonary diseases) as a result of exposure to particulate matter. However, as already mentioned before, not all PM is tyre related; also other sources (e.g. oil and grease) contributed to the PM load. Especially the observed high concentrations of aldehydes are most likely not related to tyre emissions.

3.3. Degradation (UV ageing and biodegradation) of tyre particles (D3.3)

In this research, four T(R)WP samples were used and these are summarised in Table 2. Two samples of tyre wear particles (TWPs) were prepared by cryogenic milling to investigate the effects of UV degradation purely on tyre material. A mix of light duty (car/van) tyres and heavy duty (truck) tyres were compared as the former contains more synthetic rubber and the latter more natural rubber. The other two samples were prepared by running tyres on a road simulator and collecting the TRWPs generated. This allows for investigation of more realistic particles that also include road wear encrustations. TRWPs were prepared from the same mix of light duty tyres, which were from the executive market segment, as the cryomilled car TWPs in order to investigate the influence of road wear encrustations and the wear process. TRWPs were also collected from a budget segment light-duty tyre, which contains different fillers and rubber formulations. Finally, all samples were sieved to a size fraction of 50 – 200 µm to be representative of T(R)WPs that are deposited in roadside soils, the environmental compartment with the most T(R)WPs.

Table 2 : Summary of T(R)WPs samples used in this study

Sample Name	Preparation Method	Tyre Details
Car TWPs	Cryomilling	Mix of four new executive segment tyres
Truck TWPs	Cryomilling	Mix of shredded end-of-life truck tyres from tyre recycler
Premium TRWPs	Road Simulator	Mix of four new executive segment tyres
Budget TRWPs	Road Simulator	One new budget segment tyre

T(R)WPs were subjected to accelerated photothermal ageing with samples taken for characterisation at four time points (0, 160, 505 and 1000 h). For converting the accelerated exposure in the UV cabinet to environmentally relevant figures, the intensity of the UV light and the temperature need to be compared with natural conditions. Since we have only done UV ageing experiments at one temperature and one UV intensity, two assumptions were made: that thermal activation increases by a factor of 2 for every 10 °C and that UV-activation increases linearly. This leads to a total acceleration factor of 24. Given 1000 h of accelerated ageing and assuming an average sunshine exposure of 8 h per day in the environment, this leads to a simulated environmental ageing time of 8.2 years. This value has been used for calculating environmental degradation rates. As this has a large degree of error, degradation rates have been provided in brackets to show a range from 5-10 environmental years.

Regarding biodegradation, the biodegradation of tyre wear particles was investigated using cryogenically milled tyre particles inoculated with microbes from sewage treatment plant sludge. Both car and truck tyres were used to investigate the influence of rubber type on biodegradation and the particles were subjected to varying degrees of UV-ageing before biodegradation testing to further elucidate the interplay of these two important processes that occur simultaneously in the environment.

The monitoring of biodegradation through oxygen demand showed that only non-aged or lightly UV-aged tyre wear particles showed noticeable degradation over the 28 day incubation period. Fresh truck tyres were the most biodegraded, exhibiting ca. 8% degradation after 28 days, whilst fresh car tyres exhibited ca. 6% biodegradation. UV-ageing of 160 h lowered this to ca. 6.5% and 2% for truck and car TWPs, respectively. TWPs that had been UV-aged for 505 and 1000 h showed negligible biodegradation. These results were confirmed through thermos-gravimetric analysis (TGA) of the samples before and after biodegradation.

Derivative thermogravimetry (DTG) analysis suggested that natural rubber degrades faster than synthetic rubber due to both abiotic and biotic degradation and this was confirmed with TED-GCMS analysis of rubber composition. TED-GCMS showed that the natural rubber content of all tested samples decreased after biodegradation. This may explain why truck tyres degrade quicker, as they contain more natural rubber, and also why UV-aged particles degrade slower, as the natural rubber is also more susceptible to UV degradation. This is in line with previous work that has shown that only cis-1,4-isoprene containing rubbers such as natural and synthetic isoprene rubbers are susceptible to biodegradation and is sensitive to abiotic degradation whilst butadiene rubber is resistant to abiotic and biotic oxidation.

Regarding UV ageing of Cryomilled tyre tread and TRWPs from a road simulator were subjected to accelerated UV-ageing to simulate abiotic environmental ageing. TGA analysis of the tyre composition as a function of ageing time showed that the average degradation rate was 0.07 h^{-1}, which when corrected for accelerated ageing corresponds to an environmental degradation rate of 0.03 (0.02 – 0.04) day^{-1}. Natural rubber was seen to degrade quicker than synthetic rubber with the consequence that heavy duty tyres, which often contain a higher percentage natural rubber, degrade quicker than light duty tyres. Particle size was also seen to be reduced during degradation with an environmental equivalent rate of 0.03 µm (0.02 – 0.05 µm) day^{-1}. A fraction of small particles <10 µm was also formed which was confirmed with SEM-EDX to occur for both the tyre tread and TRWP samples. This suggests that nanosized tyre wear particles may form in the environment due to degradation.

Regarding the biodegradation study, future work should focus on how we can combine the insights learned through both the abiotic and biotic degradation parts of this deliverable into environmental degradation rates for use in fate modelling. This is challenging due to the different acceleration factors and timescales of the two degradation studies. Translating lab-scale biodegradation results into environmental rates is also especially challenging. A literature study showed that the average accelerated and non-accelerated biodegradation rates can differ by up to an order of magnitude. They also showed that the variation between different studies of non-accelerated degradation can vary up to an order of magnitude, showing that the exact microbial community and degradation conditions play a large role and any environmental value calculated from an accelerated lab-based test will have a large margin of error.

3.4. Tyre friction abrasion model (D3.4)

3.4.1. Application of the tyre wear release model

It takes a lot of effort to mimic driving conditions and behaviour in the real world. For testing tyre wear it would be easier if an accelerated approach, taking less time and costing less, could be applied for estimating tyre wear. Or that even a laboratory test could be used to derive emission factors representing real world conditions. The aim of this model is to provide a first attempt at linking abrasion rates measured under very specific conditions to real world conditions. This is done by estimating the abrasion coefficient (*Figure 2*) which does not depend on driver behaviour, vehicle or road conditions. This allows for the estimation of emission factors for specific conditions based on the abrasion coefficient which is a much more generic measure of tyre wear, almost exclusively depending on characteristics of the tyre alone. The tyre friction abrasion model should be further developed and tested with more case studies before it can be applied for regulatory purposes.

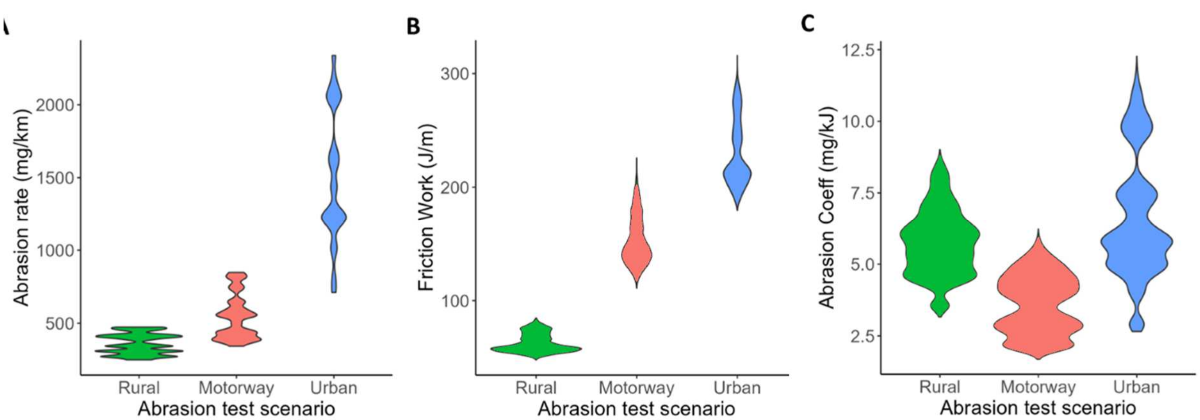


Figure 2 : Violin plots of (A) measured tyre abrasion rates in mg/km (B) simulated friction work (J/m) and (C) estimated abrasion coefficients (mg/kJ) for the IDIADA test scenarios for rural, motorway and urban environments.

3.4.2. Modelling approach and analysis

The tyre friction abrasion model describes the interplay between friction and wear and the following factors per meter driven:

- Peak friction coefficient based on the tyre grip index (GripIndex_u) using a correction factor for the maximum friction coefficient across different undergrounds (x_correct_mu_max_track_u, e.g. for wet-> dry) and the slip ration between the tyre and the track at the peak friction coefficient (optimal_slip_ratio_track_u).
- Acceleration and Deceleration manoeuvres of the vehicle based on a start and end velocity (v_start/v_end) and the acceleration or deceleration constant.
- Constant speed driving at specified velocity (v_const).
- The rolling coefficient (RolCoef_u) of the tyre based on the tyre label fuel efficiency.
- Vehicle characteristics such as weight (Mass), Frontal surface area (Surface Area),
- External factors such as Wind velocity (v_wind), banking or slope of the road and the size of a corner (based on corner radius (e.g. sharp or slight turn) and angle (e.g. 90 degrees for a right or left turn).

Results from a sensitivity analysis indicate (*Figure 3*) that in the most balanced scenario (FrictionWork_7x_pm) external factors (e.g. slope), vehicle characteristics (e.g. mass) and driver behaviour (e.g. degree of deceleration) are the most sensitive to how and where tyre wear will take place. The overall degree of tyre wear is also dependent on the grip and abrasion coefficient. Further work should focus on the effect of different road surfaces as this was only done for the standard road surface as applied in tyre tests affecting the Grip Index.

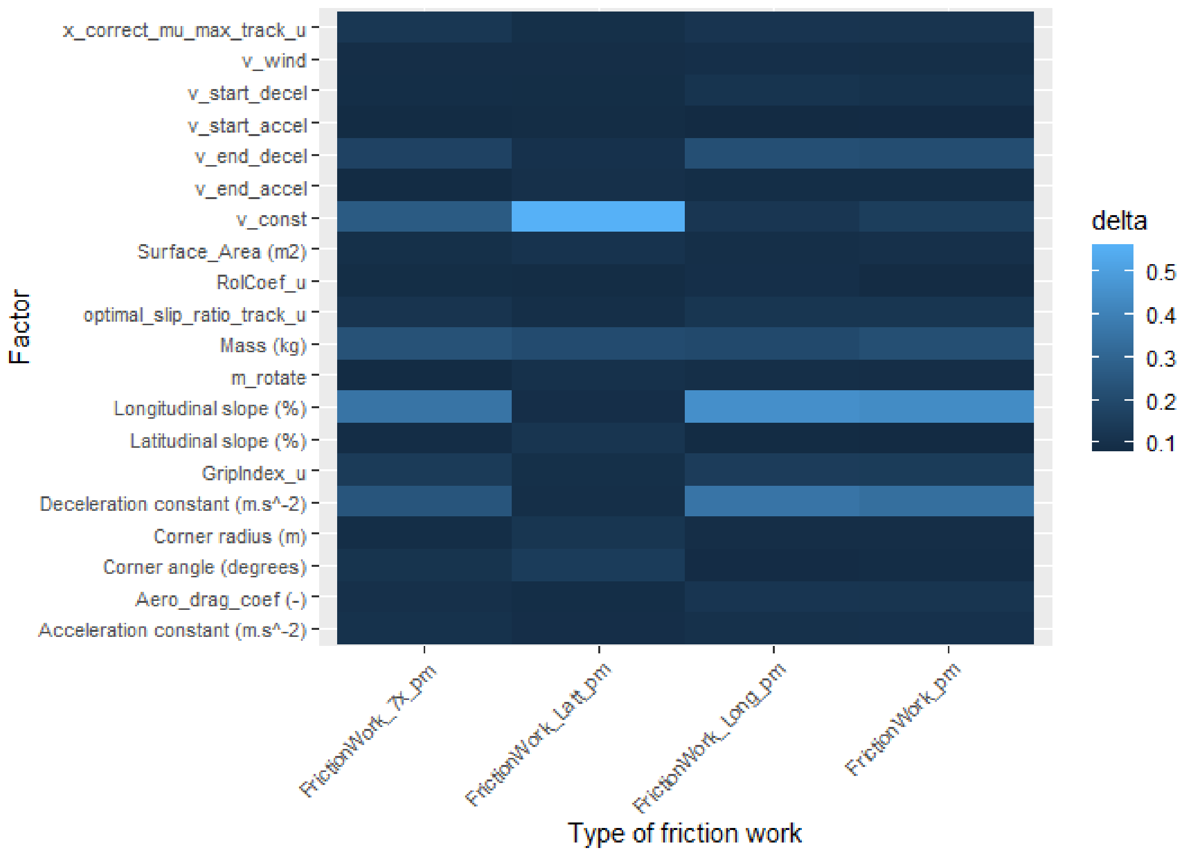


Figure 3. Sensitivity analysis of the Tyre Wear Friction model for 4 different scenarios estimating friction work at the tyre (J/m). FrictionWork_7x and Friction Work are the scenarios of combined longitudinal and latitudinal forces with 7 times as much friction in lateral direction or equal amount of friction in each direction, respectively. The other two scenarios (Lat and Long) indicate the separate friction work in each direction.

It is recommended that tyre friction abrasion modelling be further developed together with abrasion measurement methods in order to optimize the cost-benefit of the data required for tyre labelling and other policy measures.

3.5. Tyre wear and other microplastics emissions to and fate in the environment (D3.5)

This study aims to quantify the emission to and further dispersion and build-up of TWP and other microplastics in different environmental compartments (air, soil, water and sediment). This allows for combining different data on specific processes and characteristics of released Tyre Wear in an estimate of the concentrations in different environmental compartments. This will be compared to field measurements of TWP in order to test the validity of the model.

3.5.1. Approach

The original model simpleBox4Nano[6] was further developed to be made fit for use with microplastics resulting in SimpleBox4Plastics[7]. The model was applied to TWP using a measured size distribution of TWP, accounting for the two major polymer types being applied: natural rubber (NR) and styrene butadiene rubber (SBR) based on LEON-T D3.2 and D2.2. Novel UV and biodegradation rate constants were derived for use in SimpleBox4Plastics based on LEON-T D3.3. The background concentrations of NR and SBR along with 13 other polymers were estimated for EU-27 and the Netherlands using a state of the art emission model[8] coupled to SimpleBox4Plastics. For the Netherlands a comparison was made to field measurements.

3.5.2. Results

Microplastics other than tyre wear make up a majority of environmental emission in the Netherlands. Whereas this is a lot less at EU scale. For the EU-27 it is estimated that tyre wear makes up the majority of microplastics releases *(Figure 4*). This is due to several factors, the main one being the material flow of certain industries is relatively large in the Netherlands for instance in the Netherlands being a large played in the transport and handling of pre-production pellets. Another factor is the use of open graded asphalt in the Netherlands (95% of highways) and the almost negligible use of this type of asphalt in the rest of the EU (5%).

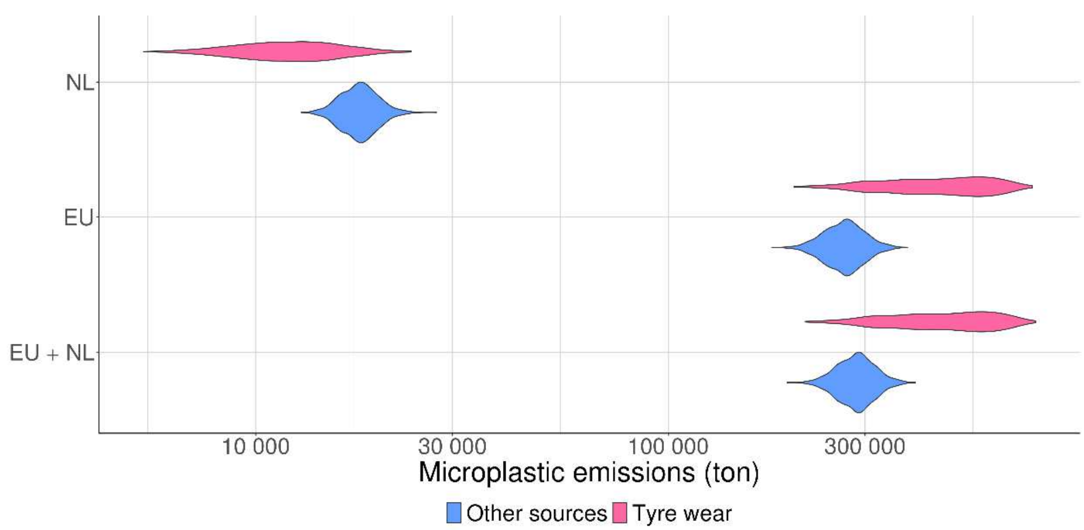


Figure 4. Violin plot of microplastic emission to the environment from tyre wear and other microplastics sources. DPMFA at different scales in 2019 (EU+NL=EU-27, EU = EU-26 (without NL)). Logarithmic scale on x-axis.

[6] Meesters, J.A.J., et al., 2014. Multimedia Modeling of Engineered Nanoparticles with SimpleBox4nano: Model Definition and Evaluation. Environmental Science & Technology 48:5726-5736.

[7] J. Quik, J. Meesters, A. Koelmans (2023). A multimedia model to estimate the environmental fate of microplastic particles. Science of the Total Environment 882, 163437, 10.1016/j.scitotenv.2023.163437

[8] J. Quik, A. Hids, M. Steenmeijer, Y. Mellink, A. van Bruggen (2024). Emission of microplastics to water, soil, and air. What can we do about it? RIVM report

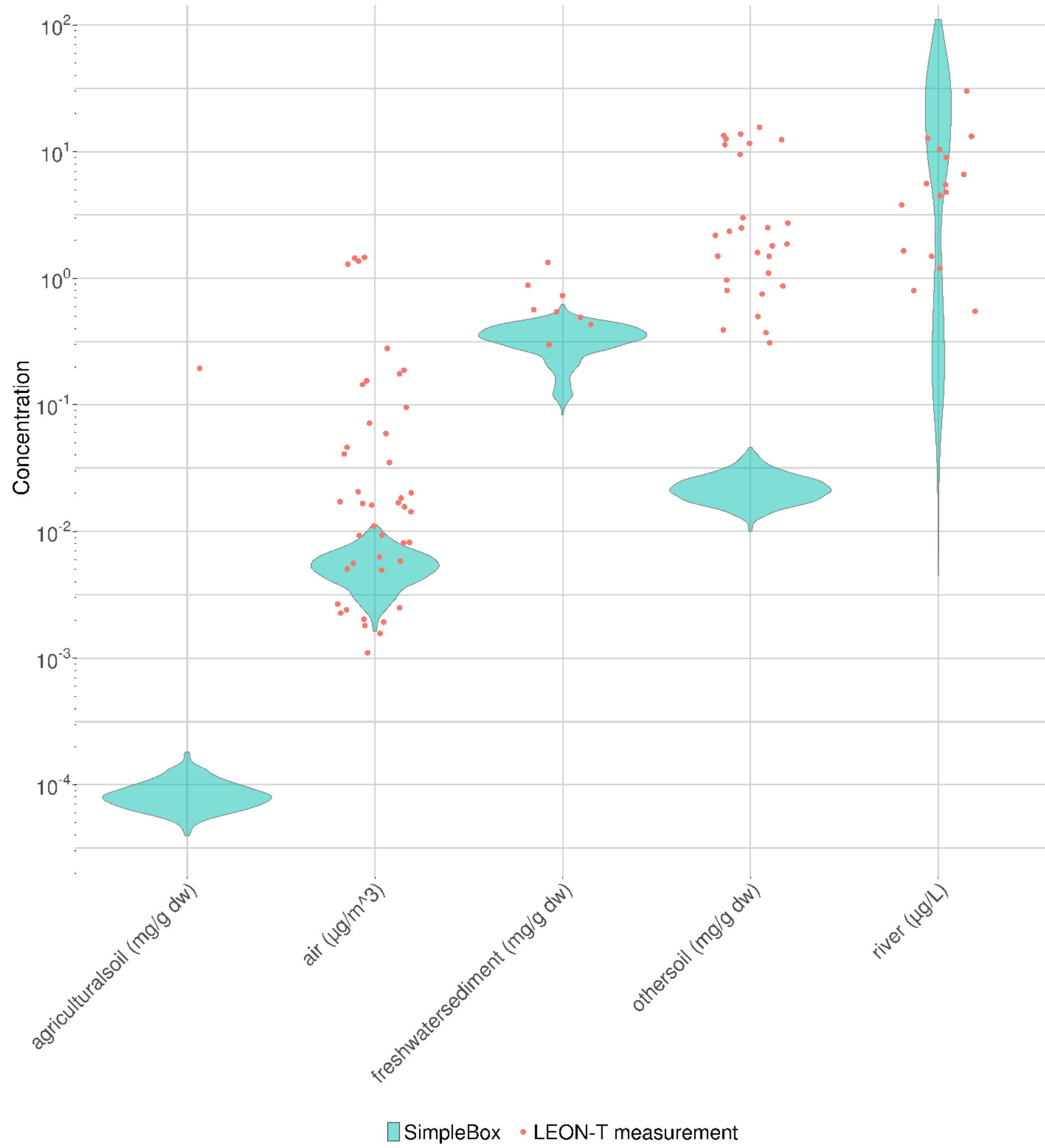


Figure 5. Predicted concentration using a DPMFA model coupled with SimpleBox4Plastics (violin plot) compared to measured total TWP concentrations in air, freshwater sediment, soil and freshwater.

The applied microplastics modelling approach resulted in remarkably similar predicted environmental concentrations compared to the field measurements of TWP in the Netherlands (*Figure 5*). This is without any calibration. Only estimates for soil where underestimated, likely due to spatial simplification of the model and further calibration is part of ongoing work on developing the model.

It is recommended that fate processes such as degradation of plastics be studied more carefully and with the intent to support modelling studies which bring together data and knowledge from different domains. The effect of open graded asphalt and cleaning regimes on TWP emissions should be further investigated to corroborate the model assumption which were found to be very sensitive to the model outcome.

4. Tyre noise effects (WP4)

The main objective of WP4 was to analyse the influence of tyre noise characteristics on the risk for human cardiovascular disease and potentially other metabolic diseases through sleep disturbances in order to propose measures to mitigate negative health impacts. The activity of this WP was divided in two specific tasks: (i) development of a methodological framework for the determination of tyre noise key parameters (in Task 4.1), and (ii) assessment of noise effect during wakefulness, sleep and on the cardiovascular system (in Task 4.2). The effect of characteristic tyre noise on human health was studied using simulated traffic sounds where the significant tyre noise features were integrated.

4.1. Psychoacoustical listening tests (D4.1 and D4.2)

Three psychoacoustical listening tests were conducted. Full results are presented respectively in D4.1 1, D4.2 2 , and Annex 1 of D4.3 3. The goal of study 1 was to provide knowledge of the acoustic perceptual space of tyre noise, and the definition of the sound parameters to be considered in the later evaluations of noise annoyance and sleep disturbance. Thirty-four pass-by noises were recorded by Applus+ IDIADA on an ISO track. These sounds were filtered in order to simulate the isolation of a typical building façade. The two sets of sounds (exterior and interior) were presented to listeners through high quality headphones in two different experiments. For each condition, a free sorting task procedure was used: the listener was asked to group together stimuli which sounded similar. Fifty-three people participated in these experiments. Individual results were used to build two distance matrices, related to the similarity of sounds, in each possible pair. Then a clustering algorithm was used, using these mean accordance matrices as inputs. Five groups could be built in the "exterior" condition, whereas only two groups defined the perceptual space in the "interior" condition. The relationship between the composition of each group and some technical and acoustical features of tyres was. Specifically, for the outdoor condition, important acoustical dimensions proved to be loudness, roughness, spectral balance of the noisy part (the part of the signal that is not a tone) and tonality. For the indoor condition, loudness and tonality were the key features.

The goal of listening experiment 2 was to study the relation between noise unpleasantness and different sound parameters, as identified in experiment 1. Thirty artificial tyre pass-by noises were synthesised, for a given speed of 70 km/h, with different values of the most important acoustical parameters for psychoacoustical response, i.e. frequency, tonality ratio, bandwidth and level. These sounds were filtered to simulate the outdoor to indoor attenuation of a typical building façade. Those sounds were presented to listeners (through high quality headphones) who assessed the perceived unpleasantness of each sound while imagining they were trying to fall asleep in their bedroom. A tree regression analysis performed on the unpleasantness scores showed that the global sound pressure level and the tonality ratio were the two major factors contributing to unpleasantness.

The goal of listening experiment 3 was to study the relationship between self-assessed short-term noise annoyance and fatigue and the physiological response to different sound parameters of tyre noises, as identified in listening test 2. In this previous experiment, participants were asked to assess the unpleasantness of sounds. They were placed in an active listening situation - their attention was entirely focused on the sounds. In experiment 3 however, the focus was on annoyance. Participants had to perform a task with their attention not focused on the sounds (passive listening situation). The exposure was longer (10 minutes for each sound condition). At the end of each condition, the participants evaluated whether the noise had disturbed them in their task. We chose a simple and relaxing task (reading a magazine, playing crossword puzzles, etc.) to represent the situation experienced by someone living near a traffic lane experience. Four different artificial traffic exposure conditions were synthesised. The traffic flow was based on public data taken from the flow of vehicles in the ring road of Paris at night. Each condition was a combination of two values of tonality and sound pressure level. We focused our attention on these parameters as listening experiment 2 showed that they could explain the unpleasantness evaluations. As previously, sounds were filtered in order to simulate the isolation of a typical building façade. Filtered sounds were presented to two groups of 24 listeners (two age groups: below 31 years and over 40 years) in a relaxing situation (e.g. reading, or doing crosswords or sudoku). Participants wore a medical grade wristband that recorded some physiological data (heart rate, skin conductance and body temperature). At the end of each traffic noise exposure, the participants had to assess their perceived annoyance and their fatigue level. Data were analysed in random intercept linear mixed models (random subject effect) adjusted for age, noise sensitivity and order of presentation of the stimuli in the study. The results showed that short-time exposure to traffic noise based on tyre noises only affected the self-assessed parameters while having no physiological effects on the participants, with a prominent effect of the tonality.

4.2. Sleep studies (D4.3)

Two experimental sleep studies were conducted into the effects of tyre noise on sleep and markers of cardiometabolic response. The first study focussed on traffic flow conditions and variations in noise level. This study included 15 young healthy participants (8 female, 7 male), each sleeping for six consecutive nights in the sleep laboratory. The second study focussed on composite tyres compared to traditional air-filled tyres and variations in lower noise levels. This study included 30 young healthy participants (18 female, 12 male), each sleeping for six consecutive nights in the sleep laboratory. Full results for both studies are reported in D4.3 3.

In every night, physiological sleep was measured using gold-standard polysomnography. Cardiovascular activity was measured with electrocardiography and finger pulse plethysmography. Blood samples were taken every morning and analysed with nuclear magnetic resonance (NMR) based targeted metabolomics to determine concentrations of plasma metabolites. Questionnaires were administered every morning, including items on different dimensions of sleep quality, sleep disturbance, recuperation, and emotional regulation. Cognitive function across 10 different cognitive domains was measured every morning and evening. All analyses were performed in linear mixed models with random subject effects, accounting for repeated measures on the same individuals.

Intermittent/impulsive traffic flow was generally more disturbing for sleep than continuous traffic flow of the same noise level. The data for this conclusion were however suggestive rather than conclusive, perhaps due to limited statistical power in Study 1.

Single tyre noise events induced acute physiological sleep fragmentation. These acute responses only translated into changes in overall sleep macrostructure at high average noise levels (40 dB L_{night} in the bedroom). Even in the absence of changes in sleep macrostructure, there was some limited evidence for downstream changes in metabolic function following acute physiological sleep fragmentation.

A shift to composite tyres could lead to reduced physiological sleep fragmentation and reduced cardiovascular arousal if the absolute levels could be reduced. However, although both objective and subjective sleep data indicate greatest disturbance at the highest sound pressure level (as expected), questionnaire data is suggestive that composite tyre noise was more disturbing than air-filled tyres. This could be due to differences in the frequency spectra of the two tyre types. Although the differences were subtle, it is possible that either the differences in spectra per se led to differential subjective response, or alternatively that the novel composite tyres were perceived as more unfamiliar. However, the sound pressure levels of the composite tyres were artificially high in the 35 dB L_{night} condition. The level reduction arising from a shift to composite tyres more than offsets a differential subjective disturbance.

4.3. Recommendations based on WP4 outputs

If composite tyres are successful in achieving reductions in sound pressure level, then a shift towards replacing traditional air-filled tyres with composite tyres would protect against subjective annoyance and physiological disturbance among people exposed to road traffic noise.

Intermittent traffic noise was generally found to be more disturbing than continuous noise of the same equivalent night-time level. This can be considered relevant because intermittent traffic is more representative of usual real world night-time traffic flow. Furthermore, intermittent noise involves exposure to single noise events during an otherwise quiet night, which can lead to acute effects on sleep with downstream biological and psychological consequences. It could therefore be beneficial for noise policy go beyond only energetic averages such as L_{night} and L_{den}, but also consider noise metrics that capture the character of traffic flow and/or single events, such as the number of vehicles pass-bys, intermittency ratio[9] and measures of maximum level such as $L_{AF,max}$.

The tonality of tyres contributed to subjective annoyance. Therefore to avoid annoyance among residents exposed to road traffic noise, future tyre designs should implement tread patterns that minimise the generation of tonal components.

[9] Wunderli, J. M. et al. Intermittency ratio: A metric reflecting short-term temporal variations of transportation noise exposure. Journal of Exposure Science & Environmental Epidemiology 26, 575-585 (2016). https://doi.org:10.1038/jes.2015.56

5. Airless tyre (WP5)

5.1. The purpose of WP5

WP5 had the overall task to construct prototypes for airless tyres for heavy goods vehicles (HGVs). Two such prototypes were actually constructed, in different versions (see D5.2) but project time was not enough to produce them to meet the durability required for the loads of HGVs. Therefore, the final testing of functional parameters had to be limited to noise testing, using a load of 60 % of the maximum (the load index, LI); see D5.3.

5.2. The noise testing results

Noise was tested on the following tyres, where one airless prototype was compared to three reference tyres constructed for the same load:

- Ref tyre #1: Produced in China and marketed at a fairly low price (Giti)
- Ref tyre #2: Produced in Japan and marketed at a moderate price (Bridgestone)
- Ref tyre #3: Produced in France and marketed at a high price (Michelin)
- Airless tyre: The LEON-T prototype designated 1b (see D5.2)

A picture of the four tyres appears in *Figure 6*. They were all in new condition; but run-in as required for rolling resistance tests. The reference tyres were selected based on their popularity on the Swedish market, in each of the price segments. The #3 is considered as a very high-quality tyre, and also fairly economical due to low wear and rolling resistance that may balance out the increased purchase cost. More information about the tyres appears in D5.3.

Please note that neither of the tyres show a clear randomization of the tread pattern (varying distance between lateral or diagonal grooves); instead, the patterns look rather regular. While randomization is common among car tyres it is uncommon among truck tyres. Randomization has the effect of spreading out the energy created by the impact of tread blocks on the pavement over a certain frequency range instead of having all energy at one frequency (plus its harmonics) or over a very narrow range. The latter case means that the sound will have a more or less tonal character, which may be disturbing to the listeners or those exposed to this.

The measurements were made with a variant of the close proximity (CPX) method (ISO 11819-2) where a microphone was mounted outside the tyre subject to the test. The tested tyre was mounted as the rear right tyre on a two-axle truck. After one of the tyres had been tested, another one was replacing the previous one and the test repeated.

Figure 6 : The reference tyres #1, #2, #3 and the airless tyre on the right

The truck was driven along a straight long test track at IDIADA proving grounds in Spain. It approached the test section at a speed just above 70 km/h, then switched-off the engine and coasted down the track until the speed was below 55 km/h. For the coast-down from 70 to 55 km/h, the sound was recorded continuously, and later analysed as overall A-weighted sound pressure level versus speed, or as A-weighted frequency spectrum versus speed. This measuring procedure is much better than the normal coast-by procedure when it comes to disclose tonal components caused by tread patterns.

The overall sound levels did not show anything of significant importance to policy matters, since differences were either small and/or inconsistent; please refer to D5.3. But the frequency spectra are interesting; see *Figure 7*. The pink and red parts of the diagrams show the most prominent parts of the frequency spectra, that ideally would have a relation to human perception. The more pinkish or reddish they are, the stronger the noise emission is at those frequencies and speeds. When there is a very narrow colour strip it indicates a tonal component and when it is prominent in pink or red it is substantial. Where the colours are horizontal without slope it means that these parts of the spectrum are independent of speed; for example, caused by structural resonances. But where there is a slope of the colour strips it means that this part is related to speed, which normally would be caused by tread block impact and release to/from the tyre/road contact patch. When such lines are red but narrow it indicates a prominent tonal component in the noise.

Such tonal components are visible for ref. tyre #3. When listening to the recordings, they are clearly heard too. The red line starting at 70 km/h at approx. 550 Hz is the basic frequency of the tread pattern impact, while the one approx. at 1100 Hz is the first harmonic. One can even note a subharmonic component in blue starting at around 275 Hz. Similar tonal components are seen for the airless tyre at around 350 Hz (believed to be a structural resonance in the spokes) and also at 600 Hz. But the tonal components for ref. tyre #3 are the strongest. It is interesting that not even the tyre (#3) supposed to be of the highest quality has a randomized tread pattern. The reason is probably that there are no requirements, neither legal nor commercial, for such randomization of truck tyre tread patterns. Nevertheless, tonal components from truck tyre noise are often heard in traffic by trained listeners.

It is worth noting that the road surface of the test track had a relatively rough texture which is known to hide special features in the sound generation, such as tonal components, as compared to the ISO surfaces (ISO 10844) which are required during legal noise measurements. We had no access to an ISO surface, so we could not show the "full" tonal effect.

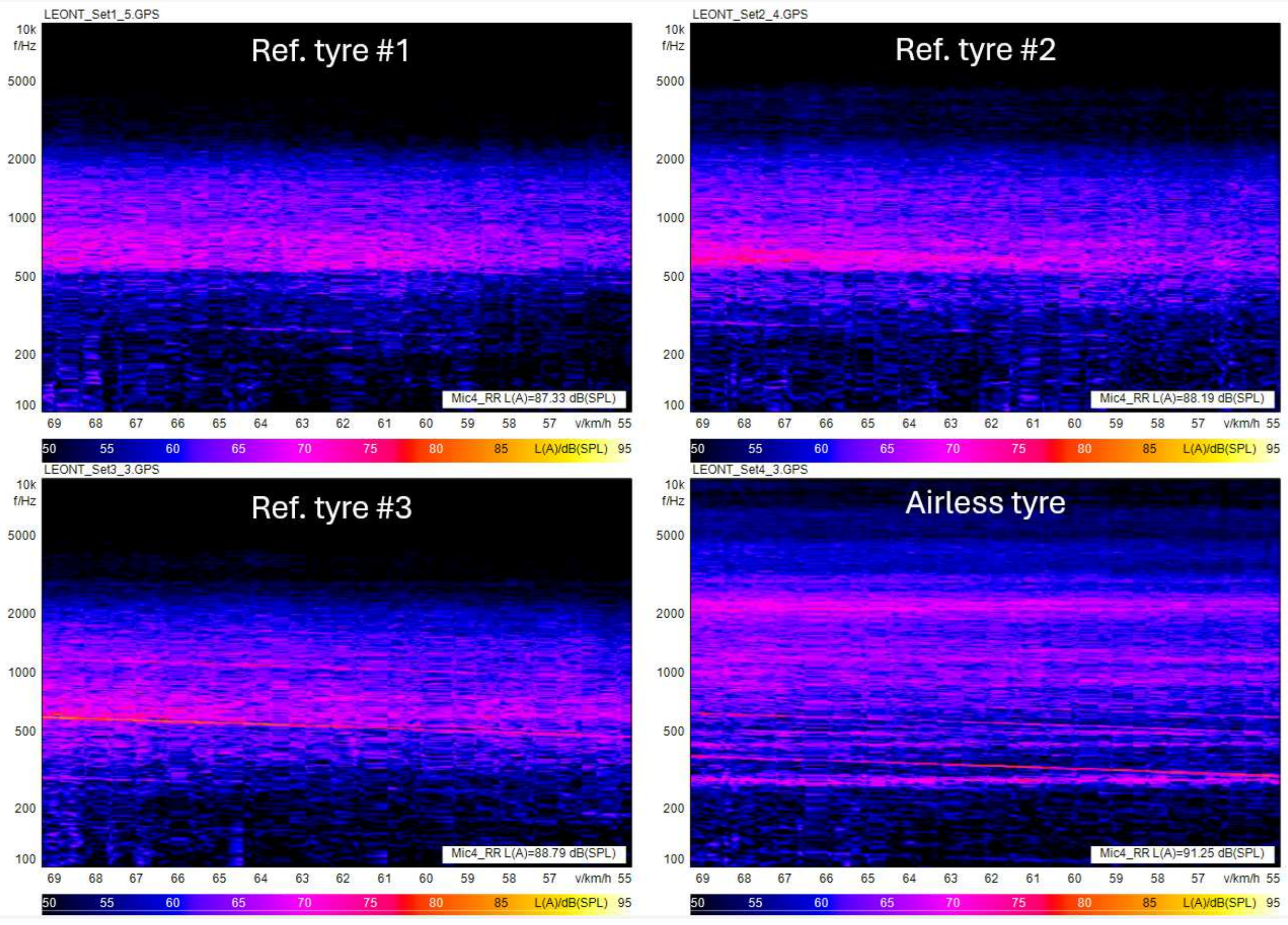


Figure 7 : Three-dimensional A-weighted frequency spectra for the four tyres versus time during coast-down of the truck from 70 to 55 km/h. Horizontal scale is speed in km/h, vertical scale is frequency in Hz and the colour scheme shows the sound pressure level in dB.

5.3. The need for substantial tyre innovations

The pneumatic tyre became common more than one hundred years ago. Since then, hundreds of innovations have been made which have had significant influence on its construction and performance. But in the last 70 years, there is only one substantial innovation that have had a major influence: the radial tyre. Nevertheless, also radial tyres are pneumatic and the overall performance effect was not dramatic as compared to the older bias ply type at the time. The radial pneumatic tyres have continued to develop in many small steps by improved belt and tread constructions and by better materials. Not the least, during the last 20 years the reduction in rolling resistance has been substantial. But with each further improvement to the old principle, one comes nearer to what is achievable and further improvements will be more and more difficult to achieve.

Currently, besides rolling resistance, there are two features which are subject to special attention: tread wear (indirectly emission of particles) and use of more sustainable materials. Significant improvements in these aspects will be made. But can they be made without sacrificing other important functions?

Instead of expecting substantial better overall performance of future pneumatic tyres, it is more likely that we will see a stronger trend where tyres are more specialized on certain functional performance. One may “lift-up” the performance on one aspect (such as wear or rolling resistance) while sacrificing the other parameters only marginally or not at all. We have had this effect already for many years when it comes to adaptation to climate: winter tyres versus “normal” or “summer” tyres. We even have two different optimizations of winter tyres: for north-European climate or for middle-European climate.

Unfortunately, a trend today in the industry is opposite, since winter and summer tyres are now offered more and more as a compromise; namely as all-season tyres. Technically, those are the best for those who do not want to change tyres with respect to season and who are willing to sacrifice safety.

There is a need for a new tyre which is substantially better overall than today’s pneumatic tyres, to be able accept the present or predicted use of road transportation allowing a sustainable future lifestyle.

5.4. Present airless tyres – concepts and prototypes

Do we have a candidate for a future tyre innovation which potentially can provide a break-through in overall performance? Where are the non-pneumatic (i.e. airless) tyres today? Michelin presented its Tweel tyre already more than 20 years ago, which is nowadays a commercial product for golf carts, grass mowers and industrial trucks. It was announced in 2019 that its much improved version called Uptis would be tried on the GM Bolt electric car and that a market introduction may happen already in 2024. We did not see that. Other global tyre manufacturers have own versions of airless tyres, and a few types (including the Uptis) are running at low or medium speeds on low-performance vehicles to gain experience. A survey of presented concepts for airless tyres and sometimes also prototypes is presented in LEON-T D5.1. A problem is that while these airless tyres are obviously puncture-free, the performance potential in other aspects are uncertain. No objective measurements on performance of the airless prototypes have been published so far; except for the background model for the LEON-T tyre[10] in passenger car size named “the Composite Wheel”. The latter suggested that the major improvement potential would be rolling resistance, with noise emission as second. But for all other airless prototypes or concepts, which are quite different constructions, nothing is known of what we can expect or hope for in terms of improved performance over pneumatic tyres.

5.5. Encouraging and limiting policies for new innovative tyres

The fast developing trend of using additive manufacturing (sometimes popularly called 3D printing) for various products may be useful for at least parts of tyre manufacturing. This can be encouraged by standardization policies (ISO, CEN and ASTM) and research and industrial policies to warrant quality aspects of this new opportunity. Additive manufacturing may make it easier to produce many tyre variants in the same line, but in lower numbers, which will encourage the trend suggested above to produce tyres for more optimized performance with focus on certain parameters. The current trend to optimize tyres for electric vehicles in combination with additive manufacturing will be favoured by this.

Airless tyres will potentially need less and fewer materials and will be easier to entirely be produced by additive manufacturing than pneumatic tyres in combination with rims. Well designed, they will also need only retreading of the rubber tread to have the same lifetime as the vehicle they sit on, thus replacement tyres will be needed in much lower volumes. This saves raw material and valuable resources. Since the tread band will be almost equally supported over its entire width by the spokes it can be made flatter which probably should reduce wear.

Another aspect important to reduce costs and increase quality is development of tyre test methods which are fast and accurate. Present method for friction (“wet grip”), noise and rolling resistance have problems in this respect. Noise and friction are based on outdoor testing on test tracks which have very limited reproducibility and rely on “good weather”. The recent project STEER showed the problems with noise measurements which at the moment makes the labelling system questionable[11]. The latter reference also noted that a similar problem appeared for rolling resistance labelling.

In summary, and according to STEER, it is necessary that tyre noise measurements for ECE regulations and EU labelling be moved indoors and rely on

[10] Sandberg, Ulf (2009): “The Composite Wheel – An innovation featuring low tire/road noise and low rolling resistance simultaneously”. Proc. of Inter-Noise 2009, Ottawa, Canada (paper 09-591).

[11] Bühlmann, et al (2022): “STEER - STrenghtening the Effect of quieter tyres on European Roads—Final Report”. CEDR report: https://www.cedr.eu/docs/view/6373a6fec0dc7-en

Sandberg, Ulf and Mioduszewski, Piotr (2022): “The EU Tyre Noise Label: The problem with measuring the noise level of only a few of all tyre variants”. Proc. of Inter-Noise 2025, Glasgow, United Kingdom additive manufacturing of test tracks on indoor drum facilities in order to meet the needed requirements on uncertainty and efficiency. It is also necessary to require measurements on noise on more tyre dimensions than the “worst” for noise emission. Such measurements will also be able to distinguish between the tonal properties of tyre noise from different tyres in the same way as was done in LEON-T.

A very serious problem for the possible introduction of airless tyres on the world market is the shift from one system of manufacturing to another, using very different procedures. Even if airless tyres will give very favourable performance, one may expect that market introduction will be delayed, for the same (and amplified) reasons as the introduction of radial tyres was delayed in North America due to restructuring of manufacturing plants combined with vehicles needing some redesign. When airless tyres, apart from the treads, may last as long as the vehicle, the tyre replacement market will die in favour of a heavily expanded retreading market. The normal lifetime of tyre manufacturing plants lasts for decades, so everybody in the tyre and vehicle industries will not be happy with too rapid developments. Consequently, and unfortunately, an anticipated airless tyre revolution will likely take a long time.

5.6. Policy recommendations

Based on experience gained in this project, we suggest:

To make it faster and easier to introduce airless tyres on the market, there should be no restrictions related to homologation due to the special features of airless tyres. As an example, the classification of pneumatic tyres in terms of geometrical dimensions will have to be different for airless tyres. The determination of load index (LI) might be challenging.

An ambitious long-term policy for EU requirements on tyres should be presented, making obvious that radically new tyres will be needed in the future, with the purpose of increasing the interest and attempts of the tyre manufacturers to develop tyres that meet such requirements.

The retreading industry should be made aware of the boost if airless tyres will be common on the market, since then the retreading will take over much of the market that the replacement tyre has for pneumatic tyres.

Since there may be limited interest in the tyre industry to abandon existing tyre technology and its manufacturing plants and gradually switch over to airless tyres, encourage the development of innovative tyres, like airless tyres, by offering EU projects with such aims and by providing other support for relevant and focused R&D.

Modelling of stresses under dynamic loads will be important in airless tyre R&D. An EU project with such aims may be an important start. The design used in LEON-T shall be part of such modelling together with some promising concepts presented by the tyre industry. Construction using additive manufacturing will be useful to encourage in connection with the modelling efforts.

The integration of airless tyres with electric motors should be encouraged. Versions of some airless tyre concepts, especially the one in LEON-T will have extra space making it easier to integrate electric motors with the tyre. This may be of particular interest to articulated trucks, where tyres on non-driven axles may be driven by electric motors in certain situations. In this way all tyres on an articulated heavy truck may be driven occasionally, for example when traction is extremely critical such as on winter roads with deep snow or icy surfaces with uphill gradients.

The development and introduction of new measurement methods that are useful for accurate and economical labelling of tyres, with respect to rolling resistance, friction (wet grip), noise and wear should be supported (via CEN and/or ISO). Such methods should be available for indoor use where standard reference tyres and test surfaces are important, with the latter potentially produced from digital standard(s) using additive manufacturing. Note especially, that it is important that tyres optimized for low or for high temperatures are actually tested under temperature conditions that are representative for their intended use. Today, for example winter tyres are tested at 20 or 25 ^{o}C despite they are intended for temperatures around (water) freezing point and below and despite that it is well-known that their performance is largely influenced by temperature.

The tonal components of sound frequency spectra of truck tyres should be subdued to negligible levels, such as has already been achieved for passenger car tyres for commercial reasons. Essentially, it means that rubber tread patters should be randomized to avoid fixed periodical features along the circumference of the tread. This is not commonly made today on truck tyres, as is illustrated in this project *Figure 7*.

There are methods to identify significant tonal components that may be applied, although it is practically difficult with today's pass-by measurements. When noise measurements are changed to use an indoor drum method, as is suggested in the previous paragraph, or if implementing the special "CPX method" used in WP5 of LEON-T (outdoors), the use of recently developed metrics in ISO to identify tonal components can be applied. However, until then, it may be as simple as adding in homologation documents that all tyres for road use, i.e. even truck tyres and even retreaded tyres, shall have tread patterns that avoid the emission of substantial tonal components when travelling on paved road surfaces. All major tyre manufacturers have advanced methods for such randomization of treads already, at least applied for passenger car tyres.

5.7. Conclusions

In WP5, project time was too short to develop a well-functioning airless HGV tyre. The prototype that was possible to test for noise emission provided a small reduction of noise (2 dB) at normal highway speeds (80-85 km/h) but was noisier than the reference (pneumatic) tyres at lower speeds than 70 km/h. However, this prototype was not fully developed. It should also be mentioned that the test was made on a test track with texture resembling that of common highways and motorways, while it is known that when tested on so-called ISO surfaces (used for regulations) noise differences become substantially higher.

6. Policy recommendations studies (WP6)

The goal of Work Package 6 (WP6) was to synthesise the knowledge gained during the project's experimental activities into potential new policies and regulations and to evaluate their possible future impact for the public health and wellbeing of citizens, as well as the social acceptance of the economic impacts that could derive from the new policies and regulations. Possible future policy scenarios included tyre airborne particle emissions (D6.1), microplastics emissions (D6.2), and tyre noise emissions (D6.3). The final executive summary (D6.4), which is this deliverable, gathered the most relevant policy recommendations in all the three topics. This outcome may contribute to identifying guidelines for future policies and envisaging specific actions to mitigate tyre emissions. All tasks built on leading projects in the space of research, policy and regulations on the environmental and human health aspects of the tyre industry. The overall recommendations as well as open issues related to tyre particle emissions were continuously discussed with European Commission and other stakeholders (e.g. in the particle measurement programme (PMP) informal working group) in order to ensure that the objectives of the project remained in line with the objectives of the European Commission. Evidence for the economic and social acceptance of proposed measures were evaluated through stakeholder workshops and public surveys.

6.1. Evaluation of future new policies and mitigation strategies on tyre wear particle emissions (D6.1)

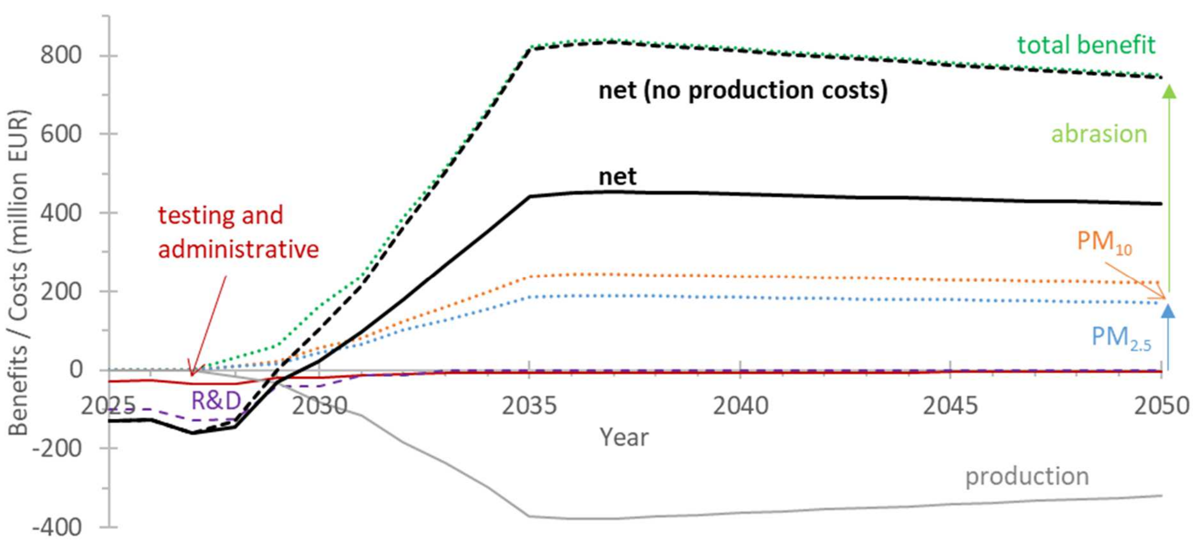
D6.1 aimed in defining future new policies and mitigation strategies on tyre wear particle emissions. The three scenarios considered were: (i) the baseline scenario investigating the possible evolution of the problem assuming a no policy change scenario; (ii) the second scenario examining the feasibility of emission regulation similar to that of exhaust emissions, i.e. particulate matter (PM); (iii) the third scenario examining the possibility to control tyre wear particle emissions through tyre abrasion rate. A cost-benefit analysis evaluated the costs and savings of PM or abrasion rate reductions.

A basic assumption was that C1 tyres are fitted to passenger cars (PCs), C2 tyres to light-commercial vehicles (LCVs), and C3 tyres to heavy-duty vehicles (HDVs). We assumed a 0.7% annual fleet stock increase, 3.2% increase of the electrified vehicles, 11,500 km, 20,000 km, and 100,000 km annual mileage for PCs, LCVs, and HDVs respectively. The electrified PCs were considered to be 20% heavier than the conventional PCs, with a direct proportional impact on the emissions. Electrified LCVs and HDVs were considered 15 and 5%, respectively, heavier from their conventional counterparts. The emission factors were taken at the lower edge of the range given in a recent review. For PCs we considered an abrasion rate of 95.7 mg/km, 2 times higher abrasion rate for LCVs and 8 times higher abrasion rate for HDVs. The cost burden of the tyre wear as PM was taken from the 'Handbook of costs'. As there is no such cost for microplastics (sizes < 5 mm), we searched the literature for cost estimations of plastics and we considered the minimum value (7.2 EUR_{2025}/kg) as cost of microplastics.

In our reference baseline scenario the fleet from approximately 255 million vehicles in 2025 reached 352 million vehicles in 2050, of which 307 million were PCs and 37 million LCVs. The electrified PCs reached 91.5% in 2050, 87.3% for LCVs and 82% for HDVs. The tyre wear mass from 867 kt in 2016, increased to 985 kt in 2025 and 1270 kt in 2050. PCs contribute to tyre pollution 32% (±1%) and HDVs 56% (±1%).

Scenario 2 examined PM and Scenario 3 abrasion. One 'Policy' case assumed a basic 10% reduction of all emission factors following the gradual Euro 7 implementing dates for C1, C2 and C3 tyres. Such reduction can be achieved by various methods; however, this study made no assumption on the final decision on the abrasion limits linked with Euro 7. These will be the object of a full evaluation following a market assessment, which is due by end of 2024 for C1 tyres. Variations of this basic scenario to test other hypotheses (with 20% and 30% reduction of emissions factors) were also analysed.

The basic 10% scenario resulted in 7% less mass from abrasion until 2050 (2,115 kt less mass) (*Figure 8*). The cost savings from reduced tyre abrasion were estimated to be around 11,000 million EUR; 1,700 million EUR from less PM10 and 3,400 million EUR from less PM2.5. The combined benefit was 15,000 million EUR (excluding overlapping size regions). Taking into account testing and administrative, research and development costs, the net benefit was still a significant 14,000 million EUR. Assuming that the high emitting tyres would increase their price due to production costs (2% per tyre), the net benefit for the 2025-2050 period would be halved (7,300 million EUR). The positive impact will start to be visible between 2029 to 2032 (depending on the assumed costs) and will reach the maximum per year in 2035.[12]



[12] Giechaskiel, B.; Grigoratos, T.; Dilara, P.; Franco, V. Environmental and Health Benefits of Reducing Tyre Wear Emissions in Preparation for the New Euro 7 Standard. Sustainability 2024, 16, 10919. https://doi.org/10.3390/su162410919

Figure 8 : Costs and benefits over the years for the 'Basic' scenario. The environmental costs of the testing are not plotted as they are negligible (<1% of the test and administrative costs).

6.2. Evaluation of future new policies and mitigation strategies on microplastics emissions (D6.2)

Task 6.2 aimed to assess the impact of microplastics emissions from tyres to the environment, public health and well-being of citizens, carrying out a cost benefit analysis. Information from WP2 regarding abrasion rate and from WP3 regarding the fate and quantification of tyre particles to different environmental compartments were used to (i) develop different policy scenarios aiming at the reduction of microplastics emissions from tyres (ii) evaluate the overall benefit of the different scenarios to the environment. Strengths and weaknesses of different scenarios were examined against the baseline scenario of no policy change in terms of economic, social and environmental impacts.

In this deliverable the fate of microplastics was examined according to the literature. A simplified model was developed to assess different mitigation strategies. The model assumes that tyre particles reach air, road or runoff. The road was assumed to be porous or non-porous with different trapping efficiencies. The runoff was assumed to be treated or not. The model was crosschecked with D3.5.

The cost of microplastics (year 2025) was assumed to be 13.8 EUR/kg for those ending up to the aquatic environment and 3.8 EUR/kg for those ending up in the soil (*Figure 9*). The cost estimates were based on cost estimates of plastics to the environment. To put the number into perspective PM10 has a cost of 29 EUR/kg, while PM2.5 160 EUR/kg in a city, and 495 EUR/kg in a metropole. The costs of mitigation measures, (runoff treatments) were based on the literature. The costs ranged from a few hundreds of thousands (ponds) to millions (wastewater treatment plants).

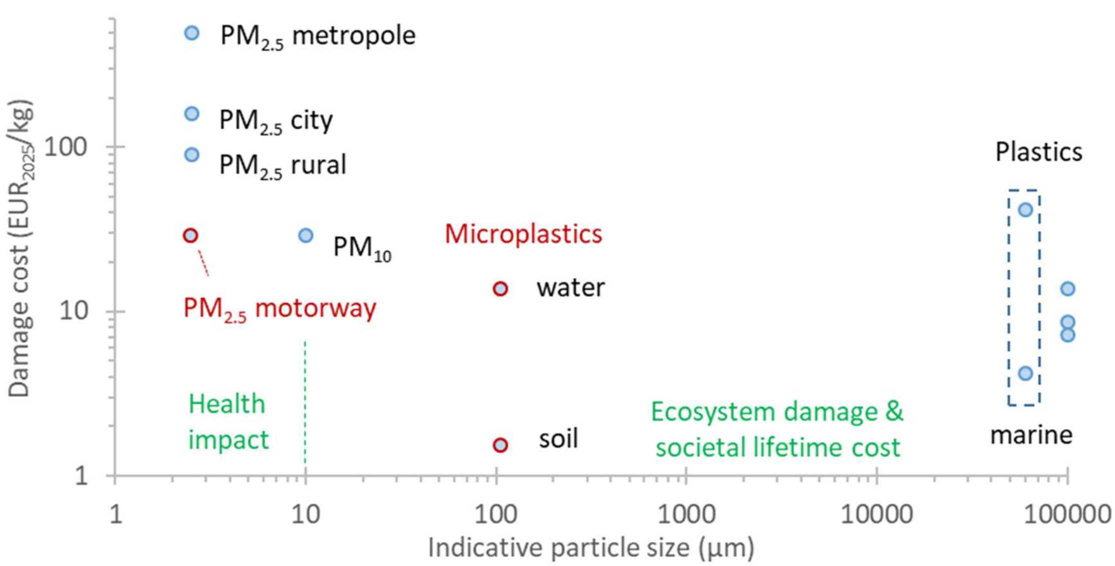


Figure 9 : Cost of PM, microplastics and plastics.

A few sample cases were examined:

1. Replacing non-porous with porous surfaces at highway roads.
2. Improving runoff treatment at highways.
3. Improving runoff treatment at urban areas.

For the first case, after full implementation of porous roads, a benefit of 460 million EUR per year is expected with expected investments recovery after 25-30 years. For the second case, after implementation of higher efficiency highway runoff treatment, a benefit of 330 million EUR per year is expected, with a total net benefit of 6,000 million EUR in the 2025-2050 period. However, for this scenario the cost of tyre particles in the surface waters and those deposited was assumed to be equal to the cost in the marine environment. Upgrade of all wastewater treatment plants with tertiary treatment can result in annual benefits of 594 million EUR. However, upgrading the facilities has high costs, which would take longer than 30 to recover if only tyre particles benefits are considered.

The model can be used to assess other mitigation measures (e.g. tyre filters if they become available) or solutions for hot spots, or accelerated biodegradation which might have faster recuperation of the investments.

Comparing with D6.1, it is clear from the analysis that addressing the source is the most cost-effective approach with an order of magnitude higher cost effectiveness compared to treating tyre particles after they have been emitted to the environment. According to D6.1 reduction of 10% of the tyres mean abrasion rate results in net savings of 7,400-14,000 million EUR in the 2025-2050 period, depending on the cost assumptions.

Thus, measures reducing tyre wear should be prioritized (e.g. tyres with less wear rate, reduction of annual mileage and smoother driving, well maintained vehicle etc.).

6.3. Evaluation of future new policies on noise emissions (D6.3)

In this deliverable we went through the noise regulations for tyres, vehicles and electric vehicles. We collected measured data to assess current noise levels. We compared them with the literature. We collected data from the European product registry for energy labelling (EPREL) and other databases and search for correlations between noise and other parameters such as wet grip, rolling resistance, abrasion and price. We developed a simplified model to estimate citizens' noise exposure and to assess various mitigation measures.

Pass-by noise levels measured at IDIADA in 2023 and 2024 were on the order of 71 dB for M1 vehicles, 66 dB for M1 plug-in hybrids, 1-2 dB higher for N1 and N2 vehicles, but around 80 dB for N3. M3 vehicles were on average at 76 dB, and M3 electrical vehicles 7-9 dB lower.

Regarding the analysis of the label parameters, it was difficult to find a correlation between the labelling parameters, as the tyre's quality level also played a role. In general, premium tyres tended to show better levels across all label parameters. The average noise levels of the five best selling tyre sizes for C1 tyres were 70.5 dB, for C2 tyres 71.7 dB, and for C3 tyres 71.5 dB. Correlations of all data (all seasons, and sizes) or even separately for each tyre dimension showed a tendency of improved rolling resistance (RR) or wet grip (WG) with lower noise tyres. Thus, in general we do not expect worse performance by lower noise tyres. Tyres with the same RR and WG levels showed that lower noise tyres had higher price only for C2 and C3 tyres. Analysis of the consumers' tyre testing data showed that there is no clear effect of reduction of noise to any parameters (safety, abrasion, RR) and on average the impact was even positive. However, there are studies that show that there is a conflict between noise and safety performances.

We developed a simplified noise calculation tool combining previous studies. We calibrated the model to the 2017 Environmental Noise Directive (END) noise exposure distributions (latest available at the writing of this deliverable) and applied it to estimate a reference scenario from year 2025 to 2050 and the impact of various mitigation measures. The key characteristics of the model were:

- Tyre rolling noise varied with speed, but the type approval values (of latest Stage 2) were used at the reference regulatory speeds.
- The vehicle noise was fixed for all speeds and equal to the type approval value (latest Phase 3). For electric vehicles we used a value of 64 dB based on our measurements. Hybrid vehicles were assumed to have noise in between the two (internal combustion engine and electric vehicles).
- Intermittent flow increased the noise by 3 dB, quieter road decreased the noise by 5 dB, barriers by 10 dB.
- Based on the traffic conditions (number of vehicles per hour, average speed, smooth or interment flow), road characteristics (quiet, with barrier) and the population living close to roads the noise exposure distribution was calculated.
- Finally, the cost to the society was calculated using the values from the Handbook of road traffic costs.
- The procedure was repeated for every year of interest (from 2025 to 2050) assuming a 0.7% fleet increase, 0.13% population increase, and electrification of the fleet (95% by 2050).

The results clearly demonstrated the decrease of the average L_{den} over the years (*Figure 10*): 57.0 dB in 2017, 55.1 dB in 2025, 54.7 dB in 2035 and 52.3 dB in 2050. A 2 dB reduction of the tyre rolling noise had an impact of 0.6 dB decrease.

The monetarised savings were large. In the first 10 years the annual savings would gradually reach 2 bil EUR per year, while until 2050 they would reach 12.5 bil EUR per year only by fleet electrification. Lowering the tyre rolling noise 2 dB would save another 4 bil EUR only in 2035 and another 5 bil EUR only in 2050.

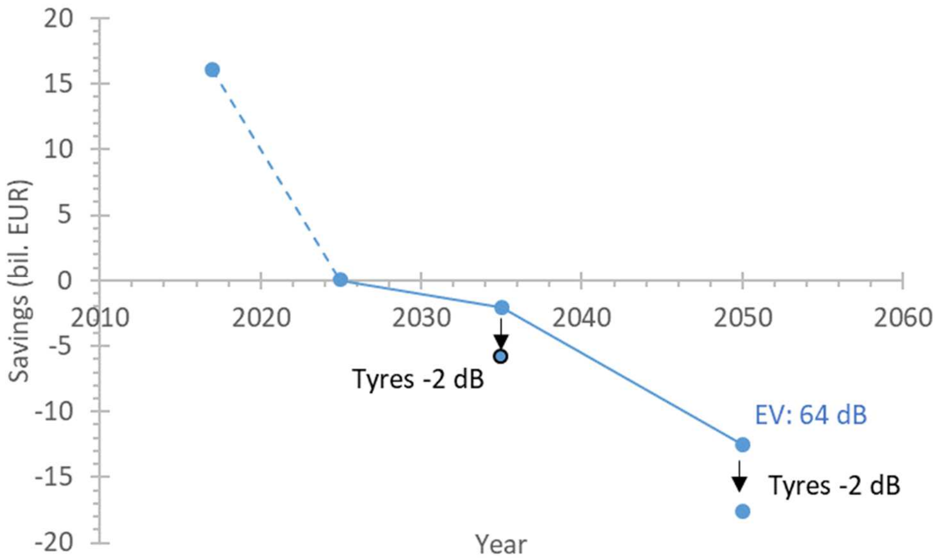


Figure 10 : Savings due to reduce noise compared to year 2025. The reference scenario is the blue line, while other mitigation measures are shown as points

7. Conclusions and policy recommendations

Tyre wear is the largest source of microplastics, with at least 35% contribution to total microplastics. In general it was shown that reduction of tyre wear and/or noise emissions will result in a huge benefit for the society under all cases examined. However the following points need to be highlighted.

7.1. Tyre wear

In WP2 it was concluded that PM and PN measurements of tyre wear particles are not ready for regulatory purposes. Thus, any reduction needs to come from regulation of total mass loss. Our cost-benefit analysis assumed proportional decrease of PM/PN and total wear. Even if the reduction is not proportional, a total mass loss reduction will still result in some PM/PN reduction. However, there might be a point that optimisation of mass loss reduction could result in PM/PN increase. Thus, further research on PM/PM from future Euro 7 tyres is important.

We also found different wear rates at urban, rural and motorway driving routes, suggesting that more research is also needed in that direction (WP2). Nevertheless, we developed a model (WP3) that can predict wear rates under different driving conditions and could be used for comparisons of tyres or extrapolation of specific tests to other conditions.

In WP6, the cost-benefit analysis assumed tyre particle costs to the society based on the Handbook of transport costs. This means that tyre PM was assumed to be equally harmful to PM from other sources. We also did not speculate on the harmfulness of specific compounds contained in tyres (e.g. PAHs, zinc etc.). The regulated method does not cover them, and such information is not available for the market tyres. Nevertheless, these compounds should be covered by e.g. Annex XVII REACH regulation, persistent organic pollutants (POP) regulation. Any other harmful compounds should be included in such regulations. In any case, more research is needed on the health and environmental impact of tyre particles, with the biggest research gap relating to their chemical characterization. Based on WP3 experience, it is recommended to use additional parameters (e.g. oxidative stress, DNA damage, omics analysis) to characterize the toxicity of particles. Also, more complex cell models (e.g. co-cultures of – possibly primary – epithelial cells and macrophages) and mode of exposure (e.g. air liquid interface exposure) may be applied.

It should be highlighted that there is no cost estimate for tyre microplastics. We assumed a value based on studies on plastic particles. This needs to be assessed in the future, and in particular whether particles ending up in soil or in the water have different environmental impact (cost). What also needs to be better understood is the impact of aged particles, as in general, were found to have higher oxidative potential (WP3).

Even with all cost uncertainties mentioned above, addressing the problem directly at the source (tyres) was found to be by far more efficient than at the various environmental compartments. However, our analysis in WP6 focused only on tyre particles. It is possible that the parallel reduction of other microplastics at the environmental compartments by the proposed (tyre) mitigation measures (e.g. porous roads, better treatment facilities) could result in higher benefits to the society (than our estimations based only on tyre particles reductions). Another source of uncertainty is the cost estimate of the treatment facilities and in particular the retention efficiencies for tyre particles and microplastics in general. Furthermore, biodegradation plays an important role, not only in mass loss, but also on toxicity (WP2/3) and different tyre compounds have different degradation rates. In addition to fate processes, such as degradation, the impact of asphalt or the cleaning should be further investigated to have better input estimates for the models. WP3 also proposed improved sample pre-treatment, thermo-analytical and microscopic methods for tyre particles.

7.2. Noise

In WP4 intermittent traffic noise was generally found to be more disturbing than continuous noise of the same equivalent night-time level. This is important because intermittent traffic is more representative of usual real world night-time traffic flow. Furthermore, intermittent noise involves exposure to single noise events during an otherwise quiet night, which can lead to acute effects on sleep with downstream biological and psychological consequences. It could therefore be beneficial for noise policy to go beyond energetic averages such as L_{night} and L_{den}, and consider additional noise metrics that capture the character of traffic flow and/or single events, such as the number of vehicles pass-bys, intermittency ratio and measures of maximum level such as $L_{AF,max}$, and tonality (which also contributed to subjective annoyance).

The literature analysis in WP6 demonstrated that a reasonably small (2 dB) reduction of pneumatic tyre noise is feasible without compromising safety, rolling resistance and other parameters. The cost analysis showed that noise reduction results in huge benefits: fleet electrification, even without any other mitigation measure, has a big positive impact. Nevertheless, further tyre rolling noise reduction (and other measures not examined) can further enhance the result. Tyre/road noise will be relatively more important as it will be the major noise component also in cases where the propulsion unit noise was important.

A promising solution is the airless tyre (WP5). Even though a prototype tyre was not fully developed, tests at a test track with surfaces resembling actual roads, suggested noise reduction potential and improved tonal components. However, the introduction of airless tyres in the market is not easy and would need support either with dedicated projects or regulated steps. It is argued that the tonal components of sound frequency spectra of truck tyres should be subdued to negligible levels, such as has already been achieved for passenger car tyres for commercial reasons. Essentially, this means that rubber tread patters should be randomized to avoid fixed periodical features along the circumference of the tread.

7.3. Survey

A survey on acceptance of future measures for tyres showed that while cost considerations remain a barrier, there is certain support for sustainable practices, stricter regulations, and noise-reduction measures based on a quite relevant awareness of traffic and in certain cases tyre contribution to pollution and noise. To build on these findings, we recommend:

- Enhancing public awareness campaigns on tyre abrasion and noise pollution.
- Developing innovative solutions to balance affordability with environmental performance.
- Prioritizing urban-focused regulations to mitigate noise and environmental impacts in densely populated areas.

Annex A. Survey on acceptance of future measures for tyres

This chapter presents the LEON-T user/consumer acceptance survey. The aim of this survey is to understand user/consumer behaviour, preferences and acceptance levels in relation to tyres and their environmental impact. The data collected will support the elaboration of policy recommendations, influencing guide tyre industry practice with a particular focus on sustainability and innovation.

The survey targeted a diverse group of people, including car owners, car manufacturers, tyre manufacturers and/or distributors and non-car owners, to ensure a holistic understanding of tyre-related issues. Most of the respondents belong to the car owners and non-car owners categories which provided us interesting insights on diverse knowledge, awareness and perceptions levels of tyre-related environmental and health impacts such as noise pollution and microplastic emissions.

The survey was conducted via an online questionnaire, distributed via email and social media, e.g., LinkedIn, EUagenda, ResearchGate, Particle Measurement Programme (PMP) group, contact lists of the LEON-T partners. It was open for responses over a twelve-week period (until mid Nov 2024) and was designed to be completed in approximately 5-10 minutes. Participation was entirely voluntary and anonymous, ensuring that respondents could share their views freely. Data collection conformed to the highest ethical standards, all information was securely stored and used exclusively for research purposes.

The questionnaire covered a wide range of topics, starting with demographic information such as age, gender, geographic location and income level. Subsequent sections delved into car ownership and tyre use behaviour, tyre replacement preferences and knowledge of tyre-related environmental concerns such as tyre wear, microplastic pollution and noise pollution. In addition, the survey explored perceptions of existing and proposed tyre regulations, such as Euro 7 and UN Regulation 117, as well as willingness to support new regulations aiming at reducing the environmental impact.

The results of this survey will provide valuable information on the environmental and social dimensions of tyre use and will serve as a basis for driving changes in industry policy and practice. By understanding people's concerns and priorities, this research aims to contribute to the development of more sustainable, efficient and user-friendly solutions for the future of mobility.

A1. Demographic profile of survey respondents

A total of 112 respondents participated in the survey, representing regions in Europe, North America and Asia, although the majority were from the EU. Regarding the area of residence we obtained a balanced representation of urban, suburban and rural perspectives.

Understanding the demographic composition of survey respondents provides valuable context for interpreting their attitudes and behaviours. This section outlines key characteristics of the individuals who participated in the survey.

In terms of respondents category we wanted to obtain responses from car owners, non-car owners, car manufacturers and tyre manufacturers or distributors. To get as many data as possible we shared the survey by different means including social media and direct emails, among others.

To obtain data from car manufacturers or tyre manufacturers/distributors we targeted specific car and tyre manufacturers associations (e.g., ERTRAC, ETRMA, ETRTO, ACEA). Unfortunately, we didn't obtain statistically relevant answers from these groups. Therefore, the analysis is focused on car owners and non-car owners groups. A potential reason behind this reluctance to reply the survey, beyond lack of interest or time constrains, is that it could be difficult for respondents to become the representatives of their whole organization in these particular fields when replying the survey.

Car ownership status

The majority of respondents (86%) identified as car owners, with only 14% as non-car owners (*Figure 11*). This disparity reflects a respondent pool that is predominantly engaged with vehicle ownership and, by extension, tyre-related issues. While non-car owners represent a smaller segment, their perspectives remain critical for understanding the level of awareness of a general audience as well as broader societal and environmental impacts of tyre-related pollution.

Age, gender, and education

The majority of respondents fell within the 25–64 age group (96%), with a very similar distribution of replies in all the ranges 35-44, 45-54 and 55-64 (ca. >20%) and a bit higher for the 25-34 age group (ca. 28%) (*Figure 12*). Including the gender distribution as a determinant, female respondents are younger than male with ca. 53% vs. 27% for 25-34 age group, respectively (*Figure 13*).

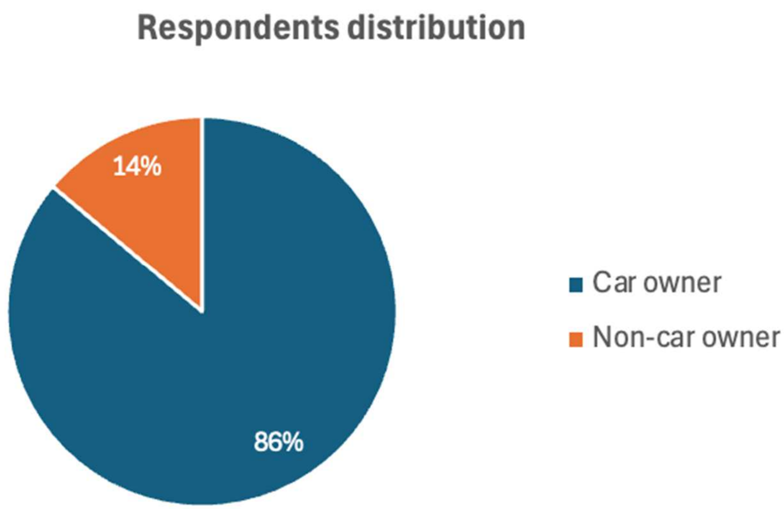


Figure 11: Car ownership distribution of survey respondents.

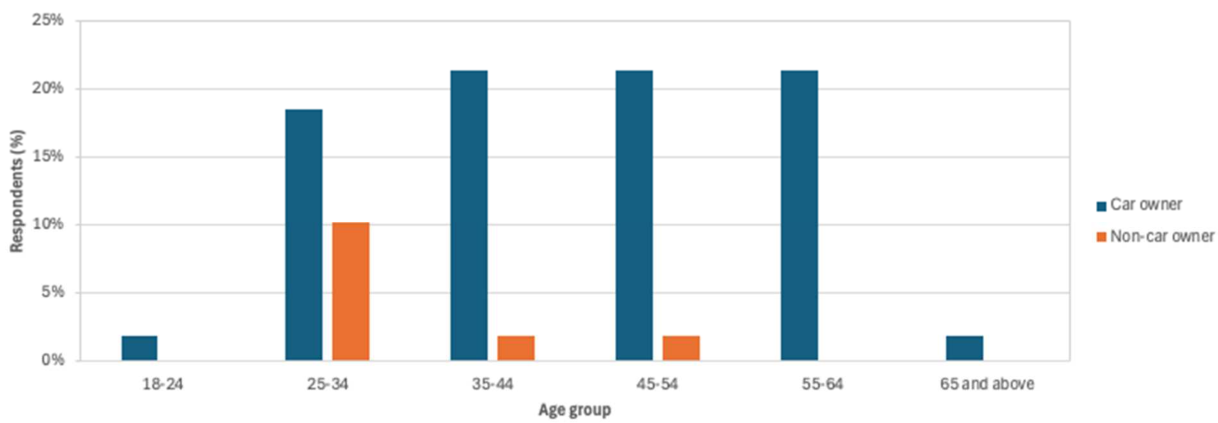


Figure 12: Age distribution of survey respondents.

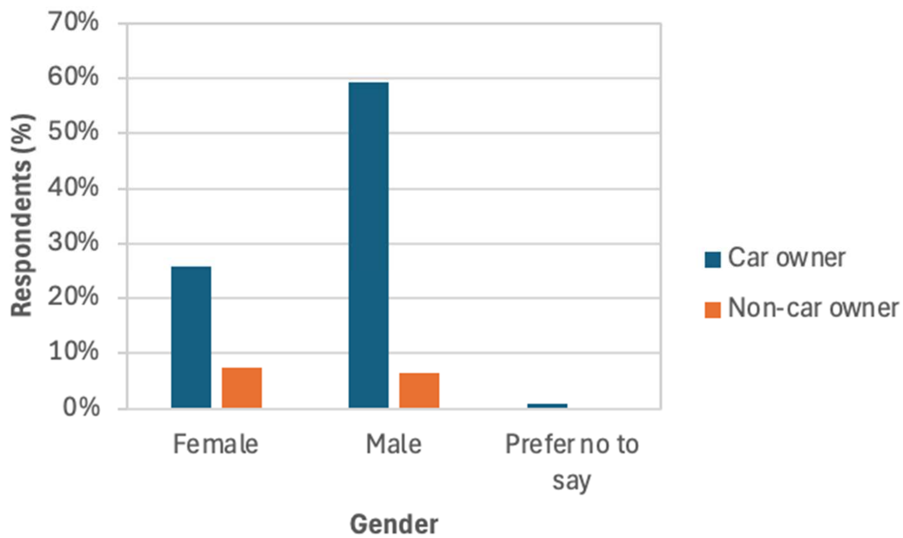


Figure 13: Gender distribution of survey respondents.

Most respondents had attained at least a bachelor's degree (ca. 90%), showcasing a highly educated sample likely to have informed opinions on environmental and regulatory topics (*Figure 14*).

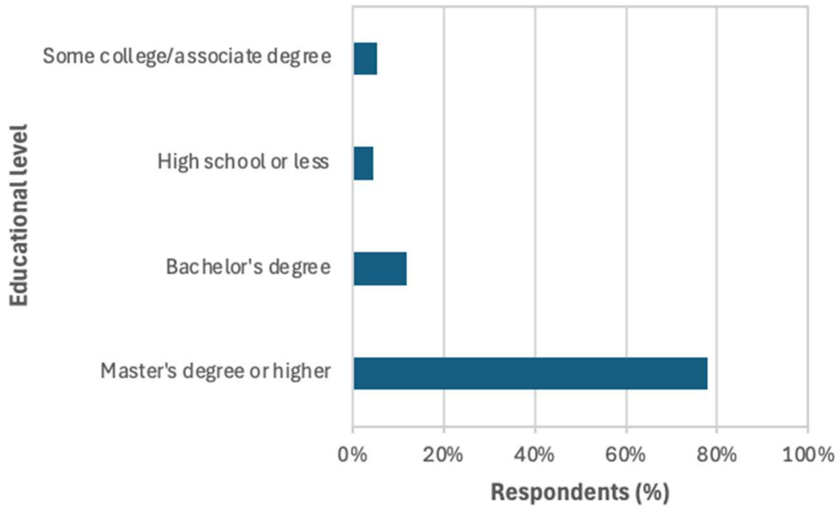


Figure 14: Educational level of survey respondents.

Geographic distribution and area of residence

Geographically, 42% of respondents were from S. Europe,. 23% from W. Europe, 24% from N. Europe and 9.3% from E. Europe countries, and >2% from other regions (*Figure 15*). Urban residents dominated the sample but just slightly (38%), with suburban and rural residents comprising both 31% (*Figure 16*). This urban skew is important given the increased relevance of tyre noise pollution in densely populated areas.

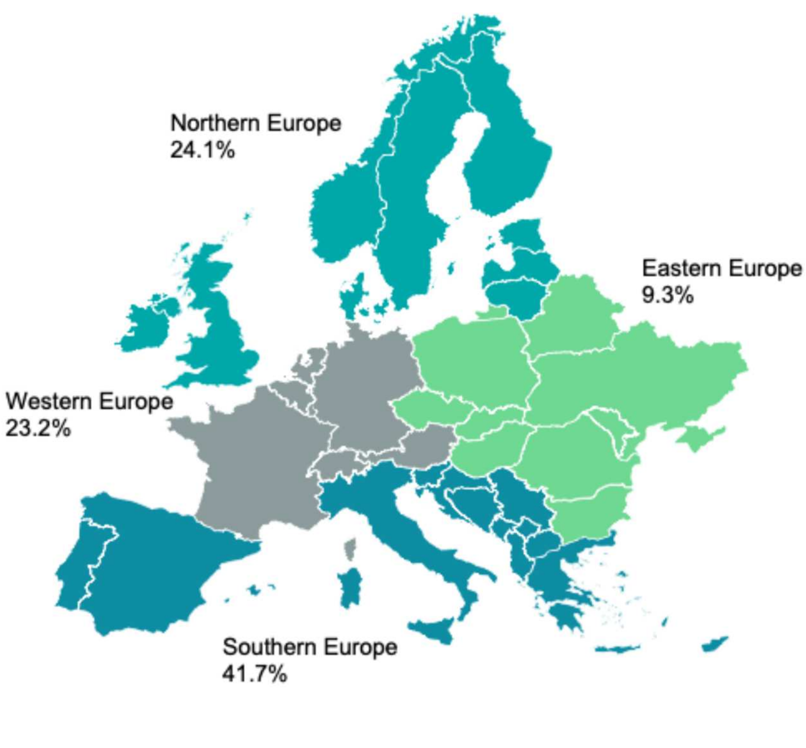


Figure 15: Geographic distribution of respondents.

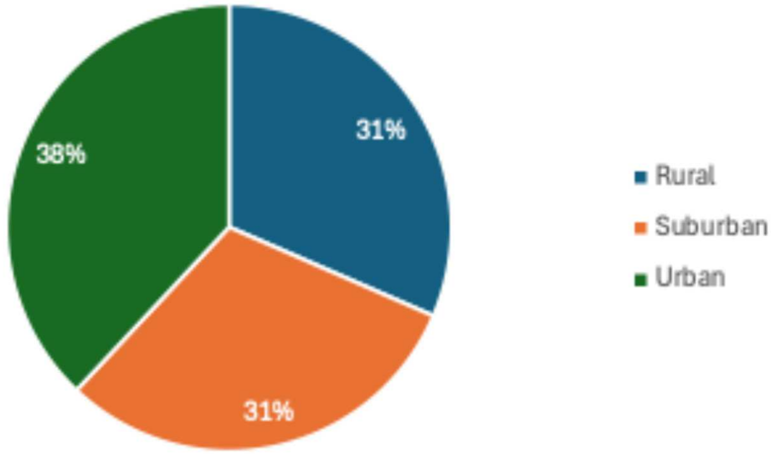


Figure 16: Area of residence of respondents.

Income level

Respondents represented a range of income levels, with almost 70% earning a middle-income (*Figure **17***). This professional diversity underscores the relevance of tyre-related issues across different economic contexts.

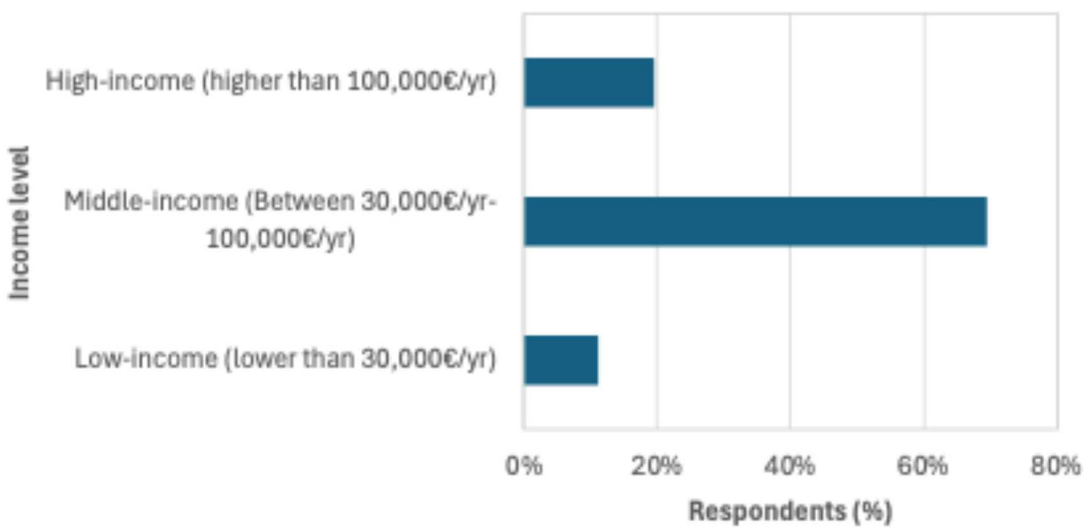


Figure 17: Income level information of survey respondents.

A2. Car ownership and tyre-use behaviour

Vehicle and tyre types

Among car owners, more than 60% owned typical passenger vehicles,. 20% owned SUVs, and 10% drove small city passenger vehicles (*Figure **18***). Regarding tyres, up to 67% used both types of tyres (winter and summer) changing them during the year, while 20% opted for summer tyres, and 13% relied on all-season tyre options.

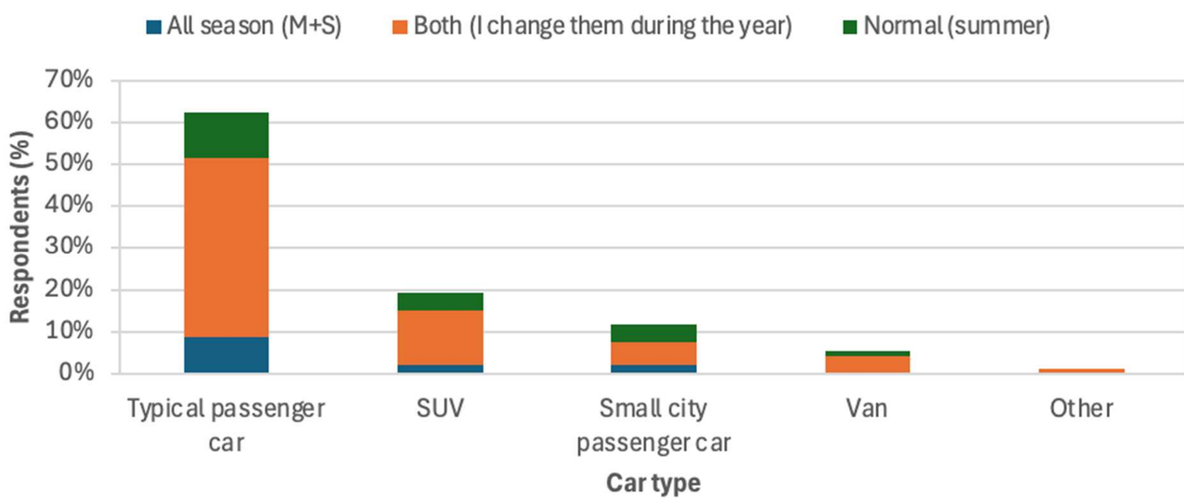


Figure 18: Vehicle and tyre types of survey respondents.

Driving patterns and tyre replacement

The average respondent drove approximately between 5,000-30,000 km annually (84%), with most kilometers driven in regional roads with speeds lower than 100 km/h (45%), followed by under mixed conditions (23%) and very closely by motorways with speeds higher than 100 km/h (20%) (*Figure **19***). On the other hand, urban segment was the less populated (12%).

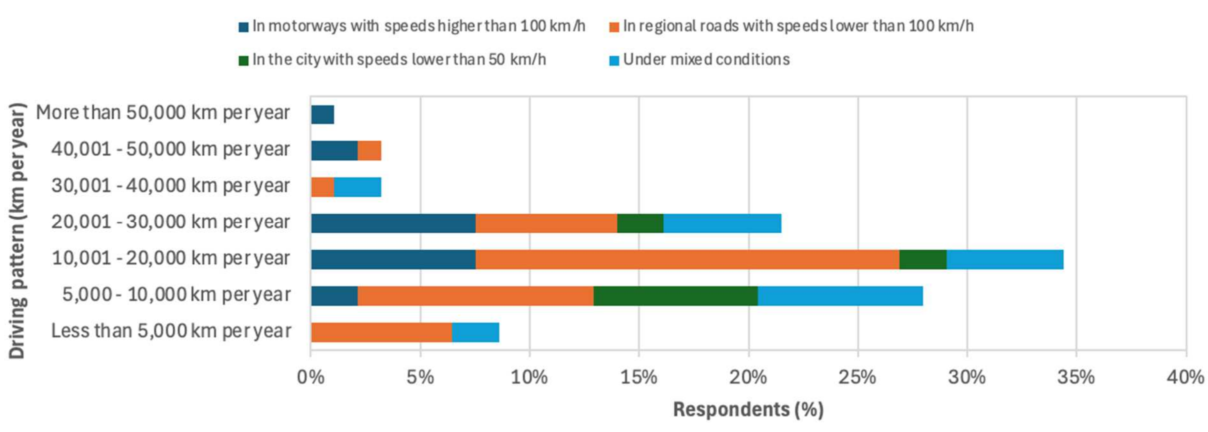


Figure 19: Annual driving pattern of survey respondents and type of road.

With regards to tyre replacement decisions, they were primarily driven by recommendations from specialists during a regular maintenance of the vehicle (48%) followed by reaching a minimum tread depth (34%), while a more planned replacement due to time or distance travelled was selected for 17% of responses (*Figure **20***).

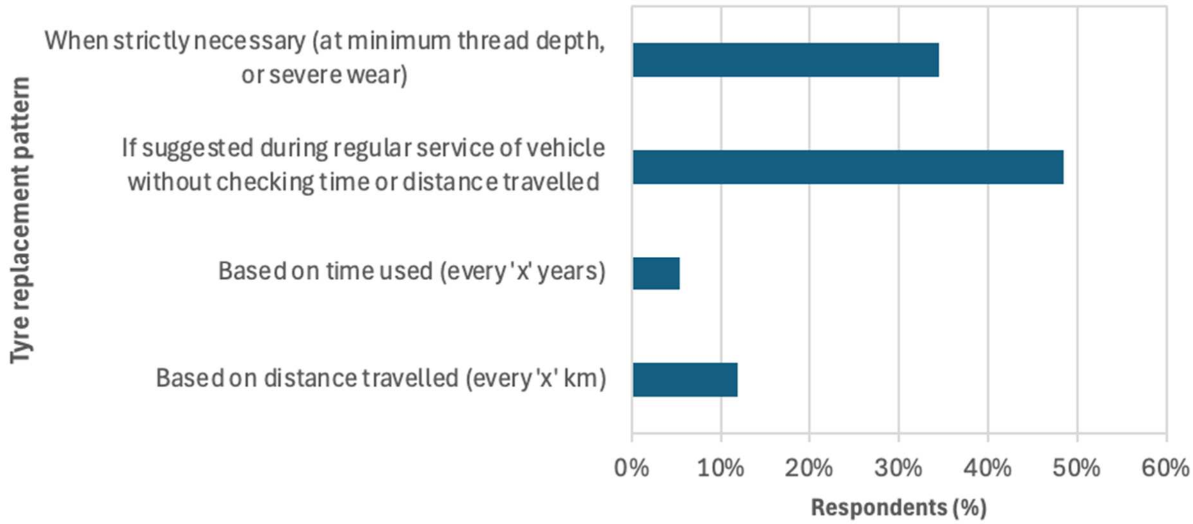


Figure 20: Pattern of tyre replacement.

Interestingly, low-income respondents presented more planned tyre replacement pattern than other segments reaching up to 28% that replace tyres based on time used or distance travelled. This segment also increases when increasing the age. By geographic location, Northern and Western Europe respondents present a larger preference for tyre replacement when strictly necessary (43% and 52%, respectively) in comparison with Southern and Eastern countries (24% and 22%, respectively). By educational level, respondents with high school education show greater reliance on specialist recommendations (60%) while bachelor's degree holders rely on suggestions at a lower extent (27%).

With regards to tyre replacement decisions these were primarily driven by safety concerns (ranked 7.9 out of 9) and reaching a certain tread depth (ranked 7.8 out of 9) followed by recommendations from specialists (6.5 out of 9) and performance deterioration (6.2 out of 9), while reaching a certain mileage concern less people (4.8 out of 9) (*Figure **21***).

Key factors influencing tyre purchases

When purchasing tyres, respondents prioritized safety (8.1), quality and durability (7.7), and price (7.0) (*Figure **22***). Fuel efficiency (6.4), which is related to environmental impact and running costs, ranked 4th. However, eco-friendliness and sustainability, linked to tyre abrasion, doesn't outstand among the other factors being ranked as the third less important (5.3 out of 9). The same trends were observed when the data are weighted by the type of tyre. Only for the respondents that used ALL SEASON tyres this factor became very relevant. However, the choice of ALL SEASON tyres, which is always a compromise, did not influence the ranking of safety as the most important feature when purchasing tyres.

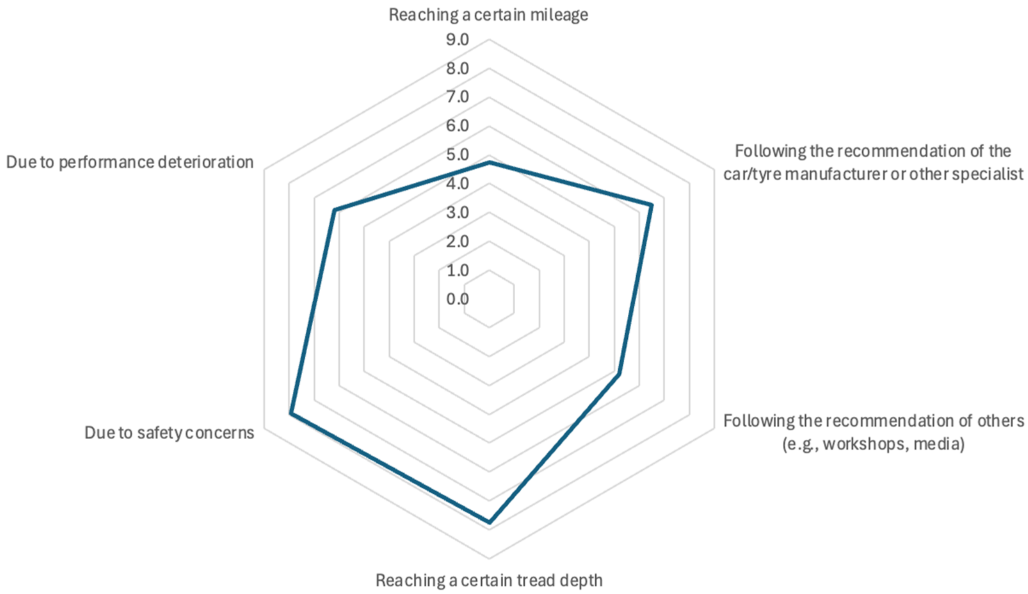


Figure 21: Key factors influencing tyre replacement decisions.

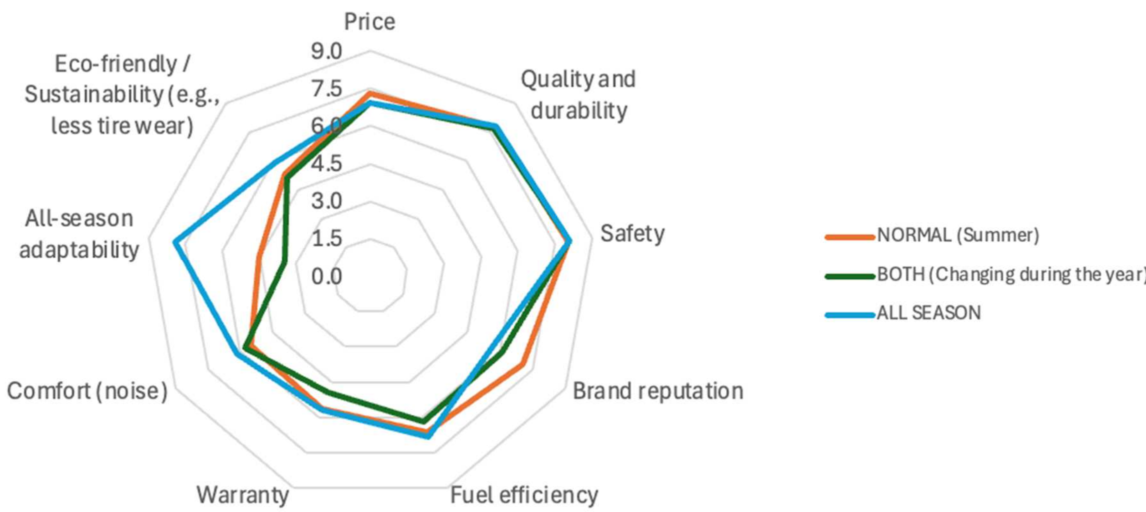


Figure 22: Most important features when purchasing tyres weighted by tyre type.

A3. Environmental awareness and concerns

Environmental impact of tyres

A significant proportion of respondents associated tyre use with tyre wear and microplastics pollution (86%), air quality degradation (76%), and noise pollution (55%) while the degradation of the road surface and infrastructure ranked 4th (*Figure **23***).

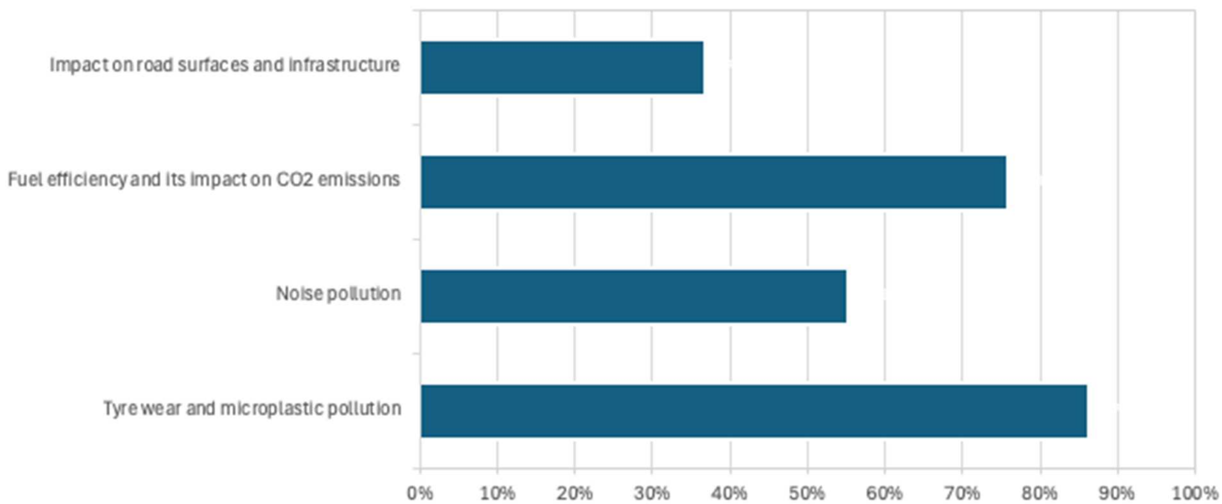


Figure 23: Environmental concerns due to tyres during use phase.

Awareness of tyre abrasion's role in microplastic pollution was relevant, with more than 50% declaring themselves as fully aware of the environmental and health impacts associated with tyre wear particles and microplastics release (*Figure **24***). Additionally, up to 35% have some kind of knowledge in this regard without understanding the whole problem.

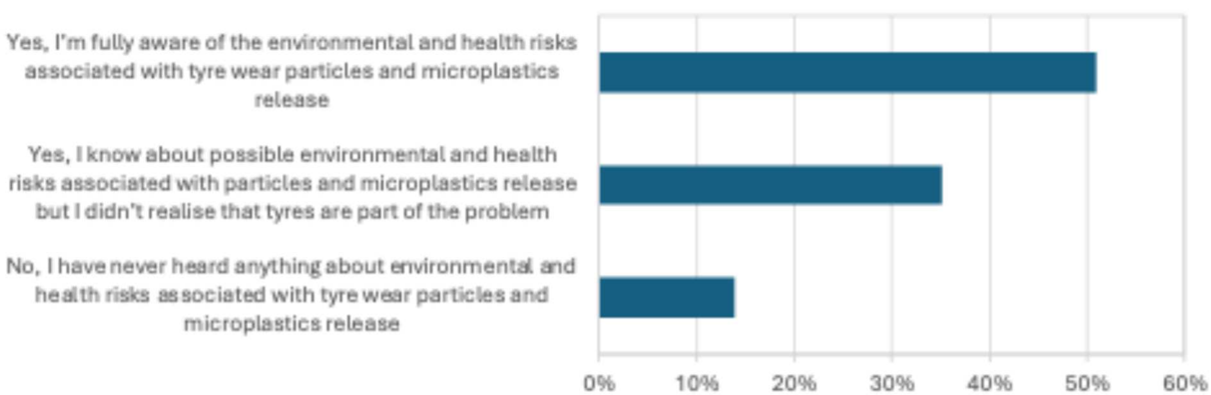


Figure 24: Awareness level of the risks associated to tyre wear particles and microplastics.

In terms of the perceived relevance of tyre abrasion contribution to microplastics pollution up to 67% considered fairly or very important this contribution (*Figure **25***). By gender, there are not representative differences. The greatest difference appeared when segmenting the data by respondent category, showing greater concerns non-car owners vs car owners (”very important” category grew from 28% up to 32%).

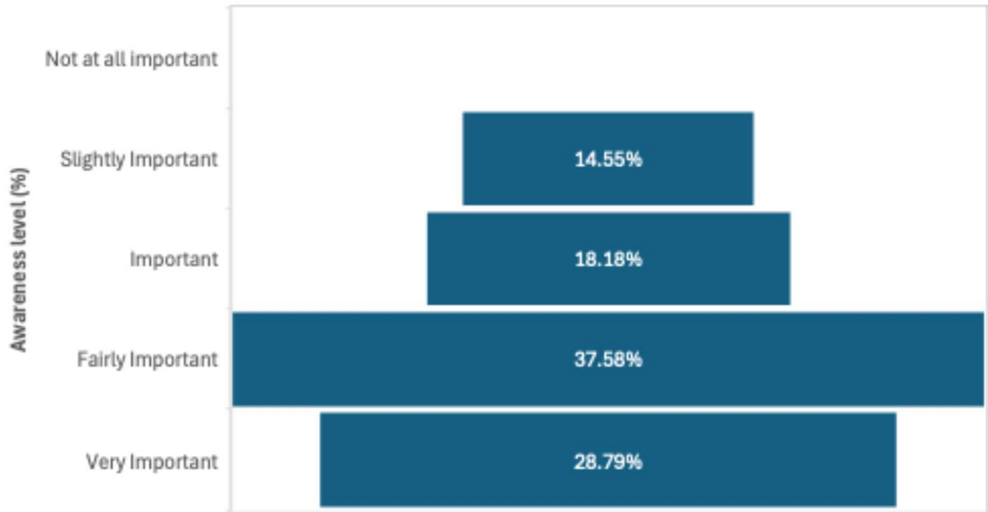


Figure 25: Perceived relevance of tyre abrasion contribution to microplastics pollution.

Regulatory awareness and support

While ca. 70% were aware of tyre-related regulations and guidelines such as Euro 7 and UN Regulation 117, only 37% knew more than one. In any case, the former data could indicate a statistical bias not being representative of average EU citizen knowledge (*Figure **26***).

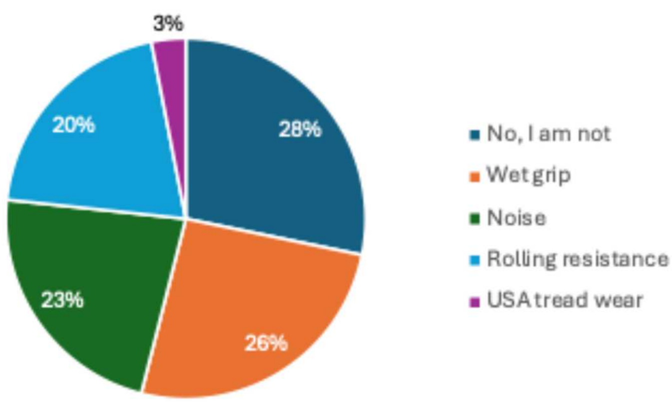


Figure 26: Environmental concerns associated to tyres during their use phase.

Nonetheless, 74% clearly supported stricter legislation to reduce tyre abrasion and noise pollution in urban areas (57%), highlighting a general willingness to prioritize sustainability (*Figure **27***).

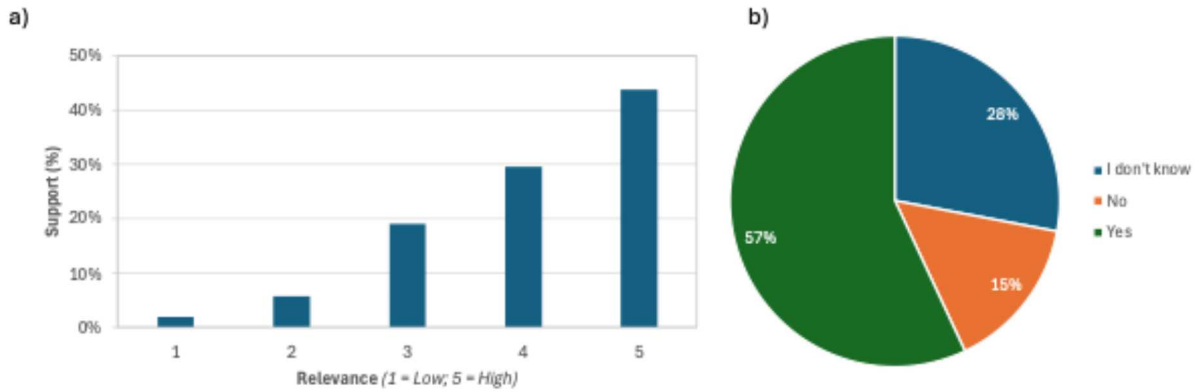


Figure 27: Support to the implementation of additional regulations, a: specific new tyre abrasion regulation (i.e., UN regulation 117) aimed at reducing the environmental impact of tyres; b: measures to address tyre noise pollution in urban areas.

A4. Perceptions of legislative impact

Expected impact on tyre safety and sustainability of upcoming tyre legislation
Respondents identified several potential benefits of the proposed legislation, including promotion of greater innovation and investment in new technologies (88%), promoting materials and processes with reduced environmental impact (81%) and implementing additional guidelines addressing noise issues (71%) (*Figure **28***). However, concerns about the opposition from the industry arose, with 51% expressing fears that stringent regulations could create resistances from tyre manufacturers and distributors.

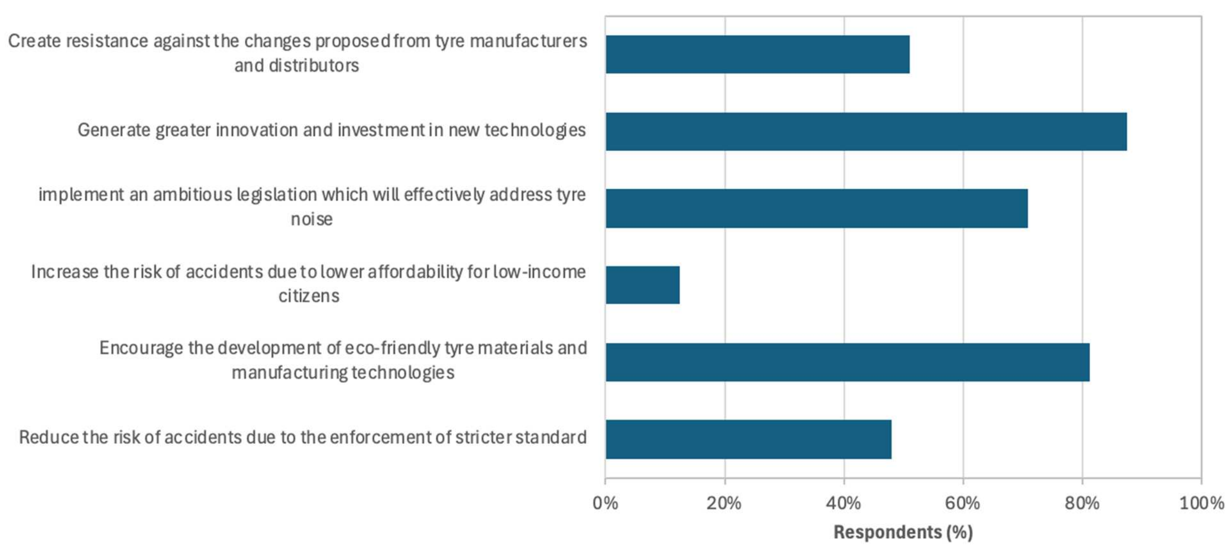


Figure 28: Expected impact of upcoming tyre regulation.

A5. Noise pollution and quality of life

Impact on daily life

Although tyre pollution is identified by an important group of respondents as a factor influencing negatively their quality of life (see *Figure **23*** and *Figure **24***), the impact in their daily life is small (*Figure **29***). Only 12% have consciously altered their outdoor activities or recreational plans due to concerns about tyre pollution (i.e., tyre wear, microplastics, noise).

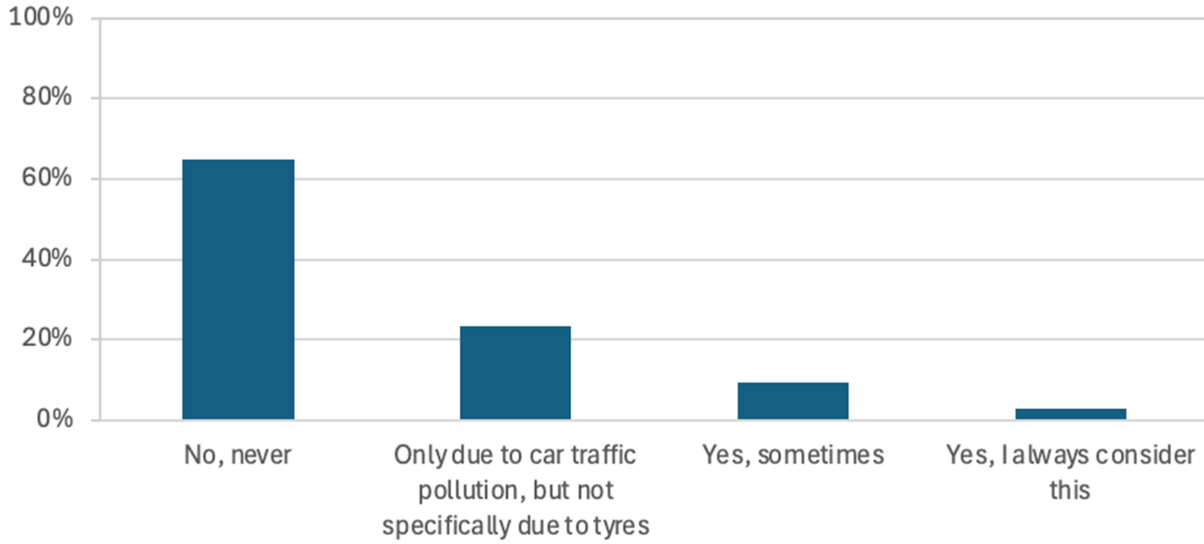


Figure 29: Alteration of outdoor activities due to tyre pollution concerns

Noise pollution emerged as a significant concern, with 74% of respondents indicating that tyre noise affects their quality of life (*Figure 30*). Of these, 30% reported disturbance or annoyance even during the day due to road traffic noise, increasing up to 41% of respondents who experienced difficulty to concentrating or sleeping due to noise from nearby roads or highway (*Figure 31*, a)). From rural to urban areas, this feature increases from 38% to 53%, respectively. When considering only the urban scenario, this pattern is altered even strongly when we consider the proximity of the residence to a major road or highway, increasing up to 73% the respondents that found concentration or sleeping difficulties, and if the bedroom window faces towards a road with frequent and/or fast traffic, slightly growing up to 88%. However, the most relevant factor seems to be the car ownership.

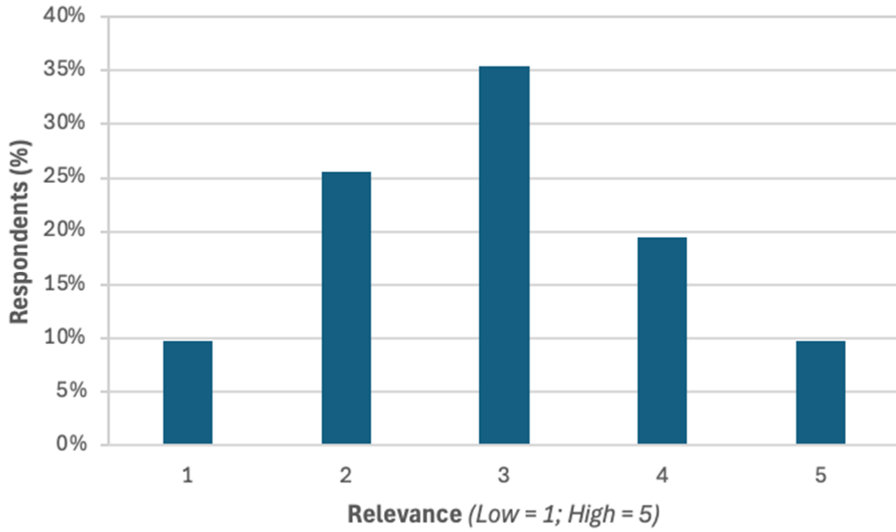


Figure 30: Tyre noise perception as a determinant affecting quality of life

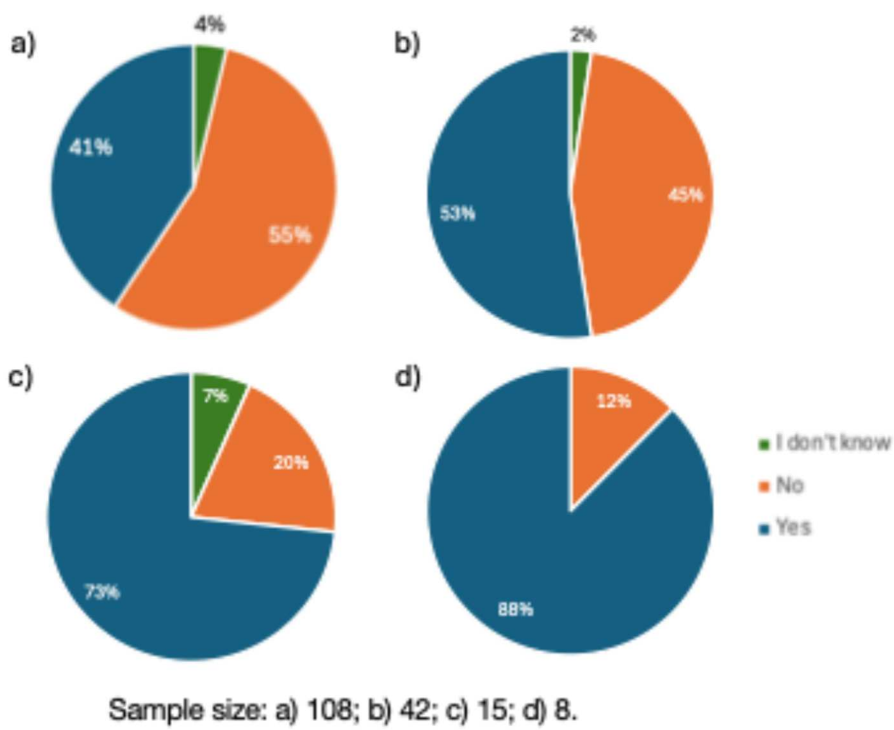


Figure 31: Difficulty on concentrating or sleeping due to noise from nearby roads or highways (a: general answer; b: proximity to a major road less than 100 m; c: bedroom window facing a busy road; d: non-car owners noise disturbance perception)

In addition to more logical determinants as proximity to a major road and to have a bedroom window facing a fast traffic road that increases the sleep disturbance perception up to 43% (distance <100m to a major road, sample size = 30) and 62% (sample size = 16), respectively; car ownership is also a very relevant determinant when assessing the sleep disturbance due to traffic noise, increasing from 14% to 40% the people that moderate or high affection of their sleep due to road traffic noise (*Figure **32***).

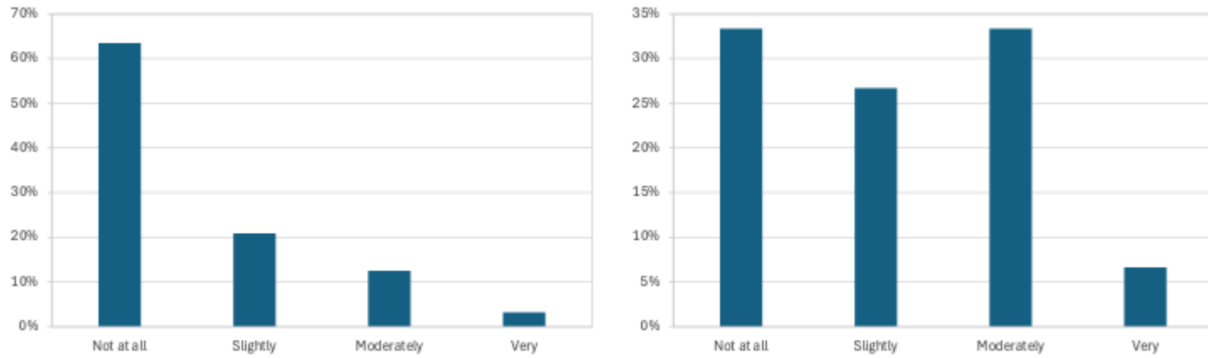


Figure 32: Sleep disturbance due to road traffic noise for: car owners (left), non-car owners (right).

Public perception of tyre noise

Respondents are aware of the significant contribution of tyres to the exterior noise (60%), especially if they don't own a car where increases until 80% (*Figure 33*). By age, younger respondents between 25-34 showed lower awareness level of the tyre contribution to total noise (43%).

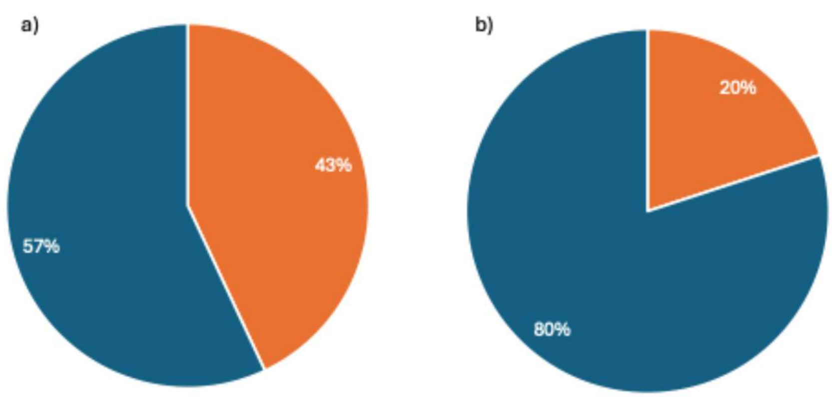


Figure 33: Awareness of environmental impact of tyre noise (a: car owners; b: non-car owners).

By geographic distribution, Western Europe respondents showed a higher awareness of tyre noise pollution (85%) vs Northern and Southern Europe respondents (54% and 53%, respectively), while Eastern Europe countries showed the lower awareness level (40%).

When considering the type of vehicle, respondents felt that tyre noise contribution to exterior noise of fossil-fuelled vehicles is lower (29% considering “very important” and “extremely important” answers), compared to electric vehicles (56%) (*Figure 34*).

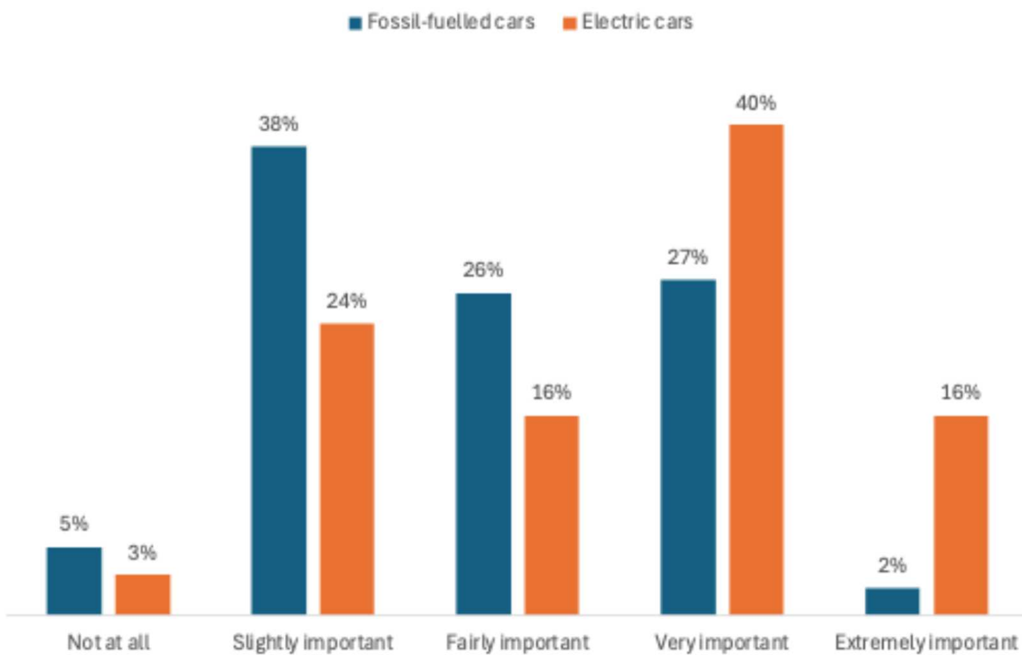


Figure 34: Perception of tyre noise contribution to exterior noise by fossil-fuelled or electric vehicles.

A6. Willingness to support environmental measures

Paying for sustainability
Key factors influencing legislative adoption could include the potential cost increases. In this regard, when asked about willingness to pay more for environmentally friendly tyres ca. 60% of the respondents indicated they would pay an additional 30-60€ per set to reduce the environmental impact of their tyres. It is noteworthy to mention that 12% were willing to pay up to €120 or more, suggesting a core group of respondents highly motivated by environmental concerns (*Figure **35***).
However, it is clear that financial implications are a barrier. In particular, by annual income, 70% of low-income respondents wants to pay less than 1% extra. By gender, female respondents showed lower willingness to pay extra (34%) vs male (22%).

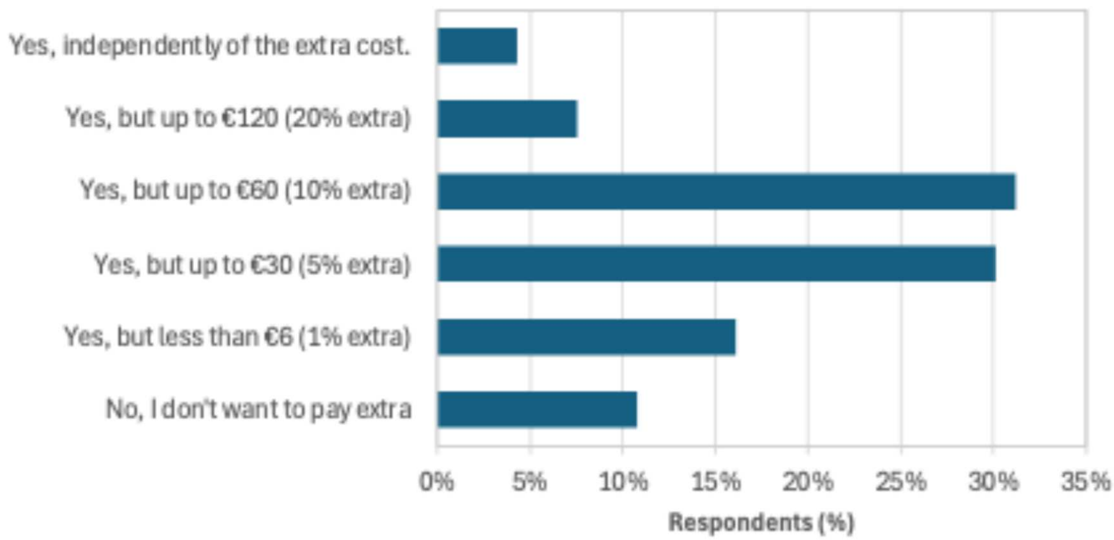


Figure 35: Willingness to make an additional payment for more eco-friendly tyres.

Shifting preferences

Analysing the willingness to change their typical tyre brand for another more eco-friendly alternative 93% of respondents indicated they would consider switching tyre brands if presented with a more sustainable option while 37% wouldn't want to assume additional cost. In any case, sustainability can be perceived as a selling point for tyre manufacturers signalling an aspect that could incentivize manufacturers to innovate (*Figure **36***).

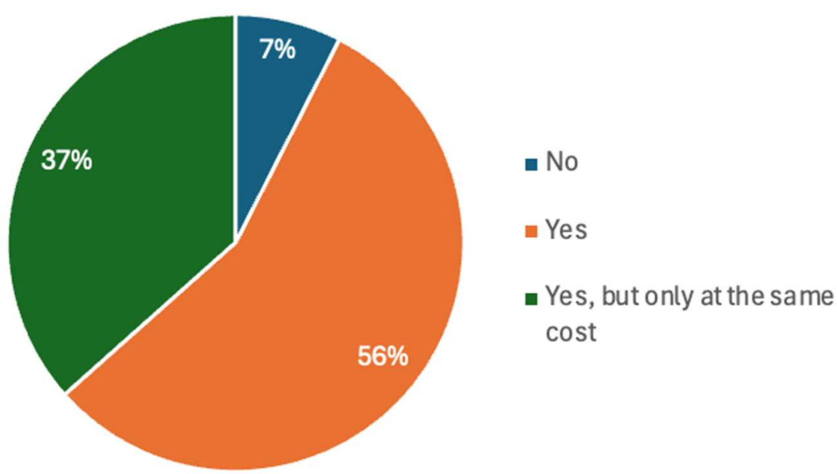


Figure 36: Willingness to change the tyre brand for another more eco-friendly

A7. Survey conclusions

This survey highlights growing awareness and concern about the environmental and quality-of-life impacts of tyres. While cost considerations remain a barrier, there is certain support for sustainable practices, stricter regulations, and noise-reduction measures based on a quite relevant awareness of traffic and in certain cases tyre contribution to pollution and noise.

On the other hand, we understand the constraints of this study due to the rather reduced amount of respondents and a potential bias when considering the general knowledge of tyre-related regulations. Besides, we didn’t succeed in gathering the attention from the industrial players: car manufacturers as well as tyre manufacturers and/or distributors, which limits the scope of the study.

To build on these findings, we recommend:

- Enhancing public awareness campaigns on tyre abrasion and noise pollution.
- Developing innovative solutions to balance affordability with environmental performance.
- Prioritizing urban-focused regulations to mitigate noise and environmental impacts in densely populated areas.

These insights provide a robust foundation for advancing regulatory and industry initiatives that align with user needs and environmental priorities.

Appendix

Below, it can be found the survey developed to gather user/consumer acceptance.

LEON-T User/consumer acceptance survey published

Fields marked with * are mandatory.

LEON-T User/consumer acceptance survey

As the automotive industry continues to evolve, the introduction of the new EURO 7 standards represents a significant milestone in the pursuit of cleaner and more sustainable transportation. EURO 7 sets for the first time stringent regulations aiming at reducing non-exhaust emissions, including brake wear PM10 and tyre microplastic emissions, while also addressing noise pollution associated with vehicle operation.

LEON-T's survey seeks to gather valuable insights from relevant stakeholders throughout the automotive value chain regarding their perspectives on the development and implementation of new legislation related to tyre emissions.

The objective is to assess the preparedness of these stakeholders to adopt new tyre legislation measures to reduce the tyres' environmental impact and to gather mitigation measures proposed by industry and academia experts to promote the efficient implementation of the EURO 7 standards.

The output of this survey aims to inform policymakers, industry stakeholders, and the public about the potential challenges and opportunities associated with the new tyre regulations, ultimately contributing to the wide acceptance of more sustainable and environmentally friendly tyres.

Your feedback is invaluable to us! To ensure we can follow up on any additional questions or insights you may have, we kindly request your email address. Please be assured that your information will be kept strictly confidential and will only be used for survey-related purposes. Your privacy is of utmost importance to us, and we appreciate your participation in helping us gather valuable insights.

☐ I accept and agree with LEON-T's survey Privacy policy.

PRIVACY_POLICY_LEON-T.pdf

QUESTIONNAIRE

* 1 What category does define you better? Please, select only one category:
  - ○ Car owner
  - ○ Car manufacturer
  - ○ Tyre manufacturer and/or distributor
  - ○ Non-car owner

Demographics

*1 Please, select your age group

- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65 and above

*2 Please, indicate your gender

- Female
- Male
- Non-binary/genderqueer
- Prefer no to say

*3 In which region do you live? (as considered by United Nations)

- Africa
- Asia
- North America
- South America
- Central America
- Eastern Europe (Belarus, Bulgaria, Czech Republic, Hungary, Poland, Moldova, Romania, Russia, Slovakia, Ukraine)
- Western Europe (Austria, Belgium, France, Germany, Liechtenstein, Luxembourg, Monaco, Netherlands, Switzerland)
- Northern Europe (Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Lithuania, Norway, Sweden, United Kingdom)
- Southern Europe (Albania, Andorra, Bosnia and Herzegovina, Croatia, Cyprus, Greece, Italy, Malta, Montenegro, North Macedonia, Portugal, San Marino, Serbia, Slovenia, Spain, Vatican City)
- Middle East
- Caribbean
- Oceania

*4 In which area do you live?

- Urban
- Suburban
- Rural

*5 Please, indicate your educational level

- High school or less
- Some college/associate degree
- Bachelor's degree
- Master's degree or higher

*6 Please, indicate your income level

2

- Low-income (lower than 30,000€/yr)
- Middle-income (Between 30,000€/yr-100,000€/yr)
- High-income (higher than 100,000€/yr)

Demographics for companies

* 1 Please, indicate your company size:

- Small (1-50 employees)
- Medium (51 - 500 employees)
- Large (501+ employees)

* 2 Please, indicate your geographic location (as considered by United Nations)

- Africa
- Asia
- North America
- South America
- Central America
- Eastern Europe (Belarus, Bulgaria, Czech Republic, Hungary, Poland, Moldova, Romania, Russia, Slovakia, Ukraine)
- Western Europe (Austria, Belgium, France, Germany, Liechtenstein, Luxembourg, Monaco, Netherlands, Switzerland)
- Northern Europe (Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Lithuania, Norway, Sweden, United Kingdom)
- Southern Europe (Albania, Andorra, Bosnia and Herzegovina, Croatia, Cyprus, Greece, Italy, Malta, Montenegro, North Macedonia, Portugal, San Marino, Serbia, Slovenia, Spain, Vatican City)
- Middle East
- Caribbean
- Oceania

* 3 What is your primary market?

- Domestic
- International

LEON-T project survey for car owners

* 1 What type of vehicle do you own?

If you own more than one vehicle, please submit one survey for each one

- Small city passenger car
- Typical passenger car
- SUV
- Van
- Truck
- Bus
- Other

3

* 2 What type of vehicle do you own?
100 character(s) maximum

* 3 What type of tyres do you have?
  - Normal (summer)
  - Winter
  - Both (I change them during the year)
  - All season (M+S)
  - Studded tyres

* 4 How frequently do you replace your tyres?
  - Based on distance travelled (every 'x' km)
  - Based on time used (every 'x' years)
  - When strictly necessary (at minimum thread depth, or severe wear)
  - If suggested during regular service of vehicle without checking time or distance travelled

* 5 How many km do you drive annually?
  - Less than 5,000 km per year
  - 5,000 - 10,000 km per year
  - 10,001 - 20,000 km per year
  - 20,001 - 30,000 km per year
  - 30,001 - 40,000 km per year
  - 40,001 - 50,000 km per year
  - More than 50,000 km per year

* 6 On average, where do you primarily drive the most kilometers annually?
  - In the city with speeds lower than 50 km/h
  - In regional roads with speeds lower than 100 km/h
  - In motorways with speeds higher than 100 km/h
  - Under mixed conditions

7 Please, indicate the most important factors that influence your decision to replace the tyres
Please, check all that apply. SCALE: 1 - Low impact; 9 - High impact.

	Low relevance 1	2	3	4	Neutral 5	6	7	8	High relevance 9
* Reaching a certain mileage									
* Following the recommendation of the car/tyre manufacturer or other specialist									

4

* Following the recommendation of others (e.g., workshops, media)									
* Reaching a certain tread depth									
* Due to safety concerns									
* Due to performance deterioration									
Other *(please select any item and include the factor in the chart appearing below)*									

* 8 Please, indicate the most important factors that influence your decision to replace the tyres and their relevance between brackets

1000 character(s) maximum

5

9 What features do you consider important when purchasing tyres for your vehicle?

Ranking: 9 - Most important; 1 - less important

	Low relevance 1	Relevance 2	Relevance 3	Relevance 4	Relevance 5	Relevance 6	Relevance 7	Relevance 8	High relevance 9
* Price									
* Quality and durability									
* Safety									
* Brand reputation									
* Fuel efficiency									
* Warranty									
* Comfort (noise)									
* All-season adaptability									
* Eco-friendly / Sustainability (e.g., less tire wear)									

Other *(please select any item and include the factor in the chart appearing below)*									

* 10 Please, indicate the features do you consider important when purchasing tyres for your vehicle and their relevance between brackets

1000 character(s) maximum

* 11 Are you aware of the regulations and guidelines associated with tyre manufacturing and usage?

- ☐ Wet grip
- ☐ Noise
- ☐ Rolling resistance
- ☐ USA tread wear
- ☐ Other
- ☐ No, I am not

* 12 Are you aware of the regulations and guidelines associated with tyre manufacturing and usage?

100 character(s) maximum

* 13 Which environmental concerns do you associate with tyres during their use phase? (Select all that apply)

- ☐ Tyre wear and microplastic pollution
- ☐ Noise pollution
- ☐ Fuel efficiency and its impact on CO2 emissions
- ☐ Impact on road surfaces and infrastructure
- ☐ Other *(please, specify it in the chart appearing below)*

* 14 Which environmental concerns do you associate with tyres during their use phase?

2000 character(s) maximum

15 How much aware are you regarding the relevance of tyre abrasion to microplastics pollution in air, soils and waters?

* 16 Have you ever altered your outdoor activities or recreational plans due to concerns about tyre pollution (i. e., tyre wear, microplastics, noise) in certain areas?

- ○ Yes, I always consider this
- ○ Yes, sometimes
- ○ No, never
- ○ Only due to car traffic pollution, but not specifically due to tyres

* 17 Are you aware of the potential risks associated with tyre wear particles and microplastics release?

- Yes, I'm fully aware of the environmental and health risks associated with tyre wear particles and microplastics release
- Yes, I know about possible environmental and health risks associated with particles and microplastics release but I didn't realise that tyres are part of the problem
- No, I have never heard anything about environmental and health risks associated with tyre wear particles and microplastics release

18 How supportive are you of specific new tyre abrasion regulation (i.e., UN regulation 117) aimed at reducing the environmental impact of tyres?

* 19 Are you aware of new regulations aiming to reduce tyres' environmental impact?

- Yes, I know about UN Regulation 117
- Yes, I know about the Euro 7 emissions standard regulation
- Yes, I know about both UN Regulation 117 and the Euro 7 emissions standard regulation
- I have heard about Euro 7 and/or UN Regulation 117
- No, I am not

20 How do you think the proposed changes in tyre legislation (i.e., Euro 7 and/or modifications of UN Regulation 117) will impact tyre safety and their environmental sustainability?

These changes will...	Answer	Please, rank from 0 (I don't know) to 1 (low) and to 5 (high) the level of impact produced in tyre safety and their environmental sustainability
reduce the risk of accidents due to the enforcement of stricter standard leading to higher-quality tyres	* Please, select one I agree I don't agree I don't know	* Level of impact 0 1 2 3 4 5

9

encourage the development of eco-friendly tyre materials and manufacturing processes	* Please, select one I agree I don't agree I don't know	* Level of impact 0 1 2 3 4 5
increase the risk of accidents due to lower affordability for low-income individuals	* Please, select one I agree I don't agree I don't know	* Level of impact 0 1 2 3 4 5
implement an ambitious legislation which will effectively address tyre noise pollution, decreasing their environmental impact	* Please, select one I agree I don't agree I don't know	* Level of impact 0 1 2 3 4 5

generate greater innovation and investment in new technologies	* Please, select one I agree I don't agree I don't know	* Level of impact 1 0 0 1 2 2 3 3 4 5 4 5
create resistance against the changes proposed from tyre manufacturers and consumers	* Please, select one I agree I don't agree I don't know	* Likelihood to happen 1 0 0 1 2 2 3 3 4 5 4 5
Other *(please select any item and include the factor in the box appearing below)*	Select if necessary Yes	Please, indicate how do you think the proposed changes in tyre legislation will impact tyre safety and their environmental sustainability including the impact between brackets

* 21 Which factors would you consider relevant in adopting new tyre legislation measures?
- Cost and affordability
- Availability and accessibility to certain tyre models
- Environmental impact
- Performance
- Safety
- Financial incentives to manufacturers
- Financial incentives to retailers
- Financial incentives to buyers
- Other *(if selected, please include the factor in the chart appearing below)*

* 22 Which factors would you consider relevant in adopting new tyre legislation measures?

100 character(s) maximum

* 23 New tyre legislation could bring additional costs. Would you be willing to pay additionally for your set of tyres (i.e., purchasing 4 tyres) if they become more environmentally friendly? As example, assuming your tyre change would cost €600, how much would you be willing to pay extra?

- No, I don't want to pay extra
- Yes, but less than €6 (1% extra)
- Yes, but up to €30 (5% extra)
- Yes, but up to €60 (10% extra)
- Yes, but up to €120 (20% extra)
- Yes, independently of the extra cost.

* 24 Would you be willing to change the tyre brand you use if you find out that another brand is more environmentally friendly?

- No
- Yes, but only at the same cost
- Yes

Noise

1 How much does tyre noise from vehicles in your environment affect your overall quality of life?

If you don't know, please leave the cursor in 0.

* 2 How close is your residence to a major road or highway?

- Less than 50 meters
- Between 50-100 meters
- Between 100-200 meters
- More than 200 meters

* 3 Does your bedroom window face towards a road with frequent and/or fast traffic?

- Yes
- No

* 4 Thinking about the last 12 months or so, when you are at home, how much does noise from road traffic bother, disturb or annoy you during the day?

- Not at all
- Slightly
- Moderately
- Very
- Extremely

* 5 Have you ever experienced difficulty concentrating or sleeping due to noise from nearby roads or highways?
  - Yes
  - No
  - I don't know

* 6 Thinking about the last 12 months or so, when you are at home, how much does noise from road traffic disturb your sleep?
  - Not at all
  - Slightly
  - Moderately
  - Very
  - Extremely

* 7 Have you ever considered the environmental impact of tyre noise, such as its contribution to overall noise pollution levels?
  - Yes
  - No

* 8 Should there be additional regulations or measures to address tyre noise pollution in urban areas?
  - Yes
  - No
  - I don't know

9 From your point of view, how much do tyres contribute to exterior noise of fossil-fueled vehicles?

10 And for Electric vehicles?

11 How important do you think it is for manufacturers to prioritize reducing tyre noise when designing vehicles, even if you're not a car owner?

If you don't know, please leave the cursor in 0.

* 12 Do you believe there should be more public awareness campaigns regarding the health and environmental effects of tyre noise pollution?
  - Yes
  - No
  - I don't know

LEON-T project survey for car manufacturers

* 1 What type of vehicle do you manufacture?

13

Please, select all that apply

- Small city passenger car
- Typical passenger car
- SUV
- Van
- Truck
- Bus
- Other *(please, specify it in the box appearing below)*

* 2 What type of vehicle do you manufacture?

100 character(s) maximum

* 3 What type of tyres do you typically fit in your vehicles?

- Normal (summer)
- Winter
- Both
- All season (M+S)
- Studded tyres

* 4 How prepared is your company to comply with new tyre abrasion legislation related to environmental impact?

Maximum 2 selection(s)

- I haven't thought about it
- Some internal awareness
- We expect that tyre manufacturers will offer tyres complying with abrasion legislation
- We plan to do internal tests when tyres are offered
- Our product plans already include tyre wear abrasion requirements
- Other *(please, include it in the chart below)*

* 5 How prepared is your company to comply with new tyre abrasion legislation related to environmental impact?

1000 character(s) maximum

* 6 What potential impact do you foresee the new legislation having on your business operations?

Maximum 2 selection(s)

- Not yet anticipated
- Limited availability of certified tyres
- Higher cost of certified tyres
- None
- Other *(please, include it in the chart below)*

* 7 What potential impact do you foresee the new legislation having on your business operations?

1000 character(s) maximum

8 Will the new tyre abrasion legislation result in higher costs for your company?

- Yes (If selected, please include the challenges or barriers in the chart appearing below)
- No
- I don't know

9 If you answered 'Yes', please indicate the types of costs you expect to incur (select all that apply):

.	Type of cost	Answer	For the costs selected, please indicate the estimated magnitude per vehicle
1	Increased manufacturing costs	. Yes No	. Less than €500 per vehicle Between €500-€1000 per vehicle More than €1000 per vehicle
2	Higher research and development expenses	. Yes No	. Less than €100 per vehicle Between €100-€500 per vehicle More than €500 per vehicle
3	Additional compliance and testing costs	. Yes No	. Less than €500 per vehicle Between €500-€1500 per vehicle More than €1500 per vehicle
4	Increased operation costs	. Yes No	. Less than €500 per vehicle Between €500-€2000 per vehicle More than €2000 per vehicle
5	Other *(please, specify it in each chart)*	.	.

10 Do you have any suggestions on how the new tyre abrasion legislation regulations could be implemented more effectively?

	Not effective	Somewhat effective	Effective	Very effective	Extremely effective	I don't know
* Clearer guidelines and definitions	○	○	○	○	○	○
* Longer implementation timelines	○	○	○	○	○	○
* Financial incentives or subsidies for compliance	○	○	○	○	○	○
* More extensive stakeholder consultation	○	○	○	○	○	○
* Better alignment with international standards	○	○	○	○	○	○
* Increased support for research and development	○	○	○	○	○	○
Other *(please select any item and include the suggestions in the chart appearing below)*	○	○	○	○	○	○

11 Do you have any suggestions on how the new tyre abrasion legislation regulations could be implemented more effectively?

* 12 Are there any specific challenges or barriers your company might face in complying with the new regulations?

○ Yes
○ No
○ I don't know

13 Are there any specific challenges or barriers your company might face in complying with the new regulations?

	Yes	No	I don't know
* Financial constraints	○	○	○
* Technical limitations	○	○	○
* Lack of skilled personnel	○	○	○
* Insufficient time for implementation	○	○	○

* Supply chain issues	◯	◯	◯
* Compliance and regulatory complexity	◯	◯	◯
Other *(please select 'YES' and include the challenges or barriers in the chart appearing below)*	◯	◯	◯

14 Are there any specific challenges or barriers your company might face in complying with the new regulations?

15 How do you anticipate the new tyre abrasion (i.e., new UN Regulation 117) affecting the design and production of tyres for vehicles?
Scale (From 0, not impact, to 5, very significant impact).

	Not impact	Slight impact	Moderate impact	Significant impact	Very significant impact	I don't know
* Material selection	◯	◯	◯	◯	◯	◯
* Manufacturing processes	◯	◯	◯	◯	◯	◯
* Product testing and quality assurance	◯	◯	◯	◯	◯	◯
* Research and development	◯	◯	◯	◯	◯	◯
* Cost of production	◯	◯	◯	◯	◯	◯
* Innovation and design features	◯	◯	◯	◯	◯	◯
* Supply chain adjustments	◯	◯	◯	◯	◯	◯
Other *(please select any item and include the factor in the chart appearing below)*	◯	◯	◯	◯	◯	◯

16 How do you anticipate the new tyre abrasion (i.e., new UN Regulation 117) affecting the design and production of tyres for vehicles?

17 How do you think compliance of EURO-7 regulation by car and/or tyre manufacturers will impact consumers?

18 Would you like to provide any info about your company (e.g., name, location, contact info)?

18

LEON-T project survey for tyre manufacturers and/or distributors

* 1 What type of tyres do you manufacture and/or distribute?

Please, select all that apply

- ☐ Passenger car - Normal (summer tyres)
- ☐ Passenger car - Winter tyres
- ☐ Passenger car - All season tyres (M+S)
- ☐ Truck tyres
- ☐ Other *(please, specify it in the box appearing below)*

* 2 What type of tyres do you manufacture and/or distribute?

3 How do you anticipate the new tyre abrasion UN Regulation 117 affecting the design and production of tyres for vehicles?

Scale (From 0, not impact, to 5, very significant impact).

	Not impact	Slight impact	Moderate impact	Significant impact	Very significant impact	I don't know
* Material selection	○	○	○	○	○	○
* Manufacturing processes	○	○	○	○	○	○
* Product testing and quality assurance	○	○	○	○	○	○
* Research and development	○	○	○	○	○	○
* Cost of production	○	○	○	○	○	○
* Operational costs	○	○	○	○	○	○
* Innovation and design features	○	○	○	○	○	○
* Supply chain adjustments	○	○	○	○	○	○
Other *(please select any item and include the factor in the chart appearing below)*	○	○	○	○	○	○

4 How do you anticipate the new tyre abrasion UN Regulation 117 affecting the design and production of tyres for vehicles?

5 What is the main impact of the tyres with lower abrasion on other tyre properties and characteristics?

Please, check all that apply. SCALE: 1 - Low impact; 9 - High impact.

	Low 1	2	3	4	Neutral 5	6	7	8	High 9	I don't know
* Noise	○	○	○	○	○	○	○	○	○	○
* Grip	○	○	○	○	○	○	○	○	○	○
* Rolling resistance	○	○	○	○	○	○	○	○	○	○
* Lifespan	○	○	○	○	○	○	○	○	○	○
* Environmental pollution	○	○	○	○	○	○	○	○	○	○
* Maintenance	○	○	○	○	○	○	○	○	○	○
Other *(please select any item and include the factor in the chart appearing below and the impact between brackets)*	○	○	○	○	○	○	○	○	○	○

6 What is the main impact of the tyres with lower abrasion on other tyre properties and characteristics?

* 7 What percentage of your portfolio is affected by the new tyre abrasion UN Regulation 117?

- ○ Less than 10%
- ○ Between 10-25%
- ○ Between 25-50%
- ○ Between 50-75%
- ○ More than 75%
- ○ I do not know/Not applicable

* 8 What specific changes do you anticipate making in response to the new legislation?

- ○ Yes, we anticipate making changes
- ○ No, we do not anticipate making changes
- ○ I don't know

9 What specific changes do you anticipate making in response to the new legislation?

Scale (From 0, not impact, to 5, very significant impact).

	Not impact	Slight impact	Moderate impact	Significant impact	Very significant impact	I don't know
* Developing new tyre materials	○	○	○	○	○	○
* Implementing new manufacturing technologies	○	○	○	○	○	○

20

* Enhancing quality control measures						
* Increase investment in R&D activities						
* Adjusting supply chain logistics						
* Redesigning tyre features						
* Implementing cost-saving measures						
Other *(please select any item and include the factor in the chart appearing below)*						

10 What specific changes do you anticipate making in response to the new legislation?

* 11 Are you prepared to comply with the new regulations related to environmental impact?

- Yes
- No
- Maybe
- I do not know/Not applicable

12 How fast will it take to adapt your business/production to new legislation?

13 Do you foresee that the new legislation affects the distribution and marketing of tyres? If you foresee any effect, please rate the anticipated impact on the following aspects:

Scale (From 0, not impact, to 5, very significant impact).

	Not impact	Slight impact	Moderate impact	Significant impact	Very significant impact	I don't know
* Distribution network adjustments						
* Changes in marketing strategies						
* Alterations to pricing structures						
* Modifications in advertising content						

* Enhancements in customer education						
* Adaptations in sales training						
Other *(please select any item and include the factor in the chart appearing below and the impact between brackets)*						

14 Foreseen effects in the distribution and marketing of tyres:

* 15 Are you satisfied with the level of participation of the tyre industry in the preparation of the relevant regulations?

- Yes
- No
- Maybe

16 Do you have any suggestions on how the new tyre abrasion legislation regulations could be implemented more effectively?

	Not effective	Somewhat effective	Effective	Very effective	Extremely effective	I don't know
* Clearer guidelines and definitions						
* Longer implementation timelines						
* Financial incentives or subsidies for compliance						
* More extensive stakeholder consultation						
* Better alignment with international standards						
* Increased support for research and development						
Other *(please select any item and include the factor in the chart appearing below)*						

17 Do you have any suggestions on how the new tyre abrasion legislation regulations could be implemented more effectively?

* 18 Are there any specific challenges or barriers your company might face in complying with the new regulations?

- Yes
- No
- I don't know

19 Are there any specific challenges or barriers your company might face in complying with the new regulations?

	Not effective	Somewhat effective	Effective	Very effective	Extremely effective	I don't know
* Financial constraints						
* Technical limitations						
* Lack of skilled personnel						
* Insufficient time for implementation						
* Supply chain issues						
* Compliance and regulatory complexity						
Other *(please select any item and include the factor in the chart appearing below)*						

20 Are there any specific challenges or barriers your company might face in complying with the new regulations?

21 How do you think the new tyre abrasion regulation will impact other performance indexes (e.g., rolling resistance, wet grip, noise emissions)? Please rate the expected impact on each index:

Scale (From 0, not impact, to 5, very significant impact).

	Not impact	Slight impact	Moderate impact	Significant impact	Very significant impact	I don't know
* Rolling resistance						
* Wet grip						
* Noise emissions						

23

* Durability	○	○	○	○	○	○
* Fuel economy	○	○	○	○	○	○
Other *(please select any item and include the factor in the chart appearing below)*	○	○	○	○	○	○

22 How do you think the new tyre abrasion regulation will impact other performance indexes (e.g., rolling resistance, wet grip, noise emissions)? Please rate the expected impact on each index:

23 Would you like to provide any info about your company (e.g., name, location, contact info)?

LEON-T project survey for non-car owners

* 1 Which environmental concerns do you associate with tyres during their use phase? (Select all that apply)

- ☐ Tyre wear and microplastic pollution
- ☐ Noise pollution
- ☐ Fuel efficiency and its impact on CO2 emissions
- ☐ Impact on road surfaces and infrastructure
- ☐ Other *(please, specify it in the chart appearing below)*

* 2 Which environmental concerns do you associate with tyres during their use phase?

2000 character(s) maximum

3 How much aware are you regarding the relevance of tyre abrasion to microplastics pollution in air, soils and waters?

* 4 Have you ever altered your outdoor activities or recreational plans due to concerns about tyre pollution (i. e., tyre wear, microplastics, noise) in certain areas?

- ○ Yes, I always consider this
- ○ Yes, sometimes
- ○ No, never
- ○ Only due to car traffic pollution, but not specifically due to tyres

* 5 Are you aware of the potential risks associated with tyre wear particles and microplastics release?

- ○ Yes, I'm fully aware of the environmental and health risks associated with tyre wear particles and microplastics release

- Yes, I know about possible environmental and health risks associated with particles and microplastics release but I didn't realise that tyres are part of the problem
- No, I have never heard anything about environmental and health risks associated with tyre wear particles and microplastics release

6 How supportive are you of specific new tyre legislation policies aimed at reducing the environmental impact of tyres?

* 7 Are you aware of new regulations aiming to reduce tyres' environmental impact?

- Yes, I know about UN Regulation 117
- Yes, I know about the Euro 7 emissions standard regulation
- I have heard about Euro 7 and/or UN Regulation 117
- No, I am not

8 How do you think the proposed changes in tyre legislation (i.e., Euro 7 and/or modifications of UN Regulation 117) will impact tyre safety and their environmental sustainability?

These changes will...	Answer	Please, rank from 0 (I don't know) to 1 (low) and to 5 (high) the level of impact produced in tyre safety and their environmental sustainability
reduce the risk of accidents due to the enforcement of stricter standard leading to higher-quality tyres	* Please, select one I agree I don't agree I don't know	* Level of impact 0 1 2 3 4 5
encourage the development of eco-friendly tyre materials and manufacturing processes	* Please, select one I agree I don't agree I don't know	* Level of impact 0 1 2 3 4 5
increase the risk of accidents due to lower affordability for low-income individuals	* Please, select one I agree I don't agree I don't know	* Level of impact 0 1 2 3 4 5

implement an ambitious legislation which will effectively address tyre noise pollution, decreasing their environmental impact	* Please, select one I agree I don't agree I don't know	* Likelihood to happen 0 1 2 3 4 5
generate greater innovation and investment in new technologies	* Please, select one I agree I don't agree I don't know	* Level of impact 0 1 2 3 4 5
create resistance against the changes proposed from tyre manufacturers and consumers	* Please, select one I agree I don't agree I don't know	* Likelihood to happen 0 1 2 3 4 5
Other *(please select any item and include the factor in the box appearing below)*	Select if necessary Yes	Please, indicate how do you think the proposed changes in tyre legislation will impact tyre safety and their environmental sustainability including the impact between brackets

Noise

1 How much does tyre noise from vehicles in your environment affect your overall quality of life?

If you don't know, please leave the cursor in 0.

*2 How close is your residence to a major road or highway?

- Less than 50 meters
- Between 50-100 meters
- Between 100-200 meters
- More than 200 meters

*3 Does your bedroom window face towards a road with frequent and/or fast traffic?

- Yes
- No

26

- I don't know

*4 Thinking about the last 12 months or so, when you are at home, how much does noise from road traffic bother, disturb or annoy you during the day?

- Not at all
- Slightly
- Moderately
- Very
- Extremely

*5 Have you ever experienced difficulty concentrating or sleeping due to noise from nearby roads or highways?

- Yes
- No
- I don't know

*6 Thinking about the last 12 months or so, when you are at home, how much does noise from road traffic disturb your sleep?

- Not at all
- Slightly
- Moderately
- Very
- Extremely

*7 Have you ever considered the environmental impact of tyre noise, such as its contribution to overall noise pollution levels?

- Yes
- No

*8 Should there be additional regulations or measures to address tyre noise pollution in urban areas?

- Yes
- No
- I don't know

9 From your point of view, how much do tyres contribute to exterior noise of fossil-fueled vehicles?

10 And for Electric vehicles?

11 How important do you think it is for manufacturers to prioritize reducing tyre noise when designing vehicles, even if you're not a car owner?

If you don't know, please leave the cursor in 0.

12 Do you believe there should be more public awareness campaigns regarding the health and environmental effects of tyre noise pollution?

- Yes
- No
- I don't know