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EXPERT PANEL ON TYRE WEAR AND CHEMICALS OF CONCERN

Expert Survey and Workshop Report

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Expert Survey and Workshop Report

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Agriculture and Forestry, Climate
and Environmental Protection,
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1 SUMMARY

background

Tyres are a significant and growing source of microplastics. According to European Commission estimates the release of tyre wear amounted to 360,000–540,000 tonnes in 2019 and will further increase with rising vehicle numbers and heavier cars, e.g due to the trend towards SUVs. Although the Euro 7 EU regulation introduces tyre abrasion limits from 2028 onwards, emissions will remain significant. Tyres also release hazardous chemicals, e.g. para-phenylenediamines, notably 6PPD and its transformation product 6PPD-quinone, which is highly toxic to aquatic life. Monitoring data suggest that numerous other tyre-derived substances occur in water, air, soil, food, and humans. At the same time, tyre wear cannot be easily prevented, as sufficient friction between the tyre and the road ensures driving safety.

Hence, reducing the impacts of tyre wear requires a holistic strategy and a mix of measures addressing both tyre wear emissions and chemical risks. Due to the complexity of the issue, the discussion and promotion of a set of effective measures should take place at an international (European) level, involving all relevant stakeholder groups.

aim

The project *"Expert Panel on Tyre Wear and Chemicals of Concern"* aimed to promote exchange among European stakeholders and to identify strategies for reducing tyre wear emissions to the environment and related chemical risks. It brought together representatives from *academia*, industry & *representation of interests (ROI)*, *government/administration*, *NGOs*, and *providers of infrastructure or public services* in an online expert survey and a follow-up expert workshop on *Tackling Tyre Wear and Associated Chemical Risks*.

methods

In the online expert survey (1 July –14 September 2025), 53 participants from four stakeholder groups (*academia*, *industry/ROI*, *government/administration*, *NGOs*) assessed 80 potential future measures to reduce tyre wear emissions and mitigate associated risks. The measures were evaluated for *effectiveness*, *feasibility* and *timeframe to take effect*. Responses were translated to scores, summing to a maximum score of 20. Measures scoring ≥16 were considered worth pursuing; those scoring <9.5 were either considered ineffective or infeasible. The measures were ranked by the average score across the four stakeholder groups and additionally analysed by stakeholder group and by action area (17 action areas clustering related measures).

The results were used to prepare an expert workshop, held in Vienna on-site and online on 27 November 2025, with over 100 international

participants. It combined expert presentations with breakout sessions focused on six topics: (1) chemicals and risk assessment; (2) exposure avoidance and end-of-life tyres; (3) distribution via dust and measures at/near the road; (4) runoff collection/retention and treatment; (5) interactions – tyre, vehicle, road, driving; and (6) mobility transition and traffic reduction. Participants evaluated selected measures within these topics regarding operationalisation, implementation needs, responsible stakeholders, added value, and potential obstacles. Participants could document their responses to the different topics in respective *workshop surveys* using an online survey tool (MS-Forms). In total, 68 responses across the six topics were received.

This project report presents the results of the online expert survey and the breakout group discussions of the expert workshop (*workshop surveys*). It synthesises these results to identify a balanced strategy (a mix of measures) to reduce tyre wear and its environmental and chemical risks, including the positions of the relevant stakeholders. The results shall inform decision makers, and this report will be distributed and communicated among stakeholders, with a European focus.

suggested strategy

The suggested *Strategy to Tackle Tyre Wear and Chemicals of Concern* combines emission reduction, risk reduction, and emission retention measures. It includes those measures that were best ranked regarding efficiency & feasibility across the stakeholder groups in the expert survey and integrates recommendations by workshop participants on their implementation, considering benefits (beyond tackling tyre wear) and potential obstacles. There was broad agreement among all stakeholder groups that a mix of measures is needed, comprising short-, medium- and long-term actions. Precautionary action and knowledge advancement must proceed in parallel. Ensuring the chemical safety of tyres (or rubber in general) and advancing risk assessment are key aspects.

The integration of measures in 6 pillars is recommended:

1. tyre wear emission reduction at the source (tyre & traffic),
2. chemical safety of tyres,
3. knowledge-based risk assessment,
4. exposure avoidance and end-of-life tyre applications,
5. smart technology advancements, and
6. targeted emission retention and mitigation.

While pillars 1–3 form the core of the strategy, pillars 4–6 comprise highly recommended supporting measures for a well-balanced systemic approach.

tyre abrasion limits The first pillar prioritises *reducing tyre wear emissions at the source*. Mandatory tyre abrasion limits (e.g. Euro 7) received the strongest support across stakeholders and are considered both effective and feasible in the short to medium term. Their success depends on standardised test methods, transparent labelling, enforcement capacity and clear consumer information, alongside safeguards against unintended trade-offs in tyre performance.

tyre choice & maintenance *Optimising tyre choice and maintenance*, including stopping the use of winter tyres in summer and strengthening consumer education, is recommended as a practical and cost-efficient step that can also improve road safety.

traffic reduction Broader *traffic reduction measures*, such as promoting telework and enabling a shift to public transport, walking and cycling, offer substantial co-benefits for climate, air quality, and public health. These require clear targets, monitoring, infrastructure investment, incentives, and sustained political commitment.

chemically safe tyres The second pillar focuses on enhancing the chemical safety of tyres. This may be achieved through a *safe-and-sustainable-by-design* (SSbD) approach, guided by a clear regulatory framework and SSbD standards with suitable control mechanisms and enabled by close industry-regulatory collaboration in trusted structures. Such a framework would supplement available regulatory tools like bans and restrictions of identified hazardous substances. SSbD fosters sustainability as it supports innovation, prevents regrettable substitution, and distributes responsibility between regulators and industry. Its implementation requires clear regulatory guidance, standardised methods, obligations for (FAIR) data provision using trusted technologies, control mechanisms, and attention to sustainability across the full life cycle of chemicals. Although resource-intensive, this approach provides long-term planning security and strengthens environmental and socio-economic sustainability.

risk assessment The third pillar strengthens *knowledge-based risk assessment*. Coordinated research and standardisation at the EU-level are needed to advance methods to address the complexity of tyre particles and chemical mixtures and to improve the understanding of leaching, chemical transformation, and human exposure. This supports advancing current regulatory and risk-assessment frameworks. Independent evidence generation, data sharing, and timely regulatory uptake of findings are critical to ensure proportionate and trusted decision-making.

exposure avoidance & end-of-life tyres The fourth pillar addresses *exposure avoidance and end-of-life tyre applications*. Evaluating exposure hotspots and vulnerable groups to enhance the knowledge base for action and to inform relevant stakeholders (e.g. operators of sports facilities and playgrounds) and the general public is recommended to empower them to avoid tyre wear or crumb rubber exposure. However, responsibility for risk reduction should not rest with the public. Awareness raising is an intermediate measure and precautionary regulatory action on high-exposure uses, such as crumb rubber in playgrounds and sports fields, should be considered until the long-term objective of upstream chemical product safety is achieved.

smart technology

The fifth pillar promotes *smart vehicle technologies* to reduce harsh acceleration and braking. Research, development, and implementation of "eco-modes", backed by international standardisation, can deliver tyre wear reductions alongside safety and emission-reduction co-benefits.

targeted emission retention

The sixth pillar supports *targeted emission retention*. Hotspot-based road sweeping, improved maintenance of runoff treatment systems, and integration of roadside greenery into road planning can complement upstream measures and deliver multiple environmental benefits. Although emission retention measures are an end-of-pipe solution and not sufficient on their own, they provide short-, medium-, and long-term gains when financed and implemented strategically.

policy mix

Taken together, the suggested *Strategy to Tackle Tyre Wear and Chemicals of Concern* calls for an integrated policy mix that combines regulatory action, innovation, research, infrastructure investment, and behavioural change, supported by clear governance, funding, and monitoring mechanisms. It includes the most promising measures to tackle the complex issue of tyre wear emissions and associated chemical risks according to experts from different stakeholder groups and provides clear recommendations that make action manageable.

2 BACKGROUND

Tyres are a Major Source of Microplastics.

Sufficient friction between tyres and the road is a prerequisite for safe driving, and tyre wear cannot be fully avoided. The European Commission (European Commission, 2023b) estimates that 360,000 to 540,000 tonnes of tyre wear were emitted into the EU environment in 2019, suggesting tyre wear to be the second largest source of unintentional release of microplastics after paints. Tyre wear emissions are still rising: From 2019 to 2022, they increased by 5.3 %, mainly due to increased vehicle weight, as assessed by the European Environment Agency (European Environment Agency, 2025).

The Euro 7 Regulation (EU) 2024/1257 (European Parliament and Council, 2024) stipulates the stepwise adoption of specific tyre abrasion limits for different tyre classes to support the EU target to reduce microplastics released into the environment by 30 % by 2030. The required test methods and abrasion-limit values (Euro 7 standard) shall be provided by the UN WP.29 (UNECE World Forum for Harmonization of Vehicle Regulations). They will apply to vehicles approved for the EU market from 01/07/2028, 01/04/2030, and 01/04/2032 for passenger car, light commercial vehicle, and heavy-duty vehicle tyres, respectively.

Despite the compulsory Euro 7 standard, tyre wear will remain a significant environmental burden. The number of passenger cars in the EU-27 is constantly increasing, e.g. from 487 per 1000 inhabitants in 2010 to 578 in 2024 (Statistisches Bundesamt, 2026). Additionally, the average vehicle weight of newly registered cars is trending upward. It increased by 17 % between 2001 and 2021. This can be attributed to a high share of SUVs among new registrations (43 % in 2021) and to hybrid and electric passenger cars jumping from 3 % in 2019 to 19 % in 2021 (ICCT Europe, 2022). Electrification typically comes with higher vehicle weight (~20 %), thus increasing tyre wear (Giechaskiel, Grigoratos, Dilara, Franco, 2024). Instant torque may aggravate tyre wear, as it allows for harder acceleration. However, the situation is more complex: driving assistants can limit acceleration and tyre wear, and the composition of the vehicle fleet may change with electrification (Müller, Unice, Panko, Wagner, 2025), as higher prices may result in people buying smaller cars.

Apart from the number of vehicles on the road, governed by mobility behaviour, and the wear resistance of tyres, addressed by the Euro 7 regulation, many additional factors influence tyre wear emissions. These include driving speed, acceleration/deceleration and lateral forces (cornering) – as related to driving behaviour and road topology, vehicle load and maintenance (e.g. tyre inflation pressure, alignment), road surface texture/roughness and management practices (e.g. grit application), tyre type (winter, summer, studded, all year), environmental conditions (e.g. temperature, humidity) (Müller, Unice, Panko, Wagner, 2025).

As tyre rubber emissions are not limited to traffic, end-of-life applications must also be considered. Tyre crumb rubber has many applications, some of which are open to the environment, e.g. sports fields and playground surfaces, docking aids, pool surrounds. Even though crumb rubber as infill in artificial turf fields is meanwhile prohibited in the EU under the REACH regulation (European Commission, 2023a), "matrix-bound" applications are still allowed. However, weathering and aging causes disintegration of such surfaces and emissions of tyre crumb rubber particles into the environment (Janajreh, Hussain, Elagroudy, Moustakas, 2021). A recent study also demonstrated that pavements are a direct source of microplastics to the environment, with crumb rubber being a common additive in pavement mixtures (Smyth, Tan, van Seters, Henderson, Passeport, Drake, 2025). Crumb rubbers can increase pavement's durability and reduce noise emissions. In Europe, Spain, Portugal, and Italy are leading regarding the application of rubberized asphalts on larger scales, but also other countries apply rubberized asphalts, promote research, and operate test sites (e.g., Germany, Austria, Slovakia, Hungary, the UK, Sweden) (Davide Lo Presti, Juan Gallego Medina, Jorge Carvalho Pais, Lily Poulikakos, Moises Bueno, Davide Dalmazzo, Ezio Santagata, 2021, Ecopneus, 2008).

Tyres are a Source of Chemical Pollution.

Tyres are complex mixtures. A typical new passenger car summer tyre consists of ~41 % natural and synthetic rubber, ~30 % fillers (e.g. soot, silica, carbon, chalk), ~15 % reinforcements (steel, polyester, rayon, nylon), ~6 % softeners (oils and resins), ~6 % vulcanisation aids (e.g. sulphur, zinc oxide) and ~2 % chemical additives (substances that avoid aging and other chemicals) (Continental, 2026). The composition varies between different tyre types (Naddeo, Viscusi, Gorrasi, Pappalardo, 2021), and there are hundreds of chemical additives to choose from, many of which are critical from a toxicological point of view (Baumann, Ismeier, 1998).

Acute mass mortality events in coho salmon in the US Pacific Northwest, the cause of which remained unclear for decades, finally brought 6PPD (for abbreviations see page 90), an antioxidant used in tyres, into the centre of media and scientific attention. Its oxidation product, 6PPD-quinone, was identified as the cause for coho salmon mortality (Tian, Zhao, Peter, Gonzalez, Wetzel, Wu, Hu, Prat, Mudrock, Hettinger, Cortina, Biswas, Kock, Soong, Jenne, Du, Hou, He, Lundeen, Gilbreath, Sutton, Scholz, Davis, Dodd, Simpson, McIntyre, Kolodziej, 2021). These acute events triggered the evaluation of the need for regulatory action in the US (DTSC, 2021) and considerations regarding potential substitutes, including PPD-group substances (e.g. 7PPD, IPPD, CPPD, DPPD, dialkyl-substituted PPDs) and other antidegradants (e.g. 6QDI, TMQ) (DTSC, 2021, Gradient, 2024). Brook and rainbow trout, which are common fish in European waters, are also sensitive to 6PPD-quinone (Brinkmann, Montgomery, Selinger, Miller, Stock, Alcaraz, Challis, Weber, Janz, Hecker, Wiseman, 2022). In the EU, a harmonised classification for 6PPD was proposed and discussed in the Committee for Risk Assessment (RAC) (ECHA-RAC, 2024), with the final opinion to classify 6PPD as acute toxic (ingestion), skin sensitiser, reprotoxic, and very toxic to aquatic life (acute & chronic exposure) (ECHA, 2021). The Netherlands and Austria are preparing an Annex XV restriction dossier on the group of PPDs and PDs under REACH. Safe alternatives will need to be identified to avoid regrettable substitution and associated consequences for environmental and human health and to enable long-term economic planning.

However, the chemical complexity of tyres goes beyond 6PPD. Scientific literature demonstrates that many chemical compounds can leach from tyres and tyre wear (Müller, Hübner, Huppertsberg, Knepper, Zahn, 2022, Foscari, Seiwert, Zahn, Schmidt, Reemtsma, 2024, Ghanadi, Caubrière, Kah, Padhye, 2025), with some being transformed rather quickly (e.g. 6PPD, DPG), resulting in a multitude of transformation products, and others (e.g. HMMM) being more stable, depending on the environmental conditions (Foscari, Seiwert, Zahn, Schmidt, Reemtsma, 2024). Several of the frequently identified leached substances are of environmental concern. For example, DPG and benzothiazole are classified as potential persistent, mobile, and toxic substances by the German Environment Agency (Müller, Hübner, Huppertsberg, Knepper, Zahn, 2022). However, tyre leachates also contain toxic substances of still unclear identity (Bergmann, Masset, Breider, Dudefoi, Schirmer, Ferrari, Vermeirssen, 2024). Various tyre-related chemicals, including PPDs, can be taken up by plants (Castan, Sherman, Peng, Zumstein, Wanek, Hüffer, Hofmann, 2023, Sherman, Hämmerle, Mordechay, Chefetz, Hofmann, 2025), were found in commercially available vegetables (Sherman, Hämmerle, Ben Mordechay, Chefetz, Hüffer, Hofmann, 2024, Breider, Masset, Prud'homme, Brüschweiler, 2025), in urine samples (Du, Liang, Li, Shen, Liu, Zeng, 2022, Huang, Jin, Zhu, Guo, Zhou, Wu, 2024, Mao, Jin, Guo, Chen, Zhong, Wu, 2024), in the air (Johannessen, Saini, Zhang, Harner, 2025, Johannessen, Liggio, Zhang, Saini, Harner, 2022), and even in groundwater (Zhang, Han, Hu, Chen, Ying, Zhao, 2025), raising both human health and environmental concerns. While it must be noted that several of these substances may originate from a variety of other sources, tyres are an important source of these substances in the above-named environmental compartments.

Finally, it has to be considered that, regarding the number of tyres, the EU is a net importer, with import figures (2011–2020) of passenger and light commercial vehicle tyres being about twice as high as export figures, and most tyres coming from China (ETRMA, 2021). Ensuring and enforcing chemical safety standards for imported tyres is thus of high importance.

Finding Strategies to Reduce Tyre Wear and Chemical Risks

The reduction of tyre wear emissions to the environment requires a holistic approach that combines societal transitions and individual behavioural changes, technological advancements, management approaches, and solutions for end-of-life tyres, accompanied by sound regulatory guidance. There must also be a focus on preventing chemical risks, as tyre wear emissions cannot be fully avoided. The case of 6PPD has opened a discussion, which offers a chance to aim for chemically safe tyres. Finding strategies to reduce tyre wear emissions and related chemical risks requires an open dialogue and close collaboration between all relevant stakeholder groups at the EU-level and beyond.

3 EXPERT PANEL ON TYRE WEAR & CHEMICALS OF CONCERN

Aim: Identifying Strategies to Reduce Tyre Wear and Chemical Risks

The project “Expert Panel on Tyre Wear and Chemicals of Concern” was initiated and conducted by the Environment Agency Austria on behalf of the Austrian Ministry of Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management (BMLUK).

The project aimed to promote the exchange between relevant stakeholder groups (focus on Europe) and to identify strategies to reduce tyre wear and its environmental impact.

This was to be achieved by an expert panel involving all relevant stakeholder groups and through an expert survey and a subsequent stakeholder workshop to elaborate measures to tackle tyre wear.

The results are intended to inform decision makers and stakeholders (with a European focus), to whom this report will be distributed and communicated.

3.1 Methods

3.1.1 Preparatory Work

Action areas and specific measures to reduce tyre wear and mitigate associated risks were identified, and an extensive contact list with experts and professionals from various stakeholder groups was compiled. The stakeholder groups comprised *academia*, *industry*, *government & administration*, *representation of interests*, *NGOs*, and *providers of infrastructure or public services*. The collection of potential mitigation measures and contacts was based on scientific literature, a general web search, and relevant conferences or events[1].

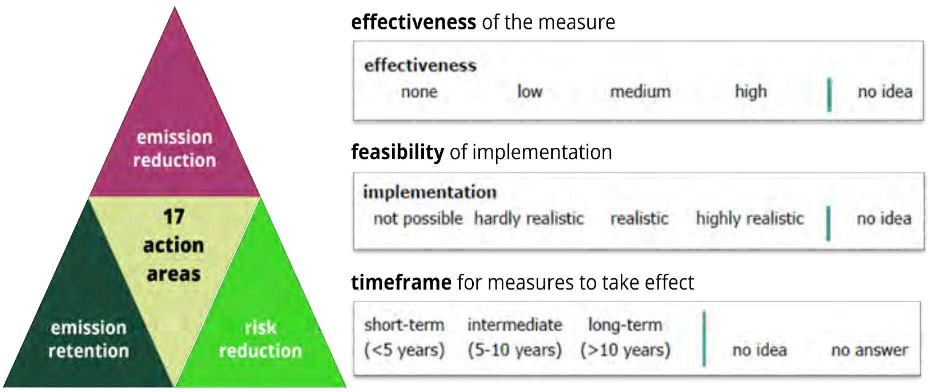
[1] *2024 Tyre Emissions Research Conference – A Tyre Industry Project Initiative*, 4-6 December 2024, Munich, Germany – *TRWP Platform Meeting on Air Pollution and the Contribution of Tyres to Non-Exhaust Emissions*, 11 March 2025, Brussels, Belgium

3.1.2 Online Expert Survey

An online expert survey was conducted to prioritise action areas and evaluate potential future measures to reduce tyre wear emissions and mitigate associated risks. Based on research, 17 action areas were identified aiming at emission reduction, emission retention, or risk reduction (see Annex I, Table 21). Each action area included 2–8 measures, which were to be assessed in terms of their *effectiveness*, *feasibility* of implementation and the *timeframe* to take effect (Figure 1). Within the 17 action areas, a total of 80 measures could be rated (see the full list of measures in Annex I, Table 22). Also, additional measures could be suggested. Participants had to provide information on their stakeholder group affiliation and rate their own level of expertise (*expert*, *well-informed*, *common sense/gut feeling*) in the specific action area before assessing potential measures. It was also possible to skip action areas and related measures (by selecting the level of expertise *none – I'd like to skip related questions*).

Figure 1. Structure of the Expert Survey.

Structure of the Expert Survey



Source: Environment Agency Austria

Invitations to participate in the survey between 1 July and 14 September 2025 were sent out to more than 500 collected stakeholder contacts, and 52 participants fully completed the survey. Data were analysed across all participants, by stakeholder group and by level of expertise, grouping *well-informed* participants and *experts* as ≥*well-informed*. The measures were ranked based on the experts' assessments as follows: The answers were translated into scores for each category evaluated (*effectiveness*, *implementation*, *timeframe*) and the total score was used to rank the measures as described in Table 1. The maximum score of 20 indicates the most preferable measures and measures that score below

9.5 are not worth pursuing, as they are either considered not effective or not feasible.

Table 1. Ranking scheme for measures based on the sum of scores allocated for *effectiveness*, *feasibility*, and *timeframe*.

rank	effectiveness (score)	feasibility (score)	timeframe (score)	total score*
1	high (7.5)	highly realistic (7.5)	short-term (5)	20
2	high (7.5)	highly realistic (7.5)	intermediate (4)	19
3	high (7.5)	highly realistic (7.5)	long-term (3.5)	18.5
3	medium (6)	highly realistic (7.5)	short-term (5)	18.5
3	high (7.5)	realistic (6)	short-term (5)	18.5
4	medium (6)	highly realistic (7.5)	intermediate (4)	17.5
4	high (7.5)	realistic (6)	intermediate (4)	17.5
5	medium (6)	highly realistic (7.5)	long-term (3.5)	17
5	high (7.5)	realistic (6)	long-term (3.5)	17
5	medium (6)	realistic (6)	short-term (5)	17
6	medium (6)	realistic (6)	intermediate (4)	16
7	medium (6)	realistic (6)	long-term (3.5)	15.5
7	high (7.5)	hardly realistic (3)	short-term (5)	15.5
7	low (3)	highly realistic (7.5)	short-term (5)	15.5
8	low (3)	realistic (6)	short-term (5)	14
8	high (7.5)	hardly realistic (3)	long-term (3.5)	14
8	medium (6)	hardly realistic (3)	short-term (5)	14
9	medium (6)	hardly realistic (3)	long-term (3.5)	13
10	low (3)	realistic (6)	long-term (3.5)	12.5
10	medium (6)	hardly realistic (3)	long-term (3.5)	12.5
11	low (3)	hardly realistic (3)	short-term (5)	11
12	low (3)	hardly realistic (3)	intermediate (4)	10
13	low (3)	hardly realistic (3)	long-term (3.5)	9.5

** total score in the categories "effectiveness", "feasibility", "timeframe"*

The results of the expert survey were used to prepare the subsequent expert workshop on tyre wear and associated chemicals of concern and are presented in 4.1.

3.1.3 Expert Workshop

The workshop *Expert Panel – Tackling Tyre Wear and Associated Chemical Risks* was held on 27 November 2025, 9:00 a.m. to 5:00 p.m., in Vienna on-site and online. The programme (see Annex II) featured talks on the state-of-the-art and breakout sessions to actively work on specific measures in selected action areas. The workshop involved more than 100 international experts and professionals from all stakeholder groups, with 37 on-site and 65 online participants.

The target of the workshop was to connect stakeholders and enhance dialogue. Breakout sessions aimed to support the identification of strategies to effectively tackle tyre wear and associated risks. Based on the results of the expert survey prior to the workshop, specific measures within six topics were selected for further discussion regarding their implementation.

The six topics comprised:

1. chemicals and risk assessment,
2. awareness and exposure avoidance (incl. end-of-life applications),
3. distribution via dust and measures at or near the road,
4. runoff collection/retention and treatment,
5. tyre – vehicle – road – driving behaviour and their interactions, and
6. mobility transition and traffic reduction.

Within each topic, 4–6 measures should be specified and evaluated by workshop participants regarding their potential implementation and related obstacles or benefits, guided by the following questions:

- How should the measure be specified and operationalised for a target-oriented implementation?
- What is most needed to effectively implement this measure?
- Which stakeholder/s is/are primarily responsible for the potential implementation?
- Are positive effects (added value) beyond tackling (adverse effects of) tyre wear to be expected, or will implementing this measure face many obstacles and high resistance?
- Which positive effects or obstacles are to be expected?

To enable both online and on-site participants to share their opinions, Microsoft Forms online surveys, referred to as *workshop surveys* in the following, were used to collect answers for each topic. Additionally, group chairs and co-chairs were assigned to summarise on-site discussions at the end of the workshop. The workshop results are given in 4.2.

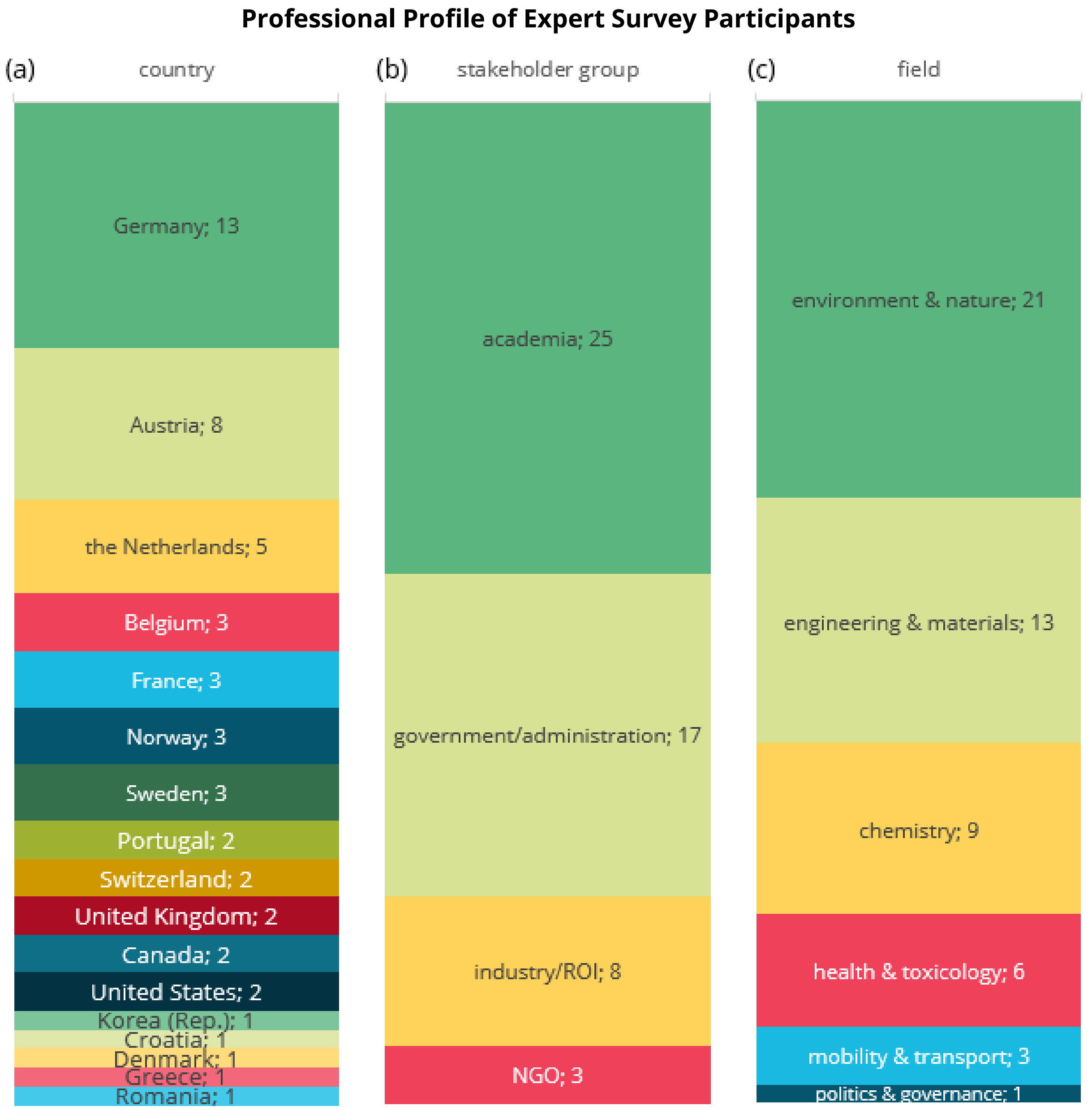
4 RESULTS

4.1 Expert Survey

4.1.1 Participants' Profile

In the expert survey, there were 53 participants from three continents (Europe: 48, North America: 4, Asia: 1) and 17 countries of employment, with the highest involvement from Germany (13), Austria (8), and the Netherlands (5) (Figure 2a). *Academia* was the most represented stakeholder group (25), followed by *government & administration* (17), *industry & representation of interests* (8), and *NGOs* (3) (Figure 2b). In the following, the stakeholder groups are referred to as *academia*, *industry/ROI*, *government/administration* and *NGOs*. It must be noted that two survey responses in the stakeholder group *industry/ROI* were completed in coordination with several experts from the respective organisation. The major fields of expertise of the participants in the expert survey included environment & nature (21), engineering & materials (13), chemistry (9), and health & toxicology (6) (Figure 2c).

Figure 2. Professional profile of expert survey participants (a) country of employment, (b) stakeholder group affiliation, and (c) field of expertise.



Source: Environment Agency Austria

More specifically, the expertise of the respondents focused on *environmental pollution*, *tyre wear*, *chemical safety & risk assessment*, and *rubber & tyres*, followed by *ecotoxicology*, *air pollution*, and *toxicology* (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

Figure 3. Fields of expertise represented by the 53 expert survey participants.

Participants' Fields of Expertise

Source: Environment Agency Austria

The font size reflects the ranking by participants as their primary, secondary, or tertiary expertise

4.1.2 General Prioritisation of Action Areas

First, participants were asked to prioritise the 17 listed action areas to reduce tyre-derived emissions (particles & chemicals) and related health and environmental risks. The following scores were allocated to the different prioritisations *high* = 9, *medium* = 3, *low* = 1, *no priority* = 0, and average scores were determined across all individual responses and within each stakeholder group. Additionally, the mean across the four stakeholder-group averages was calculated and used to sort/rank the action areas.

The results are given in Figure 4, and indicate where different stakeholder groups agree or disagree on the prioritisation of action areas. The stakeholder groups largely agreed on the importance of measures regarding

- the reduction and avoidance of hazardous substances in tyres,
- the optimisation of tyres for low wear,
- the advancement of risk assessment, and
- the generation/provision of knowledge on exposure avoidance,

as indicated by the green shading and high prioritisation scores for these action areas by most stakeholders (Figure 4). The stakeholder groups also agreed on the relatively low priority of measures regarding

- the equipment of vehicles with (tyre) particle collection systems,
- the optimisation of practices regarding grit/salt application and road dust removal to reduce tyre wear, and

- particle retention at/near roads (e.g. porous asphalts, roadside greenery, constructed wind barriers) to avoid wind drift.

More controversial action areas include

- the reduction of (individual) traffic volume,
- the optimisation of roads (surfaces, topology etc.) to reduce tyre wear,
- the protection of environmental media, sensitive ecosystems, and crops to minimise exposure (e.g. by limit values, buffer zones etc.),
- the retention of hazardous substances leached from tyre wear to avoid sinks becoming sources.

NGOs and *academia* would welcome *traffic reduction* measures and measures to *ensure retention of hazardous leachates* within sinks, while *industry/ROI* and *government/administration* would not prioritise these action areas to tackle tyre wear. *Industry/ROI* would, however, prioritise the *optimisation of roads*, which other stakeholders would not. *NGOs* would favour measures to *protect the environment (e.g. limit values, buffer zones),* which *industry/ROI* does not consider a priority, while scientists and *government/administration* are rather neutral about it.

Figure 4. Prioritisation of action areas to reduce tyre-derived emissions (particles & chemicals) and related health and environmental risks.

Prioritisation of Action Areas

action areas	all responses (n=53)	academia (n=25)	gov./adm. (n=17)	ind./ROI (n=8)	NGO (n=3)	stakeh. average (n=4)
reduce or avoid the use or presence of hazardous substances in tyres	7.5	7.3	7.8	6.8	9.0	7.7
optimise tyres for low wear (materials, design/dimensions etc.)	6.8	6.8	6.4	7.5	7.0	6.9
generate and provide knowledge on how to avoid exposure to tyre particles or related substances to empower individuals and to inform stakeholders (producers, legislators etc.)	6.0	5.5	6.1	6.1	9.0	6.7
advance risk assessment to handle the complexity of tyre wear particles and related substances (incl. transformation products)	5.8	5.9	5.4	6.3	6.0	5.9
protect environmental media (soil, water, air etc.), sensitive ecosystems, and crops to minimise exposure of humans & biota (e.g., by limit values, buffer zones, monitoring etc.)	4.9	5.0	4.8	3.6	9.0	5.6
ensure the retention of hazardous substances leached from tyres/tyre wear (at/near roads, in treatment facilities, end-of-use tyre applications etc.) to avoid sinks becoming sources	4.5	5.3	2.9	3.8	9.0	5.2
avoid emissions from end-of-life tyre utilisation (e.g., tyre crumb rubber on playgrounds or as drainage material)	4.8	4.6	4.8	4.4	7.0	5.2
reduce (individual) traffic volume	4.6	5.8	2.9	2.5	9.0	5.1
optimise vehicles (weight, smart vehicles etc.) and vehicle maintenance (wheel alignment etc.) to reduce tyre wear	4.8	5.1	3.5	6.5	4.3	4.9
foster a low wear driving style	4.1	4.0	2.9	5.5	7.0	4.9
expand collection and treatment of contaminated materials from roads/roadsides (e.g. roadside greenery, snow, road dust, banquet/roadside soils)	4.3	5.4	1.9	5.3	6.3	4.7
expand runoff collection from roads and sealed surfaces (in cities) and optimise treatment efficiency (for particles and chemicals)	4.5	5.3	2.7	5.5	4.3	4.5
optimise tyre choice and maintenance for low wear (tyre management)	4.7	4.9	5.4	3.5	3.0	4.2
foster particle retention at roads or roadsides to reduce wind drift (e.g. by porous asphalts, roadside greenery, constructed wind barriers)	4.0	4.1	3.5	4.5	4.3	4.1
optimise roads (surfaces, topology etc.) to reduce tyre wear	3.9	3.4	3.2	7.5	2.0	4.0
optimise practices regarding road dust removal, grit/salt application to reduce tyre wear	3.6	3.6	3.2	5.3	2.3	3.6
equip vehicles with (tyre wear) particle collection systems	2.6	2.2	2.0	4.1	4.3	3.2

Source: Environment Agency Austria

Numbers represent the average prioritisation scores based on the following translation: "high" = 9, "medium" = 3, "low" = 1, "no priority" = 0. High values (green shading) indicate high priority, low values (grey shading) indicate low priority.

4.1.3 Evaluation of Measures Across all Action Areas

A total of 80 measures within 17 action areas could be rated (see Annex I). The measures were ranked on a stakeholder-average basis by their total score (combining the ratings of *effectiveness*, *feasibility*, and *timeframe* for implementation as described in 3.1.2). Measures scoring ≥16 (given in Figure 5) are considered worth pursuing. They comprise short-, medium-, and long-term measures that were assessed as *medium to highly effective* and *realistic to highly realistic* for implementation. For measures with a stakeholder-average score <16, see Annex III.

Figure 5. Ranking of all measures by their stakeholder-average total score, part I (for continuation, see Annex III).

Ranking of All Measures by Stakeholder-Average Total Score (Part I)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

TOTAL SCORE*)

measures	all responses	stakeholder groups				stakeh. average	level of expertise	
		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
implement tyre-emission limits (e.g. Euro 7)	17.0	16.8	16.8	17.8	17.7	17.2	15.8	17.4
understand the degradation of tyre particles and the release of hazardous substances in different environmental media to evaluate persistence and long-term leaching behaviour	16.9	17.5	15.9	17.1	17.7	17.1	14.8	17.4
understand the leaching/transformation/degradation of tyre-related hazardous substances in environmental media and biological fluids to evaluate risk	16.8	17.1	16.2	17.0	17.7	17.0	15.2	17.2
understand the uptake, behaviour and fate of tyre wear particles in humans	16.2	16.3	15.4	17.6	17.8	16.8	14.5	16.6
promote safe-and-sustainable-by-design practices (e.g. consulting on chemical hazards in a trusted environment, installation of chemical substitution centres, subsidising production of non-hazardous alternative substances etc.)	16.2	16.6	15.4	15.8	18.7	16.6	16.4	16.2
promote telework	16.2	15.8	16.5	16.3	17.8	16.6	16.3	16.0
stop the use of winter tyres during summer (softer winter tyres generate more wear at higher temperatures)	16.8	17.6	18.4	13.3	17.0	16.6	17.5	16.5
ensure the suitability of human and environmental hazard and risk assessment for (tyre wear) particles (what works for chemicals doesn't necessarily work for particles)	16.2	16.4	15.7	16.4	17.7	16.5	15.2	16.5
ensure that human and environmental hazard and risk assessment captures the complexity of tyre-related substances (e.g. mixture effects, transformation products, unintentionally present substances)	16.2	16.7	15.3	16.4	17.7	16.5	14.8	16.5
evaluate human exposure to particles & hazardous substances by end-of-life tyre applications (e.g. crumb rubber in playgrounds/turf fields, flooring & mats, gardening/playground equipment etc.) and derive recommendations	16.2	17.0	14.9	16.9	16.8	16.4	15.4	16.4
optimise tyre materials (formulation/composition) for low wear	16.0	15.5	15.6	17.7	16.8	16.4	16.2	15.9
assess the impact of mobility behaviour (e.g. cycling/walking/jogging along roads, driving in cars etc.) on human exposures to tyre-derived particles & hazardous substances and derive recommendations	16.0	16.9	14.6	16.6	17.2	16.3	13.4	16.7
optimise tyre design (e.g. physical factors, weight, dimensions, rolling resistance) for low wear	16.4	16.4	15.8	17.0	15.8	16.3	16.4	16.4
shift personal transport from cars to public transport, walking, and cycling	15.8	16.2	15.0	15.8	17.8	16.2	15.4	16.5
avoid applications of tyre crumb rubber products in the environment (e.g. artificial turf, playground equipment, landscaping gardens/parks, fillers/embankments)	16.3	16.5	17.3	13.5	16.8	16.1	15.9	16.5
avoid stop-and-go traffic (harsh braking & accelerating) by enabling green waves	16.5	17.5	12.3	17.8	16.7	16.0	15.4	16.9
implement a wear-based tyre labelling scheme (allowing informed consumer decisions)	15.7	15.8	14.5	16.4	17.5	16.0	16.0	15.6
smart vehicles to optimise torque, acceleration & deceleration behaviour (depending on speed, terrain, load, traction conditions etc.) by automatic optimisation or pop-up driver information	16.1	16.1	15.8	16.8	15.3	16.0	15.0	16.6
inform/train consumers (drivers) on optimal tyre choice, maintenance and storage	15.9	16.1	16.2	15.1	16.5	16.0	15.5	16.1
road dust: expand sweeping (include more roads, pavements, parking lots etc.) and optimise frequency, timing, locations (e.g. tyre wear "hot spots" or predicted wind/rain events)	16.4	17.4	13.1	17.7	15.7	15.9	16.5	16.3
promote smooth traffic using dynamic speed limits according to traffic load	16.0	16.8	13.0	16.2	17.2	15.8	13.2	16.9

Source: Environment Agency Austria

The measures in Figure 5 did not only score well (≥16) regarding the stakeholder-average but also regarding the average score by participants considering themselves *well-informed* or *experts*. The top three measures suggest that all stakeholders agree (scores ≥16) on a precautionary implementation of tyre-emission limits but identify a strong need to better understand the fate & behaviour of tyre particles and related chemicals in the environment and within organisms to properly assess risks. Considering further top-ranked measures, *precautionary action* combined with *advancing problem understanding and risk assessment* emerges as a common preferred strategy (Table 2). Although *government & administration* clearly rated *immediate (and cost-efficient) action* better than *advancing understanding & risk assessment* (see 0).

Table 2. Top-ranked measures grouped by their strategic aims into “precautionary action” and “advancing problem understanding & risk assessment”.

precautionary action	**better problem understanding & risk assessment**
• implementation of tyre-emission limits (e.g. Euro 7) • promote safe-and-sustainable-by-design practices (e.g. consulting on chemical hazards in a trusted environment, installation of chemical substitution centres, subsidising production of non-hazardous alternative substances) • promote telework (to reduce traffic) • stop the use of winter tyres during summer (softer winter tyres generate more tyre wear at higher temperatures • optimise tyre materials (formulation/composition) for low wear • optimise tyre design (e.g. physical factors, weight, dimensions, rolling resistance) for low wear	• degradation of tyre particles and the release of hazardous substances in different environmental media to evaluate persistence and long-term leaching behaviour • understanding leaching/transformation/degradation of tyre-related hazardous substances in environmental media and biological fluids to evaluate risk • understand the uptake, behaviour, and fate of tyre wear particles in humans • ensure the suitability of human and environmental hazard and risk assessment for (tyre wear) particles (what works for chemicals doesn't necessarily work for particles) • ensure that human and environmental hazard and risk assessment captures the complexity of tyre-related substances (e.g. mixture effects, transformation products, unintentionally present substances) • evaluate human exposure to particles & hazardous substances by end-of-life tyre applications (e.g. crumb rubber in playgrounds/turf fields, flooring & mats, gardening/playground equipment etc.) and derive recommendations • assess the impact of mobility behaviour (e.g. cycling/walking/jogging along roads, driving in cars etc.) on human exposures to tyre-derived particles & hazardous substances and derive recommendations

4.1.3.1 Stakeholder Group Preferences and Differences

Please note that the position of the stakeholder group *NGOs* is not discussed separately, as there were only three participants in the survey.

Stakeholder Group: Government/Administration

The measures preferred (score ≥16, Figure 6) by *government/administration*, clearly focus on *immediate and cost-efficient action* and include:

1. stop the use of winter tyres in summer,
2. avoid open-environment applications of tyre crumb rubber (in sports fields, playgrounds, landscaping),
3. implement tyre abrasion limits (e.g. Euro 7),
4. optimise storage (conditions, max. duration etc.) at producers & retailers to avoid aging impacts on tyre wear,
5. promote telework,
6. understand the leaching/transformation/degradation of tyre-related hazardous substances in environmental media and biological fluids to evaluate risk,
7. inform/train consumers (drivers) on optimal tyre choice, maintenance, and storage.

Optimising storage was not considered worth pursuing by the other stakeholders (Figure 6), foremost *industry/ROI*, which rated its *effectiveness* and *feasibility* very low. Also, the average score across participants with a higher level of expertise was low for this measure.

Government/administration rated only 7 measures as high as to score ≥16. *Academia* (32 measures with a score ≥16) and *industry/ROI* (28 measures with a score ≥16) had a broader conception of what could be target-aimed measures.

Figure 6. Top-rated measures (score ≥16) according to the evaluation of effectiveness, feasibility, and timeframe by *government/administration*.

Top-Rated Measures (Score ≥16) by Government/Administration

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

	TOTAL SCORE*)							
	all responses	stakeholder groups				stakeh. average	level of expertise	
measures		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
stop the use of winter tyres during summer (softer winter tyres generate more wear at higher temperatures)	16.8	17.6	18.4	13.3	17.0	16.6	17.5	16.5
avoid applications of tyre crumb rubber products in the environment (e.g. artificial turf, playground equipment, landscaping gardens/parks, fillers/embankments)	16.3	16.5	17.3	13.5	16.8	16.1	15.9	16.5
implement tyre-emission limits (e.g. Euro 7)	17.0	16.8	16.8	17.8	17.7	17.2	15.8	17.4
optimise storage (conditions, max. duration…) at producers and retailers (incl. second-hand) to avoid aging impacts on tyre wear	12.9	13.4	16.5	8.4	13.0	12.9	14.5	12.0
promote telework	16.2	15.8	16.5	16.3	17.8	16.6	16.3	16.0
understand the leaching/transformation/degradation of tyre-related hazardous substances in environmental media and biological fluids to evaluate risk	16.8	17.1	16.2	17.0	17.7	17.0	15.2	17.2
inform/train consumers (drivers) on optimal tyre choice, maintenance and storage	15.9	16.1	16.2	15.1	16.5	16.0	15.5	16.1

Source: Environment Agency Austria

Stakeholder Group: Industry/ROI

The top-rated measures by *Industry/ROI* (**score ≥17**, Figure 7) included the following (further measures **scoring ≥16**, see Annex IV, Figure 30):

1. implement tyre-emission limits (e.g. Euro 7),
2. avoid stop-and-go traffic (harsh braking & accelerating) by enabling green waves,
3. optimise tyre materials (formulation/composition) for low wear,
4. expand sweeping to retain road dust and optimise frequency, timing, and locations,
5. Identify/develop asphalt types for low wear,
6. understand the uptake, behaviour, and fate of tyre wear particles in humans,
7. optimise management of banquet materials and roadside soils to retain tyre wear (e.g. prevent wind/water erosion; optimise renewal-frequency to prevent tyre wear remobilisation)
8. understand the degradation of tyre particles and release of hazardous substances in different environmental media to evaluate persistence and long-term leaching behaviour,
9. optimise tyre design (e.g. physical factors, weight, dimensions, rolling resistance) for low wear,
10. understand leaching/transformation/degradation of tyre-related hazardous substances in environmental media and biological fluids to evaluate risk,
11. ensure maintenance/cleaning of decentralised road-runoff or snow collection/treatment facilities to avoid leaching and breakthrough of hazardous substances.

These measures focus on *advancing tyres and asphalts to limit wear* (1., 3., 5, 9.), *management approaches to avoid or retain tyre wear* (2., 4., 7., 11.), and *enhancing knowledge-based risk assessment* (6., 8., 10.). *Academia* and *government/administration* were least optimistic about the *management of banquet materials & roadside soils* (Figure 7), probably because it would generate much waste soil and considerable costs for treatment or landfilling (see Annex VI). This measure also scored not so high among participants with a higher level of expertise.

Figure 7. Top-rated measures (score ≥17) according to the evaluation of effectiveness, feasibility, and timeframe by *industry/ROI*.

Top-Rated Measures (Score ≥17) by Industry/ROI

TOTAL SCORE*)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups				stakeh. average	level of expertise	
		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
implement tyre-emission limits (e.g. Euro 7)	17.0	16.8	16.8	17.8	17.7	17.2	15.8	17.4
avoid stop-and-go traffic (harsh braking & accelerating) by enabling green waves	16.5	17.5	12.3	17.8	16.7	16.0	15.4	16.9
optimise tyre materials (formulation/composition) for low wear	16.0	15.5	15.6	17.7	16.8	16.4	16.2	15.9
road dust: expand sweeping (include more roads, pavements, parking lots etc.) and optimise frequency, timing, locations (e.g. tyre wear "hot spots" or predicted wind/rain events)	16.4	17.4	13.1	17.7	15.7	15.9	16.5	16.3
identify/develop asphalt types for low wear (considering driving speed, climate, impacts of road dust & salt/grit)	16.3	17.2	14.9	17.6	12.7	15.6	16.3	16.4
understand the uptake, behaviour and fate of tyre wear particles in humans	16.2	16.3	15.4	17.6	17.8	16.8	14.5	16.6
optimise management of banquet materials and roadside soils to retain tyre wear (e.g. prevent wind/water erosion; optimise renewal-frequency to prevent tyre wear remobilisation)	14.4	15.2	8.0	17.5	15.3	14.0	15.5	13.7
understand the degradation of tyre particles and the release of hazardous substances in different environmental media to evaluate persistence and long-term leaching behaviour	16.9	17.5	15.9	17.1	17.7	17.1	14.8	17.4
optimise tyre design (e.g. physical factors, weight, dimensions, rolling resistance) for low wear	16.4	16.4	15.8	17.0	15.8	16.3	16.4	16.4
ensure maintenance/cleaning of decentralised road-runoff or snow collection/treatment facilities to avoid leaching and breakthrough of hazardous substances	15.1	15.6	13.1	17.0	14.8	15.1	15.6	14.8
understand the leaching/transformation/degradation of tyre-related hazardous substances in environmental media and biological fluids to evaluate risk	16.8	17.1	16.2	17.0	17.7	17.0	15.2	17.2

Source: Environment Agency Austria

Stakeholder Group: Academia

The top-rated (**score ≥17**) measures by *academia* include the following (further measures **scoring ≥16**, see Annex IV, Figure 31):

1. avoid the application of tyre crumb rubber as filter/drainage materials to prevent leaching,
2. stop the use of winter tyres in summer,
3. understand the degradation of tyre particles and release of hazardous substances in different environmental media to evaluate persistence and long-term leaching behaviour,
4. avoid stop-and-go traffic (harsh braking & accelerating) by enabling green waves
5. expand sweeping to retain road dust and optimise frequency, timing, and locations
6. establish limit values for tyre-related hazardous substances in environmental media (water, soil etc.) coupled with monitoring
7. Identify/develop asphalt types for low wear
8. understand leaching/transformation/degradation of tyre-related hazardous substances in environmental media and biological fluids to evaluate risk
9. evaluate human exposure to particles & hazardous substances by end-of-life tyre applications (e.g. playgrounds, sport fields, flooring, mats, gardening equipment) and derive recommendations

These measures focus on *immediate cost-efficient action* (1., 2.), *management approaches to avoid or retain tyre wear* (4., 5.), and *enhancing knowledge-based risk assessment* (3., 8., 9.). *Academia* was the only stakeholder group that strongly recommended *environmental limit values for tyre-related hazardous substances coupled with monitoring* (6.). Especially, *government/administration* and *industry/ROI* considered limit values less effective and feasible (Figure 8). *Academia* and *industry/ROI* agreed on the importance of *low-wear asphalts* (7.), certain *management approaches* (4., 5.), and certain measures to *advance knowledge-based risk assessment* (3., 8.). The latter were also well-rated by *government/administration*, while *management approaches* (4., 5.) were not (Figure 8). *Academia* and *government/administration* both considered *stopping the use of winter tyres in summer* a very good measure, while *industry/ROI* considered it hard to implement and less effective.

Figure 8. Top-rated measures (score ≥17) according to the evaluation of effectiveness, feasibility, and timeframe by *academia*.

Top-Rated Measures (Score ≥17) by Academia

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	TOTAL SCORE*) all responses	stakeholder groups academia	gov./adm.	ind./ROI	NGO	stakeh. average	level of expertise gut feeling	≥well inf.
avoid the application of tyre crumb rubber as filter/drainage material (e.g. in stormwater and urban runoff management or in drainage layers for roads/railways/landfills etc.) to avoid leaching of hazardous substances	16.3	18.1	14.4	14.7	14.8	15.5	17.2	15.5
stop the use of winter tyres during summer (softer winter tyres generate more wear at higher temperatures)	16.8	17.6	18.4	13.3	17.0	16.6	17.5	16.5
understand the degradation of tyre particles and the release of hazardous substances in different environmental media to evaluate persistence and long-term leaching behaviour	16.9	17.5	15.9	17.1	17.7	17.1	14.8	17.4
avoid stop-and-go traffic (harsh braking & accelerating) by enabling green waves	16.5	17.5	12.3	17.8	16.7	16.0	15.4	16.9
road dust: expand sweeping (include more roads, pavements, parking lots etc.) and optimise frequency, timing, locations (e.g. tyre wear "hot spots" or predicted wind/rain events)	16.4	17.4	13.1	17.7	15.7	15.9	16.5	16.3
establish limit values for tyre-related hazardous substances or transformation products in environmental media (e.g. soil, sediment, water, air etc.) coupled with monitoring programmes	14.9	17.3	12.9	12.9	14.5	14.4	12.1	15.5
identify/develop asphalt types for low wear (considering driving speed, climate, impacts of road dust & salt/grit)	16.3	17.2	14.9	17.6	12.7	15.6	16.3	16.4
understand the leaching/transformation/degradation of tyre-related hazardous substances in environmental media and biological fluids to evaluate risk	16.8	17.1	16.2	17.0	17.7	17.0	15.2	17.2
evaluate human exposure to particles & hazardous substances by end-of-life tyre applications (e.g. crumb rubber in playgrounds/turf fields, flooring & mats, gardening/playground equipment etc.) and derive recommendations	16.2	17.0	14.9	16.9	16.8	16.4	15.4	16.4

Source: Environment Agency Austria

In summary, the survey suggests that *academia* and *industry/ROI* are aligned on pursuing a rather diverse and comprehensive strategy with a mix of measures, while *government/administration* strongly focuses on immediate cost-efficient measures.

All three stakeholder groups largely agreed on the importance of measures to advance *knowledge-based risk assessment*. *Industry/ROI* and *academia* also suggested *management approaches to avoid or retain tyre wear* (such as sweeping, green waves) to be effective, while *academia* and *government/administration* agreed on some measures focused on *immediate cost-efficient action* (e.g. no winter tyres in summer). This reveals the importance of convincing *government/administration* to support a more comprehensive strategy to tackle tyre wear and related substances of concern, employing a suitable mix of measures. The elaboration of such a strategy involving all stakeholders should also be fostered, as some approaches are mainly favoured by certain stakeholder groups, such as *advancing tyres to limit wear* (supported by *industry/ROI*) or *environmental limit values for tyre-related hazardous substances & monitoring* (supported by *academia*). Even though not a priority for all stakeholder groups, such approaches may be very valuable to achieve a comprehensive mitigation strategy.

4.1.4 Evaluation of Measures Within Action Areas

Considering the top-ranked measures in each of the 17 action areas can help to identify a diverse and comprehensive mix of reasonable measures. The online expert survey comprised measures aiming at emission reduction (38 measures in 8 action areas), emission retention (17 measures in 4 action areas), or risk reduction (25 measures in 5 action areas) (see Annex I, Table 22), which are evaluated in the following sections.

4.1.4.1 Emission Reduction Measures

Please note that emission reduction measures refer to actions reducing the emissions of tyre wear particles. Measures to reduce emissions of tyre-related hazardous chemicals were considered “risk reduction measures”, as tyre wear emissions and chemical emissions may be decoupled by enhancing the chemical safety of tyres.

Action Area: Traffic – Reducing (Individual) Traffic Volume

Emissions of tyre wear and related substances of concern may be reduced by reducing (individual) traffic volume. The top-ranked measures to achieve this were *promoting telework* and *shifting personal transport* *from cars to local public transport, walking, and cycling*, according to both, the average across stakeholder groups and across participants with a higher level of expertise (Figure 9). *NGOs* were the only stakeholder group recommending the *reduction of distances between workplaces, housing, & shopping* and the *promotion of car-free holidays as a concept for regions.*

Figure 9. Emission reduction measures in the action area TRAFFIC, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Reduction – Action Area: TRAFFIC

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups				stakeh. average	level of expertise	
emission reduction - action area: TRAFFIC		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
	(n=42)	(n=21)	(n=13)	(n=6)	(n=2)	ave.	(n=26)	(n=16)
promote telework	16.2	15.8	16.5	16.3	17.8	16.6	16.3	16.0
shift personal transport from cars to public transport, walking, and cycling	15.8	16.2	15.0	15.8	17.8	16.2	15.4	16.5
shift freight transport from road to rail and ship transport	15.0	15.3	14.7	14.6	14.8	14.8	14.7	15.4
promote local sourcing	14.1	14.4	12.7	15.2	15.5	14.4	14.4	13.8
promote proximity of workplaces, housing, and shopping	12.6	12.6	12.4	11.4	17.3	13.4	11.6	14.1
promote car-free holidays	10.6	10.5	10.7	7.5	19.3	12.0	10.5	10.6

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Tyre – Optimising Tyres for Low Wear

The most recommended measure is the *implementation of tyre-emission limits (e.g. Euro 7)*, but all the measures in the action area TYRE achieved a stakeholder-average total score of ≥16 (Figure 10) and were similarly rated by participants with a higher level of expertise. Especially *industry/ROI* sees a good lever in *improving tyres (tyre materials, tyre design)*. A wear-based tyre labelling scheme for informed consumer decision is considered less useful (low effectiveness), except by *NGOs*.

Figure 10. Emission reduction measures in the action area TYRE, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Reduction – Action Area: TYRE

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups: academia	gov./adm.	ind./ROI	NGO	stakeh. average	level of expertise: gut feeling	≥well inf.
emission reduction - action area: TYRE	(n=44)	(n=23)	(n=10)	(n=8)	(n=3)	ave.	(n=11)	(n=33)
implement tyre-emission limits (e.g. Euro 7)	17.0	16.8	16.8	17.8	17.7	17.2	15.8	17.4
optimise tyre materials (formulation/composition) for low wear	16.0	15.5	15.6	17.7	16.8	16.4	16.2	15.9
optimise tyre design (e.g. physical factors, weight, dimensions, rolling resistance) for low wear	16.4	16.4	15.8	17.0	15.8	16.3	16.4	16.4
implement a wear-based tyre labelling scheme (allowing informed consumer decisions)	15.7	15.8	14.5	16.4	17.5	16.0	16.0	15.6

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Tyre Management – Optimising Tyre Choice and Maintenance for Low Wear

The top-ranked measures in this action area were *stopping the use of winter tyres in summer* and *informing/training consumers (drivers) on optimal tyre choice, maintenance, and storage* (Figure 11). Both were lower rated by *industry/ROI*. Fostering *tyres as a service* and *avoiding aging impacts by optimising the tyre use phase or storage conditions/duration* were considered less effective and feasible.

Figure 11. Emission reduction measures in the action area TYRE MANAGEMENT, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Reduction – Action Area: TYRE MANAGEMENT

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups: academia	gov./adm.	ind./ROI	NGO	stakeh. average	level of expertise: gut feeling	≥well inf.
emission reduction - action area: TYRE MANAGEMENT	(n=34)	(n=16)	(=8)	(n=7)	(n=3)	ave.	(n=12)	(n=22)
stop the use of winter tyres during summer (softer winter tyres generate more wear at higher temperatures)	16.8	17.6	18.4	13.3	17.0	16.6	17.5	16.5
inform/train consumers (drivers) on optimal tyre choice, maintenance and storage	15.9	16.1	16.2	15.1	16.5	16.0	15.5	16.1
optimise tyre choice for the destination market (based on regional conditions: climate, road conditions, speed-limits etc.) involving tyre & automotive industry and retailers	15.6	15.6	15.9	15.6	14.3	15.4	15.8	15.5
provide "tyres as a service" for fleets or tyre leasing for individual vehicles to optimise tyre choice and maintenance	14.2	14.4	14.3	12.8	16.3	14.5	14.9	14.0
optimise the tyre use phase (e.g. "expiry date") to avoid aging impacts on tyre wear (limiting also the second-hand tyre market)	12.6	11.8	15.6	9.2	16.7	13.3	16.0	10.7
optimise storage (conditions, max. duration…) at producers and retailers (incl. second-hand) to avoid aging impacts on tyre wear	12.9	13.4	16.5	8.4	13.0	12.9	14.5	12.0

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Vehicle – Optimising Vehicles to Reduce Tyre Wear

Regarding the adaptation of vehicles to reduce emissions of tyre wear (Figure 12), only one measure scored ≥16 on stakeholder-average: *"smart" vehicles to optimise torque, acceleration, and deceleration, e.g. automatically or by pop-up driver information*. Participants with a higher level of expertise were slightly more optimistic about most measures. The assessment of *academia* suggests *optimum wheel alignment* and *promotion of lighter (smaller) vehicles (without compromising safety)* are also good options, without clear support from other stakeholders. Note that *reducing vehicle weight (size)* scored best regarding effectiveness but was considered hard to implement. It may be hard to influence the people's desire or need (e.g. families) for larger cars, and safety may be an issue with lighter/smaller cars. *Autonomous driving* and *active suspension* were considered the least powerful to reduce tyre wear emissions.

Figure 12. Emission reduction measures in the action area VEHICLE, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Reduction – Action Area: VEHICLE

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups: academia	gov./adm.	ind./ROI	NGO	stakeh. average	level of expertise: gut feeling	≥well inf.
emission reduction - action area: VEHICLE	(n=35)	(n=16)	(n=9)	(n=7)	(n=3)	ave.	(n=14)	(n=21)
smart vehicles to optimise torque, acceleration & deceleration behaviour (depending on speed, terrain, load, traction conditions etc.) by automatic optimisation or pop-up driver information	16.1	16.1	15.8	16.8	15.3	16.0	15.0	16.6
smart vehicles to ensure optimum tyre pressure by automatic adjustment (depending on speed, terrain, load, traction conditions etc.) or maintenance pop-ups	15.5	15.7	15.4	15.7	14.3	15.3	15.4	15.6
ensure optimal wheel alignment (e.g. by regular maintenance, sensors & maintenance pop-ups, automatic alignment in future?)	15.7	16.5	15.0	15.5	13.8	15.2	15.9	15.6
promote lighter (smaller) vehicles (without compromising safety)	15.3	16.2	14.8	13.7	15.8	15.1	14.9	15.6
smart vehicles to optimise driving speed (depending on curves, terrain, load, traction conditions etc.) by automatic adaptation or pop-up driver information	15.2	15.7	14.7	14.9	14.3	14.9	14.6	15.4
smart vehicles to optimise steering movement & curve behaviour (depending on speed, terrain, load, traction conditions etc.) by automatic adaptation or pop-up driver information	14.6	15.1	13.9	14.8	14.3	14.5	14.1	14.9
smart vehicles with active suspension to reduce tyre wear (depending on speed, terrain, load, traction conditions etc.)	13.8	13.9	14.1	12.7	14.3	13.8	14.4	13.5
promote autonomous driving to reduce tyre wear	12.7	13.5	12.3	12.0	9.7	11.9	12.8	12.6

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Driving – Fostering a Low Wear Driving Style

Since *government/administration* were critical about measures aimed at smooth driving, only *avoiding stop-and-go traffic* by traffic management reached a stakeholder-average score ≥16 (Figure 13). Other stakeholders would also support *dynamic speed limits for smooth driving,* which is also suggested as a good measure by participants with a higher level of expertise.

Figure 13. Emission reduction measures in the action area DRIVING, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Reduction – Action Area: DRIVING

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	TOTAL SCORE*) (n = no. of participants)							
	all responses	stakeholder groups				stakeh. average	level of expertise	
		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
emission reduction - action area: DRIVING	(n=33)	(n=16)	(n=7)	(n=7)	(n=3)	ave.	(n=9)	(n=24)
avoid stop-and-go traffic (harsh braking & accelerating) by enabling green waves	16.5	17.5	12.3	17.8	16.7	16.0	15.4	16.9
romote smooth traffic using dynamic speed limits according to traffic load	16.0	16.8	13.0	16.2	17.2	15.8	13.2	16.9
reduce or optimise speed limits for low tyre wear (regarding road surface conditions and topography, curve radii/inclinations)	15.4	15.9	14.5	13.8	18.2	15.6	14.3	15.8
ensure enforcement of existing/adapted speed limits (stricter controls)	15.2	15.8	13.0	14.6	17.5	15.2	13.9	15.7
educate drivers on smooth (low tyre wear) driving style (by information material, training etc.)	14.8	14.6	11.9	16.8	17.2	15.1	11.8	15.9
install traffic-calming (speed-limiting) construction measures	14.6	16.3	11.7	12.5	16.2	14.2	12.6	15.3

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Road – Optimising Roads for Low Tyre Wear

None of the measures reached a stakeholder-average score ≥16 (Figure 14), but *industry/ROI* and *academia*, as well as the ≥*well-informed* participants, see *optimising asphalt types* as a strong lever to reduce tyre wear, at least in the long term, as new asphalts would only be used for maintenance or new roads, delaying the effect.

Figure 14. Emission reduction measures in the action area ROAD, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Reduction – Action Area: ROAD

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	TOTAL SCORE*) (n = no. of participants)							
	all responses	stakeholder groups				stakeh. average	level of expertise	
		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
emission reduction - action area: ROAD	(n=34)	(n=14)	(n=10)	(n=7)	(n=3)	ave.	(n=18)	(n=16)
identify/develop asphalt types for low wear (considering driving speed, climate, impacts of road dust & salt/grit)	16.3	17.2	14.9	17.6	12.7	15.6	16.3	16.4
foster maintenance and repair of worn road surfaces and "upgrade" of terrain for low tyre wear	15.7	16.7	15.2	15.6	13.8	15.3	15.8	15.7
optimise road planning to favour low tyre wear (e.g. curve radii and inclination, dimensions of de-& acceleration lanes, roundabouts vs. crossroads) considering road surface type, speed limits etc.	14.3	14.6	13.6	15.2	12.7	14.0	14.6	14.0

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Practices – Optimising Practices Regarding Road Dust Removal, Grit/Salt Application to Lower Tyre Wear

None of the stakeholders rated the *removal of road dust* or an *optimisation of grit (or salt) application in winter* very high (score <16), with regard to the reduction of tyre abrasion (Figure 15). The highest rating was given by *government/administration,* suggesting that road dust removal may support a lower tyre abrasion.

Figure 15. Emission reduction measures in the action area PRACTICES, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Reduction – Action Area: PRACTICES

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups				stakeh. average	level of expertise	
		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
emission reduction - action area: PRACTICES	(n=29)	(n=15)	(n=5)	(n=6)	(n=3)	ave.	(n=15)	(n=14)
increase road cleaning to remove dust that may enhance tyre wear	14.6	14.7	15.6	13.8	14.0	14.5	14.3	14.9
valuate/optimise the use of road salt vs. grit in winter to reduce tyre wear	13.5	14.1	11.8	14.0	12.0	13.0	15.1	12.2
evaluate/optimise the use of grit (grit type, particle size/shape etc.) in winter to reduce tyre wear	13.3	14.0	11.5	12.6	12.0	12.6	14.6	12.2

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: End-of-Life Tyres – Avoiding Emissions from End-of-Life Tyre untilisation

Avoiding applications of tyre crumb rubber products in the environment (e.g. sports fields, playgrounds, parks etc.) was considered a suitable measure to reduce emissions at the end-of-life stage (Figure 16). Matrix-bound crumb rubber was not assessed as a relevant emission source, although chemicals may also leach from these materials. In general, *industry/ROI* was critical about these measures and assessed them as hardly effective (all measures) and hardly feasible (all but the first).

Figure 16. Emission reduction measures in the action area END-OF-LIFE TYRES, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Reduction – Action Area: END-OF-LIFE TYRES

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups				stakeh. average	level of expertise	
		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
emission reduction - action area: END-OF-LIFE TYRES	(n=42)	(n=21)	(n=12)	(n=6)	(n=3)	ave.	(n=15)	(n=27)
avoid applications of tyre crumb rubber products in the environment (e.g. artificial turf, playground equipment, landscaping gardens/parks, fillers/embankments)	16.3	16.5	17.3	13.5	16.8	16.1	15.9	16.5
avoid tyre (crumb) rubber modified materials exposed to the environment (e.g. asphalt, concrete, roofing materials, acoustic barriers along roads/railways)	14.5	15.8	14.8	10.4	13.2	13.5	15.2	14.1
promote the retreading of tyres	13.8	14.7	14.6	9.4	14.3	13.2	15.6	12.8

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

4.1.4.2 Emission Retention Measures

It should be noted that emission retention measures refer to actions aimed at retaining tyre wear particles. Measures to specifically retain tyre-related hazardous chemicals were considered "risk reduction measures", as tyre wear particle fate and chemical fate may be decoupled upon leaching.

Action Area: Vehicle – Equipping Vehicles with Particle Collection Systems

None of the suggested measures to *equip vehicles with particle capture devices* reached a stakeholder-average score ≥16 (Figure 17). Effectiveness was especially doubted by *government/administration*, but also by *academia* and *industry/ROI*. Feasibility was highly doubted by *industry/ROI*, followed by *academia*. The average scores among *≥well-informed* participants reflect the scepticism toward these measures. The two responding *NGOs*, however, rated all these measures very high.

Figure 17. Emission retention measures in the action area VEHICLE, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Retention – Action Area: VEHICLE

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups: academia	gov./adm.	ind./ROI	NGO	stakeh. average	level of expertise: gut feeling	≥well inf.
emission retention - action area: VEHICLE	(n=28)	(n=15)	(n=5)	(n=6)	(n=2)	ave.	(n=11)	(n=17)
p vehicles with nozzle-collection systems at the wheels to collect particles	13.6	13.1	14.8	12.2	18.5	14.6	14.1	13.3
equip vehicles with tyre housings to collect particles	12.9	12.6	13.3	11.2	18.5	13.9	14.0	12.3
quip vehicles with electrostatic modules at the wheels to collect tyre wear	12.8	12.8	13.3	10.8	18.5	13.8	12.8	12.8
equip vehicles with filters (e.g. on the roof or in the front fascia) to collect suspended particles (while driving and/or when parked)	9.9	9.3	8.1	9.3	18.5	11.3	9.8	10.0

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Road/Roadside – Fostering Particle Retention at Roads or Roadsides to Reduce Wind Drift

Since especially *government/administration* strongly doubted the effectiveness and feasibility of the suggested measures to retain emissions at or near the road, their average score remained <16 (Figure 18). Still, *promoting roadside greenery as wind barriers & particle traps* was considered worth pursuing by *industry/ROI* and *academia*. *Industry/ROI* also rated *constructed barriers (e.g. walls, fences, nets)* quite high, but they may be more difficult to implement due to a lower acceptance. Respondents who considered themselves *well-informed* or *experts* would additionally pursue the installation of particle-collecting/trapping road surfaces (e.g. porous or permeable pavements). This would again be a long-term measure, with a delayed effect (see 4.1.4.1 – Action Area: Road).

Figure 18. Emission retention measures in the action area ROAD / ROADSIDE, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Retention – Action Area: ROAD / ROADSIDE

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups: academia	gov./adm.	ind./ROI	NGO	stakeh. average	level of expertise: gut feeling	≥well inf.
emission retention - action area: ROAD / ROADSIDE	(n=33)	(n=17)	(n=7)	(n=6)	(n=3)	ave.	(n=14)	(n=19)
install particle collecting/trapping road surfaces (e.g. porous or permeable pavements)	14.6	15.7	11.3	15.2	14.2	14.1	12.2	16.4
promote roadside greenery (grass, bushes, trees etc.) as wind barriers and particle traps	14.9	16.4	10.4	16.6	12.7	14.0	13.8	15.8
install (or redesign existing) constructed barriers (e.g. walls, fences, nets) as wind barriers and particle traps	13.7	14.5	8.5	16.7	15.0	13.7	12.4	14.7
promote high embankments ("road-canyons") to favour particle retention along roads	13.0	15.3	8.4	14.0	8.7	11.6	10.4	14.9

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Contaminated Materials – Expanding the Collection and Treatment of Contaminated Materials from Roads/Roadsides

The best-ranked measure to retain contaminated materials was the *expansion of road dust collection (sweeping more traffic areas) and optimisation of frequency, timing, and location of sweeping (e.g. hotspots)* (Figure 19). It was rated very high by *industry/ROI* and *academia*, and ≥*well-informed* participants. Only *government/administration* remained sceptical about its effectiveness and feasibility. *Industry/ROI* would also welcome the *optimisation of banquet and roadside soil management* (see also 0 – Stakeholder Group: *Industry/ROI*). *Expanding the collection/treatment of (contaminated) snow and roadside greenery* was generally not considered a major factor in the retention of emissions.

Figure 19. Emission retention measures in the action area CONTAMINATED MATERIALS, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Retention – Action Area: CONTAMINATED MATERIALS

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

	TOTAL SCORE*) (n = no. of participants)							
	all responses	stakeholder groups				stakeh. average	level of expertise	
measures		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
emission retention - action area: CONTAMINATED MATERIALS	(n=30)	(n=14)	(n=7)	(n=6)	(n=3)	ave.	(n=14)	(n=16)
road dust: expand sweeping (include more roads, pavements, parking lots etc.) and optimise frequency, timing, locations (e.g. tyre wear "hot spots" or predicted wind/rain events)	16.4	17.4	13.1	17.7	15.7	15.9	16.5	16.3
optimise management of banquet materials and roadside soils to retain tyre wear (e.g. prevent wind/water erosion; optimise renewal-frequency to prevent tyre wear remobilisation)	14.4	15.2	8.0	17.5	15.3	14.0	15.5	13.7
roadside greenery: expand the collection and appropriate treatment of materials (shed leaves, grass, cuttings etc.) and optimise management to retain tyre wear (e.g. when/how to cut trees/bushes?)	13.9	15.3	10.4	13.5	14.3	13.4	14.1	13.7
snow: expand the collection and treatment of snow from roads (incl. roadsides, pavements, parking lots etc.)	13.4	15.1	11.5	10.3	14.3	12.8	14.6	12.4

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Runoff – Expanding Runoff Collection from Roads and Sealed Surfaces and Optimising Treatment Efficiency

Measures targeting emission retention in the area of runoff collection and treatment are not a priority, based on the stakeholder-average score (Figure 20). However, *NGOs* rated all the measures very high, and *optimising maintenance/cleaning of decentralised road-runoff (and snow) collection/treatment facilities to avoid remobilisation of tyre particles* was also considered a measure worth pursuing by *industry/ROI* and *academia*. *Industry/ROI* additionally considered the *expansion of rainwater and sealed-surface runoff collection in cities* and the *optimisation of the technical efficiency of road-runoff collection/treatment* as useful measures to retain tyre wear. *Government/administration* doubted the effectiveness of these measures and considered them hardly feasible.

Figure 20. Emission retention measures in the action area RUNOFF, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Emission Retention – Action Area: RUNOFF

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups: academia	gov./adm.	ind./ROI	NGO	stakeh. average	level of expertise: gut feeling	≥well inf.
emission retention - action area: RUNOFF	(n=30)	(n=15)	(n=7)	(n=6)	(n=2)	ave.	(n=11)	(n=19)
ensure optimal maintenance/cleaning of decentralised road-runoff (and snow) collection/treatment facilities to avoid (re)mobilisation or breakthrough of tyre wear particles	15.6	16.4	11.5	16.6	18.0	15.6	16.1	15.4
ensure the collection/treatment of stormwaters (no "overflow" emissions into the environment)	15.1	15.7	12.2	15.8	17.5	15.3	16.9	14.2
optimise the technical efficiency of road-runoff collection/treatment facilities to retain tyre wear	15.1	15.7	11.6	16.0	17.5	15.2	16.0	14.6
expand sealed-surface runoff collection (in cities) from the local/decentralised to the centralised level ("sponge city")	14.4	14.9	10.1	16.3	17.5	14.7	14.4	14.5
expand the network of road-runoff collection/treatment facilities from the local/decentralised to the centralised level	13.7	14.3	10.2	14.3	17.5	14.1	13.4	13.9

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

4.1.4.3 Risk Reduction Measures

Risk reduction measures include measures regarding hazardous chemicals in tyres (e.g. avoidance and retention measures), measures to advance risk assessment and avoidance, and measures to protect sensitive environments.

Action Area: Leaching – Ensuring the Retention of Hazardous Substances Leached from Tyres or Tyre Wear

Risk reduction measures that aim to avoid or retain tyre-material leachates did not reach a stakeholder-average score ≥16 (Figure 21). Some measures were, however, promoted by single stakeholder groups. *Academia* strongly supported the *avoidance of tyre crumb rubber application as filter/drainage materials (e.g. in stormwater/runoff treatment or drainage layers for roads/railways/landfills). Industry/ROI* considered an optimal *maintenance/cleaning of decentralised road-runoff collection/treatment facilities to avoid breakthrough of hazardous substances* highly relevant, and supported the *addition of absorbers, e.g. to (permeable) asphalts, banquet, roadside, or buffer-zone soils, to retain hazardous substances*. A frequent replacement of banquet, roadside, or buffer-zone soils was not considered worth pursuing, foremost by *government/administration* and *academia* (see also 0 – Stakeholder Group: *Industry/ROI* and 0 – Action Area: Contaminated Materials)

Figure 21. Risk reduction measures in the action area LEACHING, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Risk Reduction – Action Area: LEACHING

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups				stakeh. average	level of expertise	
		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
risk reduction - action area: LEACHING	(n=31)	(n=14)	(n=10)	(n=5)	(n=2)	ave.	(n=12)	(n=19)
avoid the application of tyre crumb rubber as filter/drainage material (e.g. in stormwater and urban runoff management or in drainage layers for roads/railways/landfills etc.) to avoid leaching of hazardous substances	16.3	18.1	14.4	14.7	14.8	15.5	17.2	15.5
ensure maintenance/cleaning of decentralised road-runoff or snow collection/treatment facilities to avoid leaching and breakthrough of hazardous substances	15.1	15.6	13.1	17.0	14.8	15.1	15.6	14.8
add absorbers that retain hazardous substances, e.g. to (permeable) asphalts, banquet materials, roadside/buffer-zone soils	14.4	14.9	12.4	16.4	15.0	14.7	14.7	14.2
ensure treatment efficiency for tyre-derived hazardous substances in facilities to collect/treat road-runoff or snow (e.g. infiltration swales, filter units, sedimentation/retention basins, wastewater treatment plants etc.)	14.6	15.7	12.0	15.4	14.8	14.5	13.9	14.9
optimise the replacement frequency of banquet materials, roadside/buffer-zone soils to avoid leaching and breakthrough of hazardous chemicals	13.6	14.7	10.5	15.4	15.0	13.9	13.3	13.8

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Substances of Concern – Reducing or Avoiding the Use or Presence of Hazardous Substances in Tyres

The stakeholder groups agree quite well on the benefits of *promoting safe-and-sustainable-by-design (SSbD) practices* to reduce risks of tyre-related substances of concern (Figure 22). *Restrictions of hazardous substances in tyres* were still considered a valid option by *academia*, *government/administration*, and *NGOs* (scores around 16), but not well rated by *industry/ROI*. *Total bans of hazardous substances in tyres* were not considered useful by the stakeholders, and *increasing transparency about substances used in tyres* was only rated very well by *NGOs*. Restrictions and bans reached high to medium effectiveness scores among all stakeholders, except *industry/ROI*. The feasibility of implementation was assessed as hardly to not realistic by all stakeholders for total bans, but as rather realistic for restrictions. Similarly, the timeframe for effectiveness was evaluated to be “long-term” for total bans and “intermediate” for restrictions.

Figure 22. Risk reduction measures in the action area SUBSTANCES OF CONCERN, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Risk Reduction – Action Area: SUBSTANCES OF CONCERN

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	TOTAL SCORE*) (n = no. of participants): all responses	stakeholder groups: academia	gov./adm.	ind./ROI	NGO	stakeh. average	level of expertise: gut feeling	≥well inf.
risk reduction - action area: SUBSTANCES OF CONCERN	(n=46)	(n=20)	(n=17)	(n=6)	(n=3)	ave.	(n=9)	(n=37)
promote safe-and-sustainable-by-design practices (e.g. consulting on chemical hazards in a trusted environment, installation of chemical substitution centres, subsidising production of non-hazardous alternative substances etc.)	16.2	16.6	15.4	15.8	18.7	16.6	16.4	16.2
restrict hazardous substances in tyres, e.g. by means of concentration limits or migration limits, based on human and environmental hazard and risk assessments for single substances or groups	15.4	15.7	15.7	13.3	16.3	15.2	15.8	15.3
increase transparency: indicate the identity (not necessarily the contents) of all substances used in the tyre and declare known/potentially hazardous substances	13.9	14.2	12.9	14.4	17.7	14.8	15.4	13.6
total ban of hazardous substances in tyres, based on human and environmental hazard and risk assessments for single substances or groups	12.1	11.9	12.7	10.3	14.7	12.4	13.6	11.8

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Environment – Protecting Environmental Media, Sensitive Ecosystems and Crops to Minimise Exposure of Humans and Biota

Measures to reduce the risks for environmental exposures did not reach stakeholder-average scores ≥16 (Figure 23). *Conducting targeted monitoring studies to ensure efficacy of measures to retain emissions (e.g. roadside greenery, runoff-collection/treatment)* received the highest stakeholder-average score (15.2). Overall, participants with a higher level of expertise were more optimistic about the measures in this action area. *Academia* would pursue *limit values for tyre-related hazardous substances in environmental media (e.g. soil, water etc.) coupled with monitoring*, followed by *preventing the use/disposal of (potentially) contaminated materials in the environment*, as well as *establishing long-term monitoring programmes for human exposure to tyre wear and related substances of concern*. *Government/administration* to some degree supports the *prevention of the use/disposal of (potentially) contaminated materials in the environment,* and *industry/ROI* is rather supportive regarding *environmental limit values* and *long-term human-exposure monitoring*.

Figure 23. Risk reduction measures in the action area ENVIRONMENT, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Risk Reduction – Action Area: ENVIRONMENT

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures / risk reduction - action area: ENVIRONMENT	all responses (n=39)	stakeholder groups: academia (n=16)	gov./adm. (n=15)	ind./ROI (n=5)	NGO (n=3)	stakeh. average (ave.)	level of expertise: gut feeling (n=7)	≥well inf. (n=32)
conduct targeted monitoring studies to ensure the efficacy of measures to retain tyre-related emissions (e.g. wind barriers, roadside greenery, buffer zones/stripes, runoff collection/treatment systems etc.)	15.2	16.3	14.1	15.6	14.7	15.2	12.0	15.9
prevent the use (e.g. agriculture, landscaping) or disposal of (potentially) contaminated materials in the open environment: e.g. sewage sludge, (composted) roadside greenery, snow from roads, roadside soils, soils/sediments/filter materials from decentralised road-runoff treatment facilities etc.	15.6	16.8	15.6	11.9	14.2	14.6	14.7	15.7
establish limit values for tyre wear in environmental media (e.g. soil, sediment, water, air etc.) coupled with monitoring programmes	14.4	15.5	12.6	15.9	14.3	14.6	12.3	14.8
install sufficient buffer zones or constructed/green barriers to ensure the protection of sensitive ecosystems or agricultural produce near roads	14.5	15.6	12.9	13.8	16.0	14.6	11.4	15.1
establish long-term monitoring programmes for human exposure (e.g. respiratory, dietary) to tyre wear particles and related hazardous substances (incl. transformation products)	14.5	16.3	12.3	15.3	14.2	14.5	10.7	15.3
establish limit values for tyre-related hazardous substances or transformation products in environmental media (e.g. soil, sediment, water, air etc.) coupled with monitoring programmes	14.9	17.3	12.9	12.9	14.5	14.4	12.1	15.5
avoid negative ecological effects of emission-retention measures (e.g. roadside greenery, retention ponds etc.) as organisms may consider these contamination hotspots attractive habitats	12.0	12.2	10.3	12.9	14.0	12.4	9.8	12.2

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Risk Assessment – Advancing Risk Assessment to Account for the Complexity of Tyre Wear Particles and Related Hazardous Substances

All measures to advance knowledge-based risk assessment achieved a stakeholder-average score ≥16 (Figure 24), which was also the case for the average of participants with a high level of expertise. The rating by *government/administration* was more moderate, but *academia*, *industry/ROI*, and *NGOs* consider *understanding the degradation and long-term leaching behaviour of tyre particles in the environment* and *the leaching/transformation/degradation of tyre-related substances in biological and environmental media* to be of high importance. The other measures in this action area aim to advance risk assessment and build on this knowledge base.

Figure 24. Risk reduction measures in the action area RISK ASSESSMENT, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Risk Reduction – Action Area: RISK ASSESSMENT

TOTAL SCORE*) (n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups				stakeh. average	level of expertise	
		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
risk reduction - action area: RISK ASSESSMENT	(n=37)	(n=16)	(n=14)	(n=4)	(n=3)	ave.	(n=7)	(n=30)
understand the degradation of tyre particles and the release of hazardous substances in different environmental media to evaluate persistence and long-term leaching behaviour	16.9	17.5	15.9	17.1	17.7	17.1	14.8	17.4
understand the leaching/transformation/degradation of tyre-related hazardous substances in environmental media and biological fluids to evaluate risk	16.8	17.1	16.2	17.0	17.7	17.0	15.2	17.2
derstand the uptake, behaviour and fate of tyre wear particles in humans	16.2	16.3	15.4	17.6	17.8	16.8	14.5	16.6
ensure the suitability of human and environmental hazard and risk assessment for (tyre wear) particles (what works for chemicals doesn't necessarily work for particles)	16.2	16.4	15.7	16.4	17.7	16.5	15.2	16.5
ensure that human and environmental hazard and risk assessment captures the complexity of tyre-related substances (e.g. mixture effects, transformation products, unintentionally present substances)	16.2	16.7	15.3	16.4	17.7	16.5	14.8	16.5

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

Action Area: Exposure Avoidance – Generating and Providing Knowledge on How to Avoid Exposure to Empower Individuals and to Inform Relevant Stakeholders

Two measures targeting exposure avoidance scored ≥16 regarding the stakeholder group average and the average score among ≥*well-informed* participants (Figure 25). Again, *government/administration* rated all the measures rather moderately. All other stakeholders strongly supported *the evaluation of human exposure to particles & chemicals by end-of-life tyre applications* and *the assessment of the impact of mobility behaviour on human exposures.* They also supported recommendations on *food-chain exposure* and *non-tyre rubber products*.

Figure 25. Risk reduction measures in the action area EXPOSURE AVOIDANCE, ranked by their stakeholder-average total score (sum of effectiveness, feasibility, and timeframe scores).

Risk Reduction – Action Area: EXPOSURE AVOIDANCE

TOTAL SCORE*)

(n = no. of participants)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups				stakeh. average	level of expertise	
		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
risk reduction - action area: EXPOSURE AVOIDANCE	(n=33)	(n=12)	(n=12)	(n=6)	(n=3)	ave.	(n=8)	(n=25)
evaluate human exposure to particles & hazardous substances by end-of-life tyre applications (e.g. crumb rubber in playgrounds/turf fields, flooring & mats, gardening/playground equipment etc.) and derive recommendations	16.2	17.0	14.9	16.9	16.8	16.4	15.4	16.4
assess the impact of mobility behaviour (e.g. cycling/walking/jogging along roads, driving in cars etc.) on human exposures to tyre-derived particles & hazardous substances and derive recommendations	16.0	16.9	14.6	16.6	17.2	16.3	13.4	16.7
assess the distribution of tyre-derived particles & hazardous substances on/within food plants and persistency during meal preparation to derive recommendations for consumers (e.g. washing, peeling, cutting off roots/greens, cooking etc.)	15.2	16.4	13.2	16.3	16.8	15.7	15.5	15.1
evaluate additional non-tyre sources of exposure to particles & hazardous substances, e.g. from rubber materials applied in food-contact, households, work environments, leisure (e.g. climbing shoes etc.) and derive recommendations	15.1	16.1	13.3	16.2	16.8	15.6	14.1	15.4

Source: Environment Agency Austria

Scores ≥16 indicate measures of medium or high effectiveness and realistic or highly realistic feasibility.

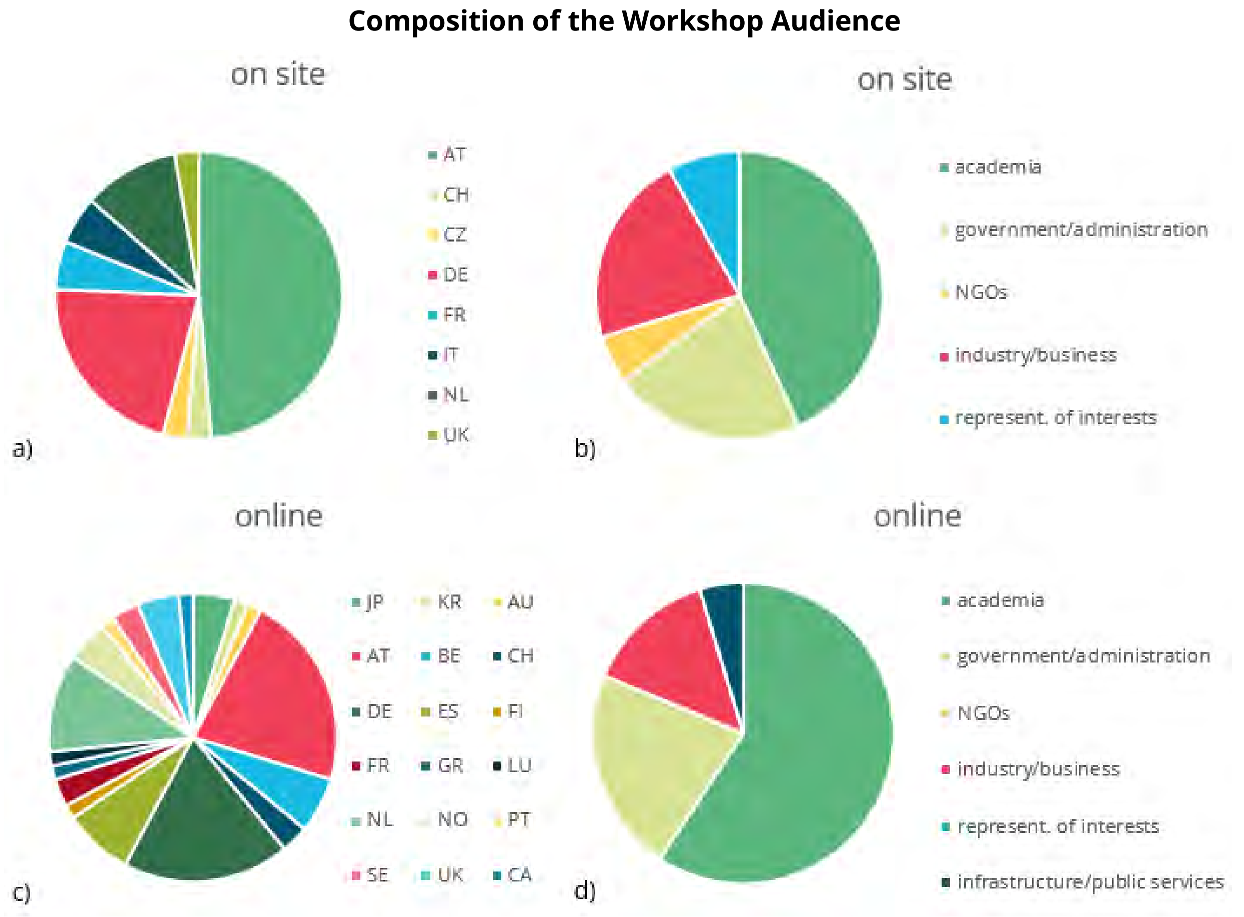
4.2 Expert Workshop

4.2.1 Participants' Profile

Workshop Audience

The expert workshop reached a total of 102 participants, with 37 participants on-site and 65 online. Most participants were affiliated with the stakeholder group *academia* (54), followed by the stakeholder groups *government/administration* (22) and *industry/business* (17). *Representation of interests* (3), *provision of infrastructure/public services* (3) and *NGOs* (2) were hardly represented. Participants mainly joined from Europe (95 participants from 16 countries), but Asia (Japan & Korea, 4), Australia (1), and North America (California, 1) were also represented. Regarding countries of employment, most participants came from Austria (32), Germany (20) and the Netherlands (11), followed by Spain (5), Belgium (4), France (4), and the UK (4). Details on on-site and online participants can be seen in Figure 26.

Figure 26. Composition of the workshop audience regarding country of employment and stakeholder group affiliation.

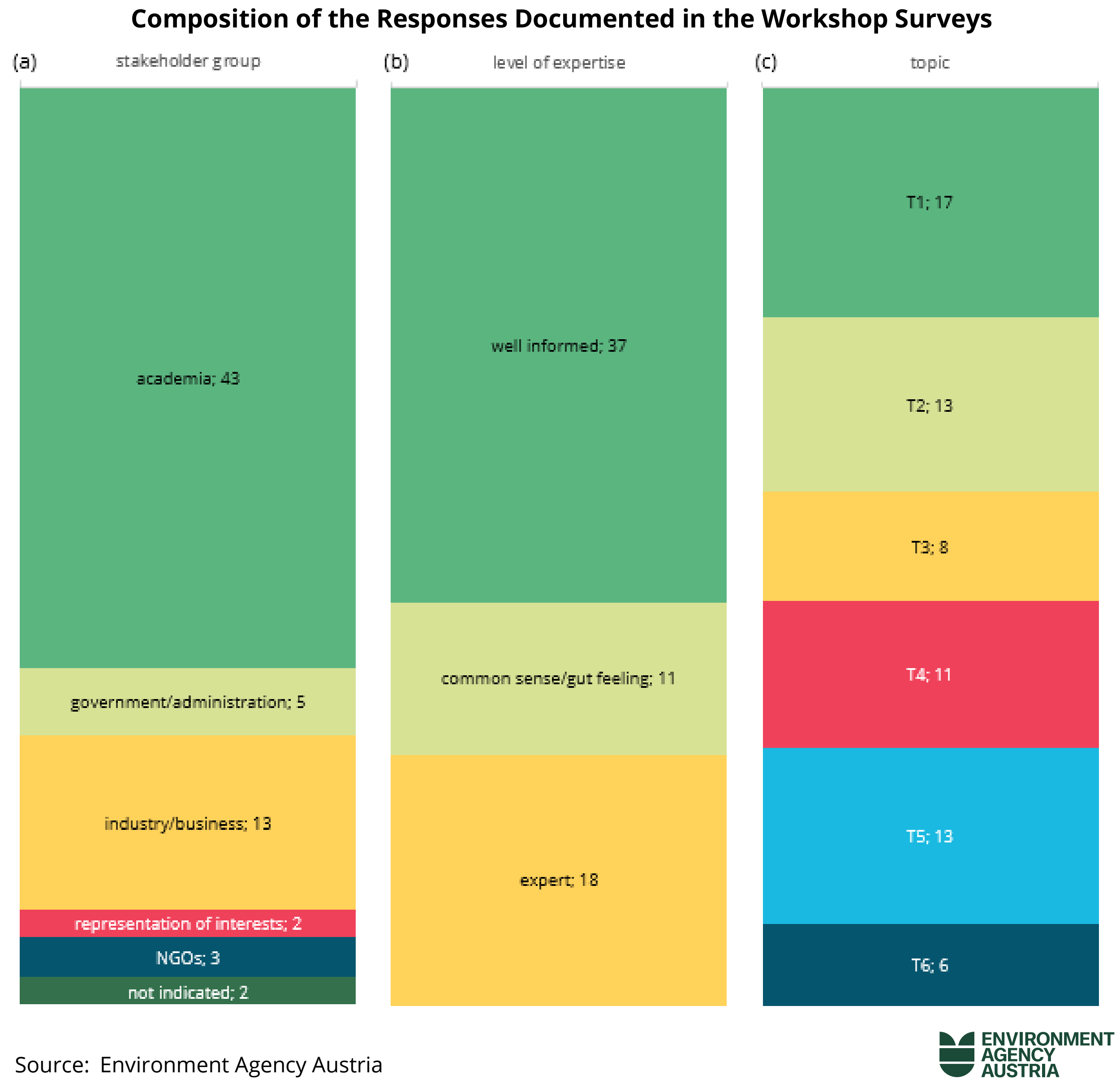


Source: Environment Agency Austria

Responses to Breakout Group *Workshop Surveys*

Across all six breakout group topics, 68 responses to the *workshop surveys* were received (via MS-Forms). Note that each participant could respond to multiple breakout group topics, and responses do not reflect the number of participants responding. The responses were received from five stakeholder groups (Figure 27a), with most responses by *academia* (43), followed by *industry/business* (13), *government/administration* (5), *NGOs* (3), *representation of interests* (2), and two with no indicated stakeholder affiliation. Regarding the declared levels of expertise (Figure 27b), 37 responses were *well-informed*, 18 *expert-level*, 11 based on *common sense/gut feeling*, and 2 not declared. The responses were unequally distributed among the topics (Figure 27c), with Topic 1: *Chemicals and Risk Assessment* (17), Topic 2: *Exposure Avoidance and End-of-Life Tyres*, and Topic 5: *Interactions - Tyre, Vehicle, Road, Driving* (15) receiving the most responses. Note that not all responses were complete, and some questions within a topic had fewer responses than others. In each topic, participants could evaluate 4–6 measures and shared ideas on the operationalisation of the measures, the requirements for implementation, the responsible actors, positive effects (beyond tyre wear), and potential obstacles (see 3.1.3).

Figure 27. Responses to the MS-Forms *workshop surveys* by (a) stakeholder group affiliation (b) level of expertise (c) selected workshop topic.



Source: Environment Agency Austria

numbers indicate the number of responses documented in the breakout group workshop surveys

T1: Chemicals and Risk Assesment, T2: Exposure Avoidance and End-of-Life Tyres, T3: Distribution via Dust and Measures at or Near the Road, T4: Runoff Collection, Retention, and Treatment, T5: Interactions – Tyre, Vehicle, Road, Driving, T6: Mobility Transition and Traffic Reduction

4.2.2 Workshop Breakout Group Results

The results of the breakout groups, as documented via the MS-Forms *workshop surveys*, are presented below. It must be noted that on some topics there were more responses (e.g. Topic 1 – Chemicals and Risk Assessment) than on others. Also, hardly any of the online participants took the chance to participate in the breakout group surveys. Due to the limited time during the workshop, not all on-site participants completed the survey they chose in each breakout session. Consequently, the level of detail in the following chapters varies depending on the input received by workshop participants.

4.2.2.1 Topic 1: Chemicals and Risk Assessment

Topic 1 focused on measures related to Chemicals and Risk Assessment, including measures to address the chemical safety of tyres and measures to advance risk assessment. 17 workshop participants submitted their opinions on related measures. General remarks on these measures were that they are intertwined, as a clearer evidence base would be required to support safer design and to provide information for future regulations. The results are presented for the single measures, however, some ideas on the implementation and expected positive external effects or obstacles/resistance associated with the measures are interchangeable. Also, measures that did not score ≥16 in the expert survey are included in this chapter, as chemical safety and risk assessment are considered the key topics in this report.

Safe-and-Sustainable-by-Design (SSbD) Practices

Promoting SSbD practices (e.g. consulting on chemical hazards in a trusted environment, installation of chemical substitution centres, subsidising production of non-hazardous alternative substances etc.) was the most recommended measure to ensure chemical safety (stakeholder-average score ≥16) according to the expert survey (see Figure 22). Regarding the question *of how that measure should be specified for implementation*, workshop participants highlighted the following requirements:

- raise general awareness and acceptance of SSbD concepts throughout society (paradigm shift – start awareness-raising already in school),
- generate a comprehensive knowledge base:
  - closing knowledge gaps on substance properties of chemicals used for or formed during tyre production and service-life (incl. non-registered substances, transformation products etc.) and

    service-life to allow hazard assessment in accordance with the intended use lifecycle of the parent chemical
  - implementing a mandatory provision of (transparent) information on substance release and transformation product formation over the tyre service life (e.g. in synergy with standard tyre ageing and performance tests conducted by industry)
  - advancing information on which substances are critical in the concentrations to be expected from tyres or tyre wear (research on threshold levels)
  - developing/providing standard procedures for physical and chemical characterisation
- implement substitution centres and enable trusted and close coordination and data transparency between regulators and industry (e.g. consulting industry on realistic replacement times, guiding safer choices and supporting substitution)
- ensure processes/structures allowing for a quick implementation of state-of-the-art research to avoid hampering innovation by excessive bureaucracy
- provide clear guidance on SSbD by regulation & standards
- implement regulation prohibiting harmful substances
- make producers legally responsible for proving safety before market release (implement control by authorities)
- check compliance with SSbD standards (e.g. standardise protocols for analytical evaluation) and ensure sufficient capabilities for enforcement
- aim for sustainability beyond chemical safety (e.g. sustainable and environmentally safe routes for extraction, production and recycling of chemicals) employing a cradle-to-cradle concept, based on the state of knowledge and the precautionary principle.

To effectively implement SSbD for tyres, workshop participants identified a need for *regulation* (national or international), followed by *research* (enhanced knowledge base), *innovation* (e.g. technology development), and *standardisation* (e.g. standardised methods). The stakeholder groups *government/administration* (national or international) and *industry/business* were considered equally responsible for implementation, followed by *academia*. Most of the participants (14 out of 17) attributed net positive effects (beyond tyres) to this measure, one participant considered it neutral, and two participants suggested that negative effects (resistance and obstacles) would predominate. The expected effects are summarised in Table 3.

Table 3. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing SSbD practices to ensure chemically safe tyres

positive external effects	encountered obstacles/resistance

• accelerated decision-making (increased efficiency) compared to single-substance assessment (REACH) and chance to close loopholes
• good SSbD framework prevents regrettable substitution by non-regulated but structurally similar (similarly toxic) substances
• synergistic effects on other products or emitting sectors to phase out hazardous chemicals identified in the tyre context
• lower sewage-treatment costs and positive effects in the feedstock and production process through safe and sustainable substitutes
• cleaner & safer work environment
• stimulating industrial innovation and companies' responsibility
• increased sustainability & reduced consumption of raw materials
• more systemic understanding (of tyre chemistry and beyond)
• greater trust, clearer evidence, and safer materials
• reduced environmental impact
	• lack of suitable alternatives may compromise important tyre properties (e.g. durability, rolling resistance, noise, safety) and eventually increase tyre wear
	• “safety concerns” may be instrumentalised to undermine measures
	• “confidential business information concerns” may hinder transparency on identity of substances (not to mention concentrations)
	• industry concerns about unfair competition with non-EU producers
	• financial hurdle – Who pays for the measure?
	  • industry: economic disadvantages for tyre-related industries and resistance by the industry due to cost and profit concerns
	  • consumers: increase in prices for tyres
	• supply chain effects (supply chain stability, new substances – more suppliers)
	• the extensive knowledge base required is a cost and time factor
	• industry resistance to transparency regarding substances used
	• unclear responsibilities, increased bureaucracy, long time until implementing measures

Restrict or Ban Hazardous Substances in Tyres

Striving for chemically safe tyres by *restrictions (e.g. concentration or migration limits) or total bans of single substances or groups of hazardous chemicals in tyres* achieved only a low stakeholder-average score in the expert survey (see Figure 22), but it reflects the common practice of substance regulation under REACH. Specific suggestions by workshop participants for a target-oriented implementation were:

- set clear concentration limits (based on hazard data) in legislation and strictly enforce them
- ensure Europe-wide restrictions/bans, preferably internationally agreed, to assure competitiveness of the industry

- ensure assessment based on hazard data and thorough cause-and-effect studies; case-by-case decisions
- ensure quick implementation upon availability of clear scientific evidence to avoid lengthy processes & enable planning security
- obligate registrants together with sector organisations to generate data on substance properties
- shift the focus from single substances to substance groups, to avoid regrettable substitution; employ the ECHA approach to group substances (by chemical similarity, by application fields etc.) and identify substances that urgently require regulatory consideration, use weight-of-evidence approaches to conclude on hazard similarities (with a certain confidence level) to known substances
- pursue a generic approach to restrict substances with certain hazard properties in tyres (like in REACH annex XVII entries no. 28-30) to avoid a lengthy and infinite process of one-by-one substance restriction
- aim for restrictions/bans addressing the whole value chain and chemical life cycle, not only the product service life (e.g. by triggering immediate corresponding obligations under the chemicals law, industrial emissions directive and directives dealing with the protection of environmental media)
- ensure that restrictions/bans are also sustainable based on socio-economic analysis
- provide an elaborate list of prohibited chemicals & groups of chemicals, regularly updated in combination with planned phase-outs, i.e., sufficient transition periods for industry to adapt their tyre models
- balance safety considerations for tyres with reduced environmental impact, e.g. combining concentration limits with reduced wear as key indicators
- provide the possibility for exemptions (e.g. allowing the application of restricted substances if they are crucial to meet safety requirements)
- provide sufficient capacities for enforcement, including "on-site" evaluations of which chemicals are needed and whether they are emitted
- evaluate effectiveness by human-/biomonitoring (populations).

The participants suggested that the requirements for implementation of this measure are *regulation* and *research*, followed by *innovation*, *standardisation*, *awareness-raising,* and *certification/labelling.* The responsibility for implementation was seen with *industry/business* and *government/administration*, followed by *academia*. Ten participants expected positive external effects (beyond tyres) by this measure, two participants voted neutral, and three expected high resistance to the implementation of bans/restrictions. Details on benefits and concerns are given in Table 4.

Table 4. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing restrictions on or bans of hazardous chemicals in tyres

positive external effects	encountered obstacles/resistance
• general stimulus for sustainable or green chemistry; safer chemicals, materials, and products • reduction of toxic wastes and cost (e.g. for sewage treatment) along the value chain • rewards investment in high-end technology, compliant products • reduction of emissions to the environment throughout the value chain → cleaner & safer environment • reduction of exposure and risks	• lack of suitable alternatives may compromise important tyre properties (e.g. durability, rolling resistance, noise, safety) and eventually increase tyre wear • industry resistance, as a reliable reduction of environmental risks by substitution requires several years of market assessment – a cost and time factor (incentives or disincentives needed to keep private costs under control) • potential increase in prices for tyres • “safety concerns” may be instrumentalised to undermine measures (e.g. many PAHs are allowed in aircraft tyres) • “rat race” against regrettable substitution: banned hazardous substances are replaced by similar chemicals, which are likely similarly hazardous, with less information being available - collection of evidence and the process of regulation has to start over again • increased bureaucracy, unclear jurisdiction & responsibility • ensuring compliance • restriction under REACH is a slow & complex process, as the information/data required for establishing the concern on which to base a restriction proposal (e.g. information on substance properties & hazards, use conditions, availability of alternatives, assessment of socio-economic impact etc.) is often not available or accessible to responsible authorities, and industry may not deliberately provide the information it has. • restricting residual concentrations in tyres is not sufficient, as emissions during production are not considered • authorisation (REACH) requires companies to provide information, and requirements to prevent emissions from the production site and protect workers can be imposed, but imports of articles from non-EU countries are not covered by authorisation

Increase Transparency on Substances in Tyres

Increasing transparency, e.g. by indicating the identity (not necessarily the contents) of all substances used in the tyre and declaring known/potentially hazardous substances, was not among the top-ranked measures in the expert survey (see Figure 22). Workshop participants suggested the following ideas to implement this measure:

- balance transparency with the protection of confidential business information: disclosure of substance lists by manufacturers, at least to authorities or selected third parties which classify the tyres
- implementation as an industry-led initiative, sector-driven with the support of 2nd to 4th level suppliers, using blockchain for tamper-resistant provision of information across the supply chain, backed by strong legal support
- provide a clear, standardised disclosure framework requiring producers to declare intentionally added substances and flag hazardous, carcinogenic, or endocrine substances (e.g. digital product pass)
- ensure that transparency requirements are internationally harmonised and legally binding (EU-regulation) across Member States
- verify compliance through independent audits, reporting, and on-site inspections
- unravel chemical composition through advanced chemical analysis (bypassing industrial disclosure)
- establish ingredient labels on tyres to enable informed consumer decisions, like declarations on other products (e.g. food)
- inform consumers in an accessible way, without breaching confidentiality and proprietary information
- conduct awareness-raising campaigns on the tyre labelling scheme.

The suggested requirements for implementation were *regulation* and *certification/labelling,* followed by *awareness-raising*, *standardisation,* and *administration (increased administrative or management efforts)*. *Industry/business* and *government/administration* were considered the responsible actors for potential implementation, followed by *NGOs*. Regarding the benefits and concerns associated with this measure*,* 9 participants felt that positive effects prevail, three participants voted “neutral”, and four expected mainly obstacles/resistance (see Table 5).

Table 5. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing measures to increase transparency on substances in tyres

positive external effects	encountered obstacles/resistance
• raises awareness • improves sustainability, safer materials • benefits public health protection • increases trust through transparency • avoiding critical substances may have positive effects on feedstock and production processes and reduce costs (e.g. for sewage treatment) • application to other product areas possible	• high administrative effort/ bureaucracy • financial hurdles (who pays?) and industry resistance due to cost • conflict with confidentiality priorities (e.g. substance identities, or formulations/recipes), fear of information leakage • objections by the extraction and manufacturing industries • lack of standardisation and testing methods • innovation inhibitor

Improve the Knowledge Base for Risk Assessment

A better knowledge base for risk assessment comprises *understanding*:

- *the degradation/persistence of tyre particles and the long-term release of hazardous substances in the environment,*
- *the leaching/transformation/degradation of tyre-related hazardous substances in environmental & biological media to evaluate risk, and*
- *the uptake, behaviour and fate of tyre wear particles in humans (and other organisms).*

All these measures scored very high in the expert survey on stakeholder-average (see Figure 24). Specific suggestions by workshop participants on how to advance the knowledge base for risk assessment included:

- focus on coordinated research to close knowledge gaps on tyre wear particles, degradation processes, chemical release, exposure pathways, and human uptake
- understand and characterise tyre and road-wear particles as a complex matrix (comprising polymers, additives, transformation products etc.), for standardised testing and risk assessment
- develop internationally standardised methods to study degradation, chemical release, exposure, and toxicity, to enable comparability of results and regulatory acceptance across countries
- align research with standardised methods accepted for risk assessments
- enhance data sharing between research, regulation and industry (e.g. through standardised methods & transparency)

- ensure credibility/acceptance of results through research and testing conducted by independent, scientifically recognised bodies
- ensure sufficient and sustainable funding for research and infrastructure in *academia* (e.g. research conducted by *academia* funded by industry, agreeing on research independence)
- generate clinical evidence: engage with medical and clinical professionals for exposure assessment (e.g. biomonitoring, toxicity testing, diagnosis & treatment), and engage with public health and safety authorities
- ensure the timely translation of clear scientific evidence into regulatory and risk management action.

To pursue implementation, the need for *research*, followed by *standardisation*, *awareness-raising* and *regulation,* was highlighted. The identified relevant actors are *academia, government/administration* and *industry/business*, followed by *NGOs*. According to 11 participants the implementation would generate positive external effects; two participants felt it would face obstacles/resistance, and three participants suggested neither nor. The expected benefits and obstacles are listed in Table 6.

Table 6. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing measures to advance the knowledge base for risk assessment

positive external effects	encountered obstacles/resistance
• increased understanding provides a stronger evidence base for risk assessment, • knowledge base helps to avoid regrettable substitution • allows identification of other (not yet declared) hazardous substances • insights can be applied to other rubber product lines beyond tyres • would serve as an example/model for other industries (e.g. plastics & additives) • knowledge increases stakeholder awareness • universal mechanistic understanding of how chemical structures/properties impact environmental fate/behaviour, bioavailability, and toxicity • generates transparency/clarity on the relevance for public health protection	• financial constraints, limited research funding for the extensive evidence required • data gaps and confidentiality claim as an obstacle • resistance by the tyre and chemical industries • the intrinsic complexity of the matter (complexity of tyre chemistry, environmental interactions, mixture toxicity etc.) • defining assessment boundaries (where to stop?), newly identified transformation products may trigger further testing under REACH (PBT & in future PMT properties) • lack of harmonised international standards/approaches

Ensure the Suitability of Risk Assessment Approaches

Measures to *ensure the suitability of human and environmental hazard and risk assessment to capture the complexity*

- *of (tyre wear) particles (what works for chemicals doesn't necessarily work for particles)* and
- *of tyre-related substance mixtures (e.g. mixture effects, transformation products, unintentionally present substances)*

were considered very useful (stakeholder-average score ≥16) in the expert survey (see Figure 24). Workshop participants' ideas on how this measure could be operationalised are summarised as follows:

- conduct focused research
- foster cross-sector collaboration and data sharing to advance risk assessment approaches
- address conceptual gaps on toxicity testing and risk assessment of complex contaminants (particles with complex physicochemical properties and time-variable mixtures of chemical substances & transformation products)
- develop methods tailored to assess particle behaviour, mixture effects and transformation products.
- standardise particle- and mixture-specific testing protocols and necessary analytical approaches
- ensure the systematic integration of tyre particle & mixture-specific testing into broader degradation and toxicity studies
- distinguish and comprehensively assess intrinsic hazard and real-world risk associated with tyre and road wear particles.

For a target-oriented implementation, the need for *research* and *regulation*, followed by *standardisation* and *innovation,* was identified. The suggested main responsible actors were *industry/business* and *academia*, followed by *government/administration*. Eleven participants associated positive external effects with this measure, three voted neutral, and one participant expected obstacles/resistance to outweigh positive effects. The mentioned specific benefits and obstacles are listed in Table 7.

Table 7. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing measures to ensure that risk assessment approaches capture the complexity of tyre wear

positive external effects	encountered obstacles/resistance
• accurate characterisation of real exposure risks and improved public-health protection • principles and approaches are relevant for other products (e.g. plastics, brakes) and contaminants (e.g. micro-/ nanoplastics, brake wear, exhaust emissions) • allows proportionate and targeted regulation, avoiding unnecessarily strict regulation based on misapplied concepts & methods	• resource constraints: amount of time and funding needed to develop, validate, and standardise scientifically sound assessment concepts • conceptual conflict between the regulatory framework (focus on substance, as registered under REACH) and assessing tyre wear (as a substance mixture) • complexity of studying mixtures (varying between products) and particles (heterogeneity) regarding the generation of valid data

4.2.2.2 Topic 2: Exposure Avoidance and End-of-Life Tyres

Topic 2 comprised measures regarding awareness-raising, exposure avoidance and end-of-life tyre applications. 13 workshop participants shared their opinions on related measures.

Prevent Emissions from End-of-Life Tyre Applications

Suggested measures to *prevent particle and chemical emissions from end-of-life tyre applications* target the following applications:

- *tyre crumb rubber products in the environment (e.g. artificial turf, playground-/landscaping equipment in gardens/parks),*
- *crumb rubber as filter/drainage material (e.g. in stormwater and urban runoff management or in drainage layers for roads/railways/landfills etc.),* and
- *tyre (crumb) rubber-modified materials exposed to the environment (e.g. asphalt, concrete, roofing materials, acoustic barriers along roads/railways).*

In the expert survey, measures regarding the first two applications were considered more relevant (see Figure 16 & Figure 21), but only the first one rated ≥16 on stakeholder-average. The opinions of the workshop participants on the operationalisation of these measures were partially controversial – most participants strongly supported precautionary bans, some considered upstream prevention of chemical risks a better solution, and one participant suggested that no measures are needed, as end-of-life tyres have already released a major amount of hazardous chemicals:

- promote upstream prevention, i.e., safer tyre design, to reduce the risk at the source
- ban all the suggested end-of-life tyre applications in favour of benign alternatives, as tyre crumb rubber is not essential for any of these use cases
- prevent/prohibit the use of end-of-life tyre materials in contact with water (e.g. as filter or drainage materials) to avoid hazardous chemicals entering the water cycle and eventually groundwater
- ban or restrict crumb rubber products in applications directly exposing humans (especially children) or the environment (e.g. playgrounds, sports fields, gyms); replace them with safer alternatives
- balance exposure risk vs. recycling and circular economy considerations, and use crumb rubber only in applications without direct exposure of humans and the environment (e.g. matrix-bound uses in concrete/asphalt, reuse in acoustic barriers)
- mitigation in that area is not needed, as end-of-life tyres have already lost a substantial amount of associated harmful substances, and exposures are expected to be low
- raise awareness to increase public pressure for political action (promoting sports or playing outdoors for health reasons and sports/playgrounds exposing children and active people to hazardous substances are controversial issues)
- foster research and conduct a risk-based evaluation:
  - include relevant exposure scenarios (human & environment)
  - and toxicity studies for the plethora of tyre-related chemicals (declaration of ingredients would be needed),
  - distinguish between particle-effects and leachate-effects,
  - include other sources of rubber (e.g. boots, gaskets, seals for food containers)
- provide for (compulsory) risk mitigation measures
  - certify the physicochemical stability of crumb rubber materials
  - (certified) particle retention units with clear requirements regarding minimum retained particle size, installation points, maintenance/inspection, and reporting of effectiveness.

The needs/tools for a successful implementation were ranked as follows: *regulation* > *innovation* > *awareness* > *research. Government/administration* and *industry/business* were considered the main responsible stakeholders. Six participants expected added value (beyond emission retention) by the implementation of such measures, three participants voted neutral and four felt that obstacles/resistance would predominate. The suggested benefits and concerns are given in Table 8.

Table 8. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing measures to prevent emissions from end-of-life tyre applications

positive external effects	encountered obstacles/resistance
• benefits for human & environmental health • increased awareness about emission sources besides tyres and concerns about rubber products in general • particle-retention filters: retain other micropollutants and particle-bound pollutants as well; support existing treatment systems; allow collection of monitoring data • stimulus for technological innovations • economic development in developing countries, breaking the monopole role of large companies	• economic interests, resistance by tyre recyclers/lobbies • lack of suitable substitutes for (crumb) rubber in sports applications • finding alternative uses / innovative recycling options for huge amounts of end-of-life tyres • unknown or insufficiently anticipated risks – weak basis for decision-making • cost of implementation • public awareness gap: implications are not understood, and policies not supported • environmental pollution & human exposure through reconstruction (e.g. artificial turf sites) • particle-retention filters: purchase & maintenance cost; staff capacity & responsibilities; lack of standards ensuring performance; disposal of collected material (waste)

Empower People to Avoid Exposure

Measures to *empower people to avoid exposure to tyre-derived particles & hazardous substances by providing recommendations* may focus on:

- *human exposure from end-of-life tyre applications (e.g. playgrounds, sports fields, flooring & mats, gardening equipment),*
- *the impact of individual mobility behaviour (e.g. cycling/walking/jogging along roads, driving in cars etc.) on human exposure,*
- *food chain exposure: distribution of tyre-derived particles & chemicals on/within food plants and persistency during meal preparation (e.g. washing, peeling, cutting-off roots/greens, cooking), or*
- *additional non-tyre sources of exposure, such as rubber used in food-contact, households, work environments, leisure (e.g. climbing shoes).*

In the expert survey, the first two options were considered most relevant and scored ≥16 (see Figure 25). Suggestions by workshop participants on how to implement these measures were:

- work on better information (research needed), e.g. exposure data for relevant locations (crossroads vs. pedestrian precincts, playgrounds, food crops, indoor sports halls), or for certain populations (e.g. athletes or children regularly exposed, people cycling to work on high-traffic roads)
- provide stakeholder-specific information and guidance (e.g. to communities/sports clubs/childcare facilities about potential risks of tyre-based products, information for water works and wastewater operators, inform consumers on exposure pathways)
- conduct public awareness campaigns to enable informed action (e.g. choosing routes for walking/cycling/jogging with low traffic density, paying attention to playground surface conditions)
- promote alternative materials: awareness supports a shift to alternative materials, but there should also be obligations to replace materials especially in settings involving children and frequent human exposure (e.g. playgrounds, sports fields)
- promote traffic reduction and mobility shifts to public transport or vehicles with lower tyre wear (e.g. smaller/lighter)
- promote safe rubbers (reduce the use of hazardous chemicals) and rubber products to solve the problem at the source, rather than placing responsibility on individuals to avoid exposure.

Awareness-raising was assessed as the most useful tool for implementation, supported by *regulation*, *certification/labelling*, *administration,* and *research*. *Government/administration* was considered the primary responsible actor, followed by *provision of infrastructure / public services (e.g. traffic, waste, water etc.)*. Most participants (7) associated positive external effects with the implementation of this measure, one participant suggested obstacles/resistance to prevail, and 5 participants considered it neutral. The mentioned benefits and obstacles are listed in Table 9.

Table 9. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing measures to empower people to avoid exposure

positive external effects	encountered obstacles/resistance
• generates public pressure to reduce toxicity of products (rubber and general plastics) • benefits public health and related literacy (understanding exposures translates to other environmental health topics) • awareness can reduce exposure to other microplastics • exposure avoidance reduces exposure to co-pollutants (e.g. traffic-related ones or pesticides on food crops) • addresses additional (non-tyre) sources of exposure	• human behaviour patterns are hard to modify • limited effectiveness of awareness campaigns (e.g. due to information overload, perceived complexity, low perceived risk)

Two measures did not score very high in the expert survey (stakeholder-average scores <16):

- *promoting the retreading of tyres* and
- *establishing long-term monitoring programmes for human exposure.*

They are not treated in this chapter, as none or only one of the stakeholder groups rated them ≥16 (in case of interest, see Annex V).

4.2.2.3 Topic 3: Distribution via Dust and Measures at or Near the Road

Topic 3 focused on emission retention and risk reduction measures at or near the road regarding the distribution of tyre wear and related chemicals via dust. Eight workshop participants submitted their opinions on related measures.

Barriers to Retain Emissions Alongside Roads and Protect the Environment

To establish *barriers to retain emissions alongside roads, the* following measures were suggested:

- *promoting roadside greenery (grass, bushes, trees etc.) as wind-barriers and particle traps,*
- *installing (or redesigning existing) constructed barriers (e.g. walls, fences, nets),*
- *targeted monitoring studies to ensure the efficacy of such measures*
- *installing buffer zones or constructed/green barriers to specifically protect sensitive ecosystems or agricultural produce near roads.*

None of these measures was highly rated in the expert survey regarding the stakeholder-average. However, the first option was very highly rated by two stakeholder groups (*academia* and *industry/ROI*), while the other options were only favoured by single stakeholder groups (see Figure 18). Suggestions by workshop participants on how to operationalise these measures were:

- greenery along roads should be mandatory (where possible), legal issues regarding land ownership need to be considered (e.g. convincing farmers and landowners to contribute)
- evaluate possible gains of such measures and generate data on emission retention (demonstrate effectiveness before implementation), consider seasonal effects (e.g. green barriers dropping leaves in winter)
- combine the measures: install (green) barriers and buffer zones, and ensure efficacy through monitoring
- provide clear guidelines (e.g. in road construction) on how barriers are effectively designed (e.g. which materials or plants are appropriate) and define the frequency, responsibility, and methods for monitoring, as well as the baseline for evaluating effectiveness
- consider lack of space (e.g. in cities), rows of houses along roads could have similar retention effects, without requiring additional space[2]; reduction of parking spaces may be an option to provide space (this might also reduce cars and favour public transport)
- such and similar measures (e.g. physical barriers, or even tunnels) are already established in road construction in the context of environmental compatibility assessments and ecosystem protection (e.g. Natura2000); measures to retain tyre wear can be established within this framework, offering synergies (e.g. regarding monitoring and required human resources)
- preferably reduce emissions of tyre wear at the source and ensure the use of safe (low or non-toxic) materials.

The implementation would mainly require *regulation* and *construction/spatial planning* activities, followed by *innovation*, *research,* and *standardisation*. The actors considered responsible are *government/administration* and *provision of infrastructure/public services*. External effects of these measures were considered mostly positive (by 6 participants), for one participant obstacles/resistance dominated, and one participant

[2] *authors' note: houses as barriers imply human exposure when opening windows*

voted "neutral". For the mentioned synergies and obstacles, see Table 10.

Table 10. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing barriers for emission retention along roads to protect the environment

positive external effects	encountered obstacles/resistance
• green belts contribute to biodiversity, have positive effects on (micro)climate (e.g. CO_2 fixation, cooling effects) • retention of other emissions (e.g. fine dust, brake wear, resuspended road dust, and other pollutants) and general improvement of air quality • reduction of particulate matter fraction in the air is beneficial to public health • barriers also help to retain littered waste • barriers may also reduce noise pollution	• lack of regulation • cost of construction • limited space • landowners may not want to sell their land, and formal processes (e.g. expropriation) may take very long • airborne particles may be less affected by these measures

Targeted Collection of Road Dust

The implementation of measures to *enhance the collection of road dust by expanding sweeping (including more roads, pavements, parking lots etc.) and optimising the frequency, timing, and locations (e.g. tyre wear hotspots, predicted rain/wind events)*, was highly rated in the expert survey (see Figure 19). Workshop participants provided the following ideas for implementation:

- conduct a cost-benefit analysis to evaluate whether other measures are cheaper & more efficient than sweeping up tyre dust
- identify relevant locations and timings: generate data on geographical/seasonal emission distribution (to identify local/temporal hotspots for cleaning, and/or specific cities or roads with high exposure)
- focus (frequent) cleaning on relevant locations: e.g. related to traffic intensity and sites where road alignment increases tyre wear (e.g. required cornering, braking etc.)
- define suitable cleaning intervals and type(s) of sweeping-machinery, define responsibilities (who pays and who conducts cleaning), as well as solutions for disposal of sweeping residues.
- requires money and manpower: consider the tight financial and personnel situation of (local) public administrations, responsible for local roads (not highways)

- raise funding for targeted measures via the "polluter-pays"-oriented regulations, rather than making the public pay: collect data to establish relations and causal links (e.g. between tyre abrasion, the weight of the vehicle, and the tyre contact area), and consider tyre abrasion, e.g. in motor vehicle taxes, this will also reduce the emission at the source.

The need for *innovation*, *research*, *regulation*, and *administration* was considered most pressing for a successful implementation of this measure, with the responsible actors being *government/administration* and *provision of infrastructure/public services*. The measure was mainly expected to generate positive external effects (5 participants), with two participants suggesting obstacles/resistance outweigh them, and one participant voting "neutral". The associated benefits and obstacles are given in Table 11.

Table 11. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing the targeted collection of road dust.

positive external effects	encountered obstacles/resistance
• cleaner roads • less clogging of gullies due to frequent removal of dirt • reduction in particulate matter levels (air pollution) • will also remove littered waste and reduce microplastic pollution (by preventing wind drift of litter into the environment and physical/chemical fragmentation)	• cost (personnel & machinery) burden for communities and public authorities (if no other solutions are found) • need to clear areas from parked cars to allow efficient sweeping • continuous expense (if emissions are not reduced) – not the most efficient way to tackle the tyre wear problem • lack of awareness and willingness to acknowledge the problem of tyre wear

Three measures did not score very well in the expert survey (stakeholder-average <16, and only one or no stakeholder group rated it ≥16):

- the *installation of emission retaining roads* (e.g. particle collecting/trapping pavements or adding absorbers for hazardous chemicals to asphalts),
- *optimising the management of banquet materials and roadside soil* (e.g. replacement frequency, erosion prevention, to retain emissions, addition of adsorbers), and
- *preventing the use or disposal of (potentially) contaminated materials in the open environment.*

These measures are not included in this chapter (in case of interest, see Annex VI).

4.2.2.4 Topic 4: Runoff Collection, Retention, and Treatment

Topic 4 focused on measures to retain emissions or reduce risks of tyre wear and related chemicals of concern through the collection, retention, and treatment of road/surface runoff. In this chapter, facilities for *runoff collection and treatment (incl. snow)* include facilities at the

- local/decentralised level (e.g. roadside gully pots, filter units, infiltration swales),
- semi-centralised level (e.g. retention, detention or sedimentation basins; infiltration ponds; constructed wetlands, and
- centralised level (e.g. wastewater treatment plants).

The measures related to this topic were evaluated by 7 to 11 workshop participants. None of the measures related to this topic achieved a stakeholder-average score ≥16 in the expert survey, but some were highly rated by multiple stakeholder groups. Since all the suggested measures are closely related, they were aggregated to avoid redundancies.

Optimise Maintenance and Cleaning of Non-Centralised Facilities

Ensuring an optimal maintenance and cleaning of non-centralised road-runoff (or snow) collection/treatment facilities to avoid (re)mobilisation or breakthrough of tyre wear particles and related hazardous substances was highly rated by all stakeholders in the expert survey, except *government/administration* (see Figure 20). As this measure is already quite specific and clear, only a few suggestions on how to implement it were made by workshop participants:

- identify and define optimised maintenance cycles & criteria
- employ/develop new technologies to monitor removal efficiency and to improve removal efficiency
- standardise methodologies for efficacy monitoring and inspection (sampling, analytical evaluation etc.)

Ensure the Collection/Treatment of Stormwater Overflows

The *avoidance of the untreated release of stormwater overflows at centralised and decentralised facilities* did not reach a stakeholder-average score ≥16 in the expert survey (see Figure 20) but was very highly rated by *NGOs* (17.7) and moderately supported by *industry/ROI* and *academia* (scores 15.8 & 15.7). Ideas by workshop participants on how to realise it included:

- focus on retaining the "first flush" of stormwater runoff, which is most contaminated
- expand storage capacities, which is cost-intensive but effective

- street sweeping might help to mitigate the first flush as well (cost-benefit analysis)
- implement sand filter systems or filters in gullies
- invest in infrastructure – most facilities are outdated and not well maintained; develop/implement new technologies since sedimentation systems are insufficient
- consider climate change in predicting expected storage capacities (increased heavy rain events), align measures with river flow conditions and expected peak concentrations.

Ensure Treatment Efficiency (Non-Centralised)

Measures to *ensure the treatment efficiency of facilities to collect/treat road-runoff incl. snow (e.g. infiltration swales, filter-units, sedimentation/retention basins, wastewater treatment plants etc.),* regarding

- *tyre wear particles*, or
- *tyre-derived hazardous substances,*

were not highly rated on stakeholder-average. As regards particle retention, the evaluation of *NGOs* and *industry/ROI*, however, scored ≥16. Workshop participants suggested

- that implementation should first focus on emission-hotspot sites (e.g. cities),
- different collection and treatment strategies would be required to target the removal of hazardous chemicals in such facilities,
- new technologies for better particle retention (e.g. MicroBubbles),
- setting minimum treatment-efficiency criteria is required.

Expand the Collection of Runoff Waters

An expansion of the collection of runoff waters can imply expanding

- *rainwater and sealed-surface runoff collection/retention in cities (traffic hotspots) from the local/decentralised level (e.g. "sponge city" concept) to the centralised level (e.g. runoff treatment in wastewater treatment plants),*
- *the network of road-runoff collection/treatment facilities from the local/decentralised to the centralised level, and*
- *the collection and treatment of snow (from roads, roadsides, pavements, parking lots etc.).*

None of the options reached a stakeholder-average score ≥16 in the expert survey (see Figure 20), but the first option was highly rated by *NGOs* and *industry/ROI*. The recommendations of the workshop participants were:

- focus on expanding rainwater and sealed-surface runoff collection/retention in cities (traffic hotspots),
- regarding decentralised facilities:
  - build awareness/political will and define a responsible division,
  - establish a centralised digital database on existing collection and treatment facilities/plants,
  - evaluate the status of maintenance and age of facilities,
  - work on improved standardisation of constructed basins,
  - invest in decentralised infrastructure.

Requirements, Responsible Actors, Benefits, and Obstacles

For all runoff-related measures *government/administration* and *provision of infrastructure/public services* were considered the main responsible actors for the implementation of measures. Accordingly, c*onstruction/spatial planning* and *regulation* were always ranked among the top four requirements for a targeted implementation (Table 12). Additionally, innovation seems highly relevant, on the one hand, for ensuring the treatment efficiency of non-centralised facilities, and on the other hand, for properly collecting/treating runoff (expansion of runoff collection, and avoidance of stormwater overflows). Increased *administrative efforts* were associated with avoiding stormwater overflows and ensuring efficient non-centralised treatment, while *standardisation* was considered necessary for the optimal maintenance/cleaning of non-centralised facilities and the expansion of runoff collection. Awareness-raising was suggested to support the optimal maintenance of non-centralised facilities.

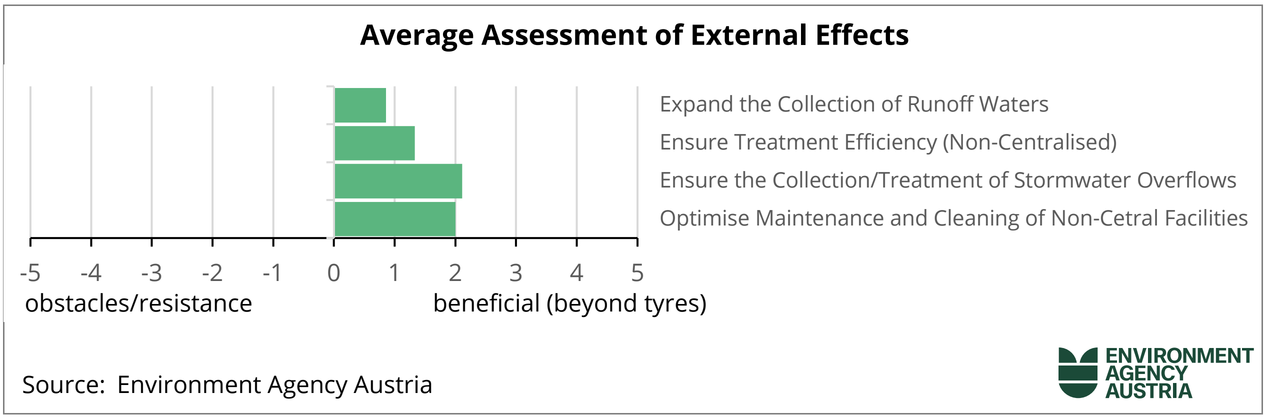
Table 12. Ranking of requirements for the target-oriented implementation of runoff-related measures.

measure	rank 1	rank 2	rank 3	rank 4
Optimise Maintenance and Cleaning of Non-Centralised Facilities	construction/ spatial planning	awareness	regulation	standardisation
Ensure the Collection/Treatment of Stormwater Overflows	construction/ spatial planning	administration	innovation	regulation
Ensure Treatment Efficiency (Non-Centralised)	innovation	administration	construction/ spatial planning	regulation
Expand the Collection of Runoff Waters	regulation	construction/ spatial planning	innovation	standardisation

Regarding external effects, each measure was associated mainly with obstacles/resistance by one participant, 2–3 voted “neutral”, and 3–6 expected benefits (beyond tyre wear). The average assessment score

(Figure 28) suggests that the avoidance of stormwater overflow and the optimal maintenance of non-centralised facilities are most beneficial.

Figure 28. Average assessment of the external effects of implementing runoff-related measures.



Details on the expected benefits and obstacles are presented in Table 13.

Table 13. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing runoff-related measures

positive external effects	encountered obstacles/resistance
• retention of many other pollutants and suspended solids • reduction of the risk of environmental exposure to contaminants • biological/green decentralised treatment facilities may offer space for recreation and a cooling effect through "greening"	• high cost (time) for infrastructure investments, improving (non-central) water treatment efficiency, and regular maintenance • decentralised treatment in general may only treat a minor part of the emissions and requires space (land-use conflicts) • will to invest in environmental infrastructure

4.2.2.5 Topic 5: Interactions – Tyre, Vehicle, Road, Driving

Topic 5 focused on emission reduction and retention measures regarding the interaction between tyre, vehicle, road, and driving behaviour. Seven to twelve workshop participants shared their opinions on the suggested individual measures.

Since many of the positive external effects apply to all the measures discussed in this chapter and were repeatedly mentioned for the single measures, they are summarised below to avoid redundancies (Table 14).

Table 14. Potential positive external effects (beyond tyres) associated with the optimisation of tyre-vehicle-road and driving behaviour interactions in general.

positive external effects
• reduced noise due to "smooth" driving behaviour and optimal tyre-road interaction
• reduced fuel consumption, saving money
• lower CO_2 emissions and other pollutant emissions (e.g. fine dust, road wear, brake wear)
• improved environmental and public health
• enhanced durability of infrastructure (e.g. less road wear), vehicles (e.g. brakes, shock absorbers), and tyres (less wear), implying less resource consumption and replacement / maintenance costs as well as less tyre waste and costs for waste-management/recycling.
• increased sustainability

Develop and Promote "Smart" Vehicles

To support tyre wear reduction, *smart technology can serve to optimise the following vehicle or driving style parameters (considering the respective relevant factors, e.g. speed, terrain, curves, load, traction conditions etc.)*:

- *torque, acceleration, & deceleration behaviour (e.g. auto-correction or pop-up driver information)*
- *wheel alignment, e.g. employing sensors and maintenance pop-ups, maybe automatic alignment (in the future?)*
- *tyre pressure (automatic adjustment or maintenance pop-ups)*
- *driving speed (automatic adaptation or pop-up information)*
- *steering movement/curve behaviour (auto-correction or pop-up info).*

The expert survey identified the first parameter as the most suitable/effective for smart solutions to tyre wear (see Figure 12). Specific ideas of workshop participants regarding the potential implementation were:

- make smart control of key parameters compulsory in new cars
- combine driver awareness/training and smart technology: some parameters can be controlled by smart vehicles, but driver behaviour remains an important factor (e.g. use of assistants)
- develop an "eco-mode" to reduce tyre wear generation
- autonomous driving allows the most comprehensive optimisation
- ensure international cooperation and common standards
- raise awareness among consumers & advertise "sustainable" cars
- grant incentives to buffer costs: e.g. for the development of smart vehicles, or for consumers to afford smart vehicles
- rather promote a mobility shift (e.g. cycling, public transport).

If such measures were to be implemented, a need for *awareness-raising*, *regulation*, *innovation & incentives*, followed by *standardisation* & *research* was identified. *Industry/business* was suggested as the main responsible stakeholder, followed by *academia*. The measures were considered positive regarding external effects by 9 participants, two felt that obstacles/resistance would outweigh the benefits, and one considered them "neutral". Specific benefits and expected obstacles are listed in Table 15.

Table 15. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing measures to promote smart vehicles to reduce tyre wear.

positive external effects	encountered obstacles/resistance
• general benefits of optimal tyre-vehicle-road-driving interactions (Table 14) • enhanced driving safety & fewer accidents, as smart vehicles prevent "moody" driving etc.	• cost of innovation to advance technology • higher prices of smart vehicles • peoples' habits: difficult to change habits (e.g. make people use "eco-modes", diving assistants etc.) • capacity: technical advances/gadgets may be overwhelming for some people, thus, avoiding usage or facing handling difficulties • ego: resistance to "paternalism", people want to keep their "independence" when driving, some people want to accelerate • safety concerns: fear of "losing control" due to (automatic) restriction/correction of the driver's intent or action • constrains industry in differentiating products by performance

Optimise Tyre Choice and Maintenance

Proposed measures to *optimise tyre choice and maintenance* for tyre wear reduction comprised:

- *stopping the use of winter tyres during summer (softer winter tyres generate more wear at higher temperatures)*
- *informing/training consumers (drivers) on optimal tyre choice, maintenance, and storage*
- *optimising tyre choice for the destination market (based on regional conditions: climate, road conditions, speed-limits etc.) involving the tyre & automotive industry and retailers*
- *provide "tyres as a service" for fleets or tyre leasing for individual vehicles to optimise tyre choice and maintenance.*

The first two options were highest ranked in the expert survey (see Figure 10 & Figure 11). Workshop participants had the following specific implementation ideas:

- prohibit winter-tyre-use in summer and ensure enforcement

- raise awareness of tyre wear and its relation to maintenance among individual drivers and fleet owners, and point out the economic benefit of a less frequent need to replace tyres
- provide trainings and educate drivers attaining their licence; a supportive mindset should be formed early
- provide service centres (or special training for auto repair shops)
- generate regulatory frameworks supporting these measures
- the best tyre management is to buy highly wear-resistant tyres.

According to workshop participants, *awareness-raising*, *regulation*, *incentives*, and *certification/labelling* would be the most needed tools for implementation and *government/administration* and *industry/business* would be the responsible stakeholders. Six participants considered these measures to come with positive external effects, two felt that obstacles/resistance would predominate, and two voted “neutral”. The suggested benefits and obstacles are given in Table 16.

Table 16. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing measures to optimise tyre choice and maintenance.

positive external effects	encountered obstacles/resistance
• general benefits of optimal tyre-vehicle-road-driving interactions (Table 14) • increased driving safety by using the right (and optimally serviced) tyre for the season or conditions • increased awareness of the consequences of mobility	• lacking economic stimulus or regulatory obligation • behaviour is hard to change, incentives are needed • industry resistance due to fear of selling fewer tyres, as price increases may be hard to realise due to an overcapacity in the sector • efforts and costs for implementation • the question of how to handle all-season tyres in case of a winter tyre ban in summer

Improve Roads

Suggested measures to *improve roads to reduce tyre wear* include:

- *identify/develop asphalt types for low wear (considering driving speed, climate, impacts of road dust & salt/grit)*
- *maintain and repair worn road surfaces and "upgrade" the terrain*
- *optimise road planning to lower tyre wear (e.g. curve radii and inclination, dimensions of de-& acceleration lanes, roundabouts vs. crossroads) considering road surface type, speed limits etc.*

In the expert survey, the first measure was very highly rated by *academia* and *industry/ROI*, and the second one by *academia*. Still, no measure achieved a stakeholder-average score ≥16 (see Figure 14). The suggestions by workshop participants on how to implement such measures were:

- fund research and develop asphalt types that minimise tyre & road wear generation
- invest in more sustainable road management (form the political will to dedicate tax money to road maintenance/repair/upgrade)
- reduce the number of trucks to maintain better road conditions
- declare the cause and effect of these measures (e.g. improved surfaces reduce tyre wear and road wear, enhancing lifetime).

The implementation requires mainly *construction/spatial planning* and *innovation*, followed by *research*, *regulation,* and *standardisation*, with the responsible actors being *government/administration* and *industry/business*. Four workshop participants expected positive external effects upon implementation, two significant obstacles, and two voted "neutral". On top of the general benefits of optimal tyre-vehicle-road-driving interactions (Table 14), the better maintenance of roads and improvement of surfaces can also enhance driving safety. Regarding obstacles, the high costs of these measures and a delayed effect were mentioned, as road surfaces will have to be replaced gradually (e.g. focusing on newly constructed and heavily worn roads).

Improve Tyres & Implement Tyre Emission Limits or Labelling

Tyre wear may be reduced by *improving tyres regarding tyre design (e.g. physical factors, weight, dimensions, rolling resistance), or tyre materials (formulation/composition)*. The additional *implementation of tyre emission limits (e.g. Euro 7) and/or wear-based tyre labelling schemes* (allowing informed consumer decisions) may provide a binding and transparent framework to promote/enforce wear-resistant tyres.

All these measures were very highly rated in the expert survey (see Figure 10). Input by workshop participants on the implementation included:

- fund research on how to optimise tyres to reduce emissions and invest in the development/introduction of new tyre technology
- focus on long-term effects and investments
- prove and demonstrate the longer lifetime of low-wear tyres (economic benefit) and the reduced emissions (sustainability)
- expand the database to define abrasion limit values or classes
- introduce and enforce related regulations and standards (e.g. standardise methods for assessment of the wear-rate & lifespan)
- raise public awareness and ensure clear consumer information

- ensure international and multi-stakeholder (public, politics, industry) consensus on the long-term development of low-wear tyres.

For improving tyre design and materials, the requirements for implementation were ranked as follows: innovation, research, regulation, and incentives, followed by certification/labelling, standardisation, and awareness-raising. The main responsibility was attributed to *industry/business* and *academia*/science, followed by *government/administration*. The implementation was mostly evaluated as beneficial beyond tyre wear (by 5 participants). Two participants had major concerns regarding the obstacles/resistance encountered, and one participant considered the implementation "neutral". Regarding the implementation of tyre emission limits or labelling, regulation, certification/labelling, standardisation, awareness-raising, and research were ranked as most needed for implementation, with *government/administration* and *industry/business* as the main responsible actors. Three participants suggested that this measure would create benefits beyond tyre wear, and four participants voted "neutral", while no participant expected that resistance would predominate. Details on the suggested added value and obstacles are presented in Table 17.

Table 17. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when improving tyres for low wear and implementing tyre emission limits or labelling.

positive external effects	encountered obstacles/resistance
• general benefits of optimal tyre-vehicle-road-driving interactions (Table 14) • driving safety may be improved as well	• potential resistance by industry, as selling fewer tyres may not be fully compensable by increasing prices • required funding for research, development, and production upscaling of new technologies • technological limits • risk of trade-offs: low-wear tyres may come with disadvantages regarding other tyre properties, potentially compromising safety • lack of awareness & willingness to pay among consumers

One measure, *promoting lighter (smaller) vehicles*, did not score very well in the expert survey (stakeholder-average score <16, and only *academia* rated it ≥16). It is therefore not included here (in case of interest, see Annex VII).

4.2.2.6 Topic 6: Mobility Transition and Traffic Reduction

Topic 6 focused on mobility transition, traffic reduction, and traffic management measures to support reducing tyre wear emissions. Four to six workshop participants shared their opinions on related measures via the MS-Forms *workshop surveys*.

Many of the positive external effects apply to all the measures discussed in this chapter and were repeatedly mentioned for the single measures. To avoid redundancies, they are summarised in Table 18.

Table 18. Potential positive external effects (beyond tyres) associated with traffic reduction and traffic calming measures in general.

positive external effects
• reduced fuel consumption, saving money
• reduced CO_2 and other traffic emissions (incl. noise, fine dust etc.)
• improved air quality and public health benefits (e.g. fine dust)
• less congestion
• fewer traffic accidents
• less road wear (especially if trucks are reduced) & savings for road maintenance

Promote Telework

Promoting telework may reduce traffic and was considered a very good measure in the expert survey (see Figure 9). The ideas of the workshop participants on the implementation of this measure were:

- clear measure that can be defined by the time spent working remotely (ideally from home, without commuting)
- can be promoted for professions not requiring physical presence
- offer incentives (e.g. tax reliefs) to companies for implementing telework percentages, link an economic stimulus to a control mechanism: check if the number of car trips is effectively reduced
- promote the economic benefits of telework to companies (e.g. savings on office space capacities, motivated employees)

  be more specific on the definition of telework for tyre wear reduction, and evaluate the reduction of total car commutes to work (also people walking/cycling or taking the train enjoy telework)
- expand company rules on telework (e.g. for commuters travelling a certain distance)
- telework does not necessarily reduce the number of car trips, e.g. leisure time trips may increase when time is saved on commuting.

The identified requirements for implementation were *awareness-raising* and *incentives*, followed by *regulation* and *administration*. *Industry/business* and *government/administration* were considered the main responsible actors. Four participants suggested positive external effects upon implementation, and one participant expected that obstacles/resistance would predominate. Anticipated benefits and obstacles are given in Table 19.

Table 19. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when promoting telework to reduce tyre wear.

positive external effects	encountered obstacles/resistance
• general benefits of traffic reduction/calming measures (Table 18) • improved work-life balance, psychological and health benefits • mediated rush hours & less stop-and-go, benefitting tyre wear reduction • employees being more motivated and focused	• less contact to colleagues and less socializing • sufficient digitalisation needed • employers' trust issues regarding homeoffice • employees' difficulties to concentrate at home or lack of suitable workspace • maybe less exercise for people usually cycling/walking to work • effectiveness is hard to assess (reduction in individual car trips) • not applicable for on-site jobs

Personal Mobility Shift

Shifting personal mobility from cars to public transport, walking, and cycling to support reducing tyre wear emissions, was very highly rated in the expert survey (see Figure 9). Workshop participants shared the following suggestions on the implementation of this measure:

- invest in expanding the necessary infrastructure
- balance personal mobility & public transport (last few kilometres)
- specify reduction targets for the total km driven by car per year and collect data on the individual level as a reference value.

Awareness-raising, *construction/spatial planning*, *incentives*, and *regulation* were considered the most suitable tools to promote personal mobility shift. *Government/administration* and *provision of infrastructure/public services* were considered the responsible stakeholders. Four participants suggested positive external effects, and one participant expected that resistance would prevail when implementing this measure. Specific benefits and concerns raised are given in Table 20.

Table 20. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when shifting personal mobility from cars to public transport, cycling, or walking.

positive external effects	encountered obstacles/resistance
• general benefits of traffic reduction/calming measures (Table 18) • health benefits if people cycle or walk more • more pedestrian/cyclist-friendly public spaces and enhanced quality of living	• high cost of infrastructure expansion • difficult to realise in rural areas • high demand for road infrastructure for recreation, congestion may increase if road infrastructure expansion is set aside • individualism: cars as a status symbol and comfort to select the type of mobility based on available time • reluctance of people to change their lifestyle/mindset • lack of political will (fear of losing the next elections)

Smart Traffic Management

Tyre wear emissions may be reduced by *employing/developing smart traffic management to avoid stop-and-go traffic (harsh braking & accelerating) by enabling green waves, and to promote smooth traffic using dynamic speed limits according to traffic load*. These measures were rather highly rated in the expert survey (see Figure 13). Workshop participants considered *construction/spatial planning, innovation, regulation, research, awareness-raising, incentives,* and *administration* to be similarly important for implementation. *Government/administration* and *industry/business* were suggested as responsible stakeholders.

Two workshop participants provided a specific opinion on implementation. They suggested that technical controls (e.g. autonomous driving, driving assistants, speed controls) built into cars are more effective in promoting smooth driving than smart traffic regulation. Green waves for motorised traffic are already frequently implemented, but drivers tend to overspeed and brake again at traffic lights. Enabling smooth driving through smart traffic regulation would also require prioritising motorised traffic over other means of transport (public transport, pedestrians, cyclists), by letting them pass first. It would probably be better to promote green waves for public transport, cyclists, and pedestrians.

Two participants associated positive external effects with the implementation, one participant rather high resistance, and one participant voted "neutral". Besides the general benefits of all *mobility transition and traffic reduction* measures (Table 18), *smart traffic management* may reduce stress when driving (for some people). Anticipated obstacles were, the cost and need for infrastructure, a potential attraction to driving if traffic is very smooth, people wanting to speed (breaking green waves, feeling patronised when smart vehicles overrule drivers' intentions), and resistance from non-motorised road users who are negatively affected by this measure.

Three measures did not score very well in the expert survey (stakeholder-average score <16, and only one or no stakeholder group rated it ≥16):

- *reducing freight transport on the road* (e.g. shifting it to rail or ship, promoting local/regional sourcing),
- *adapting/enforcing speed limits* (e.g. lower speed limits, stricter enforcement, traffic-calming construction measures), and
- *educating drivers on smooth driving.*

These measures are therefore not included in this chapter (in case of interest, see Annex VIII).

5 STRATEGY TO TACKLE TYRE WEAR AND CHEMICALS OF CONCERN

A suggested strategy to tackle tyre wear and chemicals of concern was identified by synthesising the results of

- the online expert survey (see 4.1) and
- the expert workshop (see 4.2).

It comprises the measures that were rated best for *efficiency* & *feasibility* across the stakeholder groups in the online expert survey and integrates recommendations on their potential implementation by workshop participants, considering benefits (beyond tackling tyre wear) and potential obstacles. For a balanced strategy, emission reduction, risk reduction and emission retention measures were included.

The results are intended to inform decision makers and stakeholders (with a European focus), to whom this report will be distributed and communicated.

5.1 Mix of Measures in 6 Pillars

Across stakeholder groups clear patterns emerged, which are the basis for recommendations on the integration of measures in the following 6 pillars:

1. tyre wear emission reduction at the source (tyre & traffic)
2. chemical safety of tyres
3. knowledge-based risk assessment
4. exposure avoidance and end-of-life tyre applications
5. smart technology advancements
6. targeted emission retention and mitigation.

There was broad agreement that a mix of measures is needed, including short-, medium- and long-term action. Precautionary action and knowledge advancement must proceed in parallel and ensuring the chemical safety of tyres (or rubber in general) as well as advancing risk assessment are of key importance. Pillars 4 to 6 are highly recommended supporting measures.

The expert survey revealed different preferences among stakeholder groups (see 0). *Government/administration* clearly tended to prefer immediate, cost-efficient and less controversial measures. *Academia* and *industry/ROI* supported a broader mix of measures, including technological innovation and enhancing the knowledge base for sustainable developments and systemic changes.

5.2 Emission Retention

5.2.1 Pillar 1: Tyre Wear Emission Reduction at the Source (Tyre and Traffic)

Implementing tyre emission limits was the highest-ranked measure in the expert survey (stakeholder-average score 17.2 out of 20). Obviously, the Euro 7 regulation receives broad support. Emission limits were considered medium to highly effective, their implementation was considered realistic to highly realistic, and effects on tyre wear emissions were expected in the short- to medium-term (<5 to <10 years). Workshop participants highlighted the need for standardised test methods, transparent certification/labelling schemes, awareness-raising among consumers, and clear communication of tyre wear declarations.

Important issues raised were the investment security for industry working on wear-improved tyres (long-term planning security is required), the need to ensure the enforcement capacity and clear consumer information. Regarding the potential obstacles, the risk of trade-offs should be noted (optimising tyres for low wear may come with disadvantages for other critical tyre properties). Potentially higher tyre prices may be justified by a longer service life of wear-resistant tyres, which needs to be communicated.

It is highly recommended to adhere to the introduction of mandatory tyre abrasion limits. This stimulates innovation to optimise tyres for low wear (improved tyre design or material composition).

Optimising tyre choice and maintenance requires *awareness-raising, regulation, incentives*, and *certification/labelling*, which should be fostered by *government/administration* and *industry/business*. It may be operationalised by combining

- *stopping the use of winter tyres in summer*, and

- *informing/training consumers (drivers) on optimal tyre choice, maintenance, and storage*.

The first option was among the best-rated measures (see Figure 5) in the expert survey (stakeholder-average score 16.6) and strongly supported by all stakeholder groups except *industry/ROI* (score 13.3). Its effectiveness was rated “medium”, with a realistic chance of implementation and a short time to take effect. Workshop participants agreed on this and suggested prohibiting the use of winter tyres in summer but raised the question of how to deal with all-season tyres.

Informing/training consumers (drivers) on optimal tyre choice, maintenance and storage would be complementary. It was considered a realistically feasible short-term measure of rather medium (to low) effectiveness and achieved a stakeholder-average score ≥16. Workshop participants suggested specifically educating drivers obtaining their licence, fleet owners and service centres on tyre wear, its implications and its relation to tyre choice, maintenance, and storage. The economic benefits of buying wear-resistant tyres and optimising maintenance, which reduces the need to replace tyres, should be highlighted.

The implementation of these measures could also improve driving safety by using the right tyre for the season and ensuring proper maintenance. Major resistance to implementation was not expected.

It is recommended to implement measures to optimise tyre choice and maintenance (e.g. by stopping winter-tyre use in summer and targeted awareness-raising on tyre choice and maintenance).

Reducing (individual) traffic volume effectively cuts emissions.

- *Promoting telework* (stakeholder-average score 16.6) and
- the *shift of personal transport from cars to local public transport, walking, or cycling* (stakeholder-average score 16.2)

were the best-rated measures in this action area on a stakeholder-average, although *government/administration* did not rate the latter very high (score 15.0). A *personal mobility shift* was considered more effective but harder to implement and rather a medium-term measure, while *promoting telework* was assessed as highly feasible in the short-term but less effective. A major benefit of traffic reduction measures are the many environmental and (public) health effects beyond tyre wear reduction (e.g. on climate, air quality, noise etc.). *Telework* additionally reduces traffic congestion and may be an incentive for employees. Workshop participants raised the point that the effect of these measures on tyre wear reduction can only be assessed if monitoring data on the total kilometres driven by car per year are collected and specific reduction targets are set.

Major expected obstacles regarding a *personal mobility shift* were the high cost of expanding public transport infrastructure (especially in rural areas), the difficulties in changing people's mindset/lifestyle, and the lack of political will (sensitivity of the topic regarding elections). *Telework*, in turn, is not possible in many jobs, and employers' trust issues can be a relevant obstacle. Some people also prefer to go to work for social contacts, to avoid distraction, or to keep work and private life separate.

For both measures, awareness-raising, incentives and regulation were considered a necessity for successful implementation. A mobility shift must also be enabled by construction/spatial planning regarding the expansion of infrastructure.

It is recommended to pursue traffic-reduction measures, combining the short-term effective promotion of telework with medium-term provision of infrastructure for sustainable mobility, supported by clear targets, monitoring, incentives, awareness-raising, and regulatory backing.

5.3 Risk Reduction

5.3.1 Pillar 2: Chemical Safety of Tyres

Promoting safe-and-sustainable-by-design (SSbD) practices was the highest ranked risk-reduction measure in the action area *substances of concern* (stakeholder-average score 16.6), with stronger support than restrictions and total bans of hazardous substances in tyres by all stakeholder groups, except *government/administration* which rated restrictions slightly higher than SSbD (score 15.7 vs. 15.4). All these measures were considered similarly effective (medium), but implementing an SSbD approach was considered to be more feasible, with a shorter time to take effect (~5 to <10 years). Workshop participants shared this opinion and highlighted the following requirements for a successful implementation:

- clear guidance by a (EU-wide) regulatory framework & standards
- standardised characterisation methods (e.g. for substance properties & hazards, transformation & release behaviour during production and service life)
- mandatory provision and generation of data/information on substances used for or formed during tyre production & service life (incl. non-registered substances, transformation products)
- substitution centres for a trusted and close industry-regulator cooperation, ensuring data transparency and protection
- (independent) control mechanisms and enforcement of compliance (e.g. by independent research on acceptable levels, safety assessments & compliance checks by authorities, sufficient enforcement capacities)
- aiming for sustainability “beyond tyres” (along the lifecycle of the parent chemical: routes of extraction/production/recycling etc.)

SSbD generates many positive effects beyond “safe tyres” and was argued to be advantageous compared to restrictions or bans, as

- the responsibility to establish a clear data basis to ensure safety is shared between authorities and industry
- decisions can be taken more efficiently – enhancing the planning-security for the industry and stimulating sustainable innovation
- regrettable substitution can be prevented, and
- socio-economic as well as environmental sustainability are increased (safer work environments and products, increased trust through clearer evidence & systemic understanding, reduced environmental impact & cost).

Obstacles may be technical limitations in maintaining tyre performance (e.g. due to a lack of alternative substances); time and money needed to generate the required in-depth knowledge base; and industry concerns about confidentiality, increased cost, bureaucracy, and competitive disadvantages on a global market (need for legal requirements for imported tyres).

It is highly recommended to promote SSbD as it is broadly accepted by all stakeholder groups and considered a forward-looking systemic approach.

5.3.2 Pillar 3: Knowledge-Based Risk Assessment

To improve the **knowledge base for risk assessment** and ensure the **suitability of approaches for particles and mixtures**, several measures were suggested, which were all highly ranked in the expert survey (stakeholder-average scores 16.5-17.1) and considered to take effect in the medium-term. All stakeholders agreed on the importance of understanding

- *the long-term leaching behaviour and degradation of tyre particles,*
- *the leaching/transformation/degradation of hazardous substances in environmental & biological media,*
- *the uptake/behaviour/fate of tyre particles in humans (and biota),*
- *and ensuring the suitability of risk assessment approaches for particles and tyre-related substance mixtures.*

The last two points were slightly less prioritised by *government/administration* (scores 15.3-15.7). Workshop participants would pursue *research* and *standardisation* involving *industry/business*, *academia*, and *government/administration* to achieve these aims. Specific ideas included:

- embrace the complexity of tyre wear (various particle properties, mix of polymers, additives, transformation products etc.) and develop & standardise mixture- & particle-specific risk assessment approaches that address these conceptual gaps,
- focus coordinated research on knowledge gaps, employing standardised methods for regulatory acceptance, and foster data sharing (between *academia*, industry, regulators),
- ensure the independence of evidence and a timely translation into regulation
- distinguish and comprehensively assess intrinsic hazard and real-world risk,
- generate clinical evidence/monitoring engaging public health & safety authorities.

Advancing risk assessment approaches generates added value by, e.g.

- identifying unknown hazardous substances & avoiding regrettable substitution,
- transferring knowledge and approaches to other mixture/particulate contaminants (microplastics, brake wear, fine dust etc.) and to other products (rubber, plastic etc.),
- ensuring accurate, proportionate, and trusted assessment.

The main obstacles mentioned were the lack of standardised particle/mixture-specific approaches, conceptual conflicts between the current regulatory framework (single-substance focus) and assessing particle/substance-mixtures, the intrinsic complexity of the matter and difficulty in defining assessment boundaries, confidentiality claims by industry, and the need for funding and time to conduct in-depth research. To allow timely action, risk management based on the current assessment and regulatory practices must be pursued, while measures to advance current approaches should be implemented in parallel.

It is recommended to establish a coordinated research and standardisation programme at EU-level with secure funding and structural knowledge transfer into regulation and to evaluate options to address particle- and mixture-assessments within the regulatory framework.

5.3.3 Pillar 4: Exposure Avoidance and End-of-Life Tyre Applications

To avoid exposure, the two highest-ranked measures in the expert survey (stakeholder-average score 16.3-16.4) were:

- *evaluating human exposure to particles & hazardous substances by end-of-life tyre applications (e.g. crumb rubber in playgrounds, sports fields, floorings etc.) and*
- *assessing the impact of mobility behaviour on human exposure (e.g. cycling/walking/jogging along low or heavy traffic roads, going by car/public transport etc.).*

These measures provide the public with recommendations and decision makers with information for potential regulatory measures and were highly rated by all stakeholders in the expert survey. They were rated slightly lower by *government/administration* (score 14.9-14.6), which expected a rather low effectiveness. Workshop participants suggested the funding of

- research on traffic-related exposure hotspots and on the exposure of certain population groups (e.g. athletes/children regularly exposed to crumb rubber applications) and
- stakeholder-specific awareness-raising (e.g. among sports clubs, communities and childcare facilities about potential risks and

safer alternatives) and public campaigns on relevant exposure pathways (e.g. preferring routes with low traffic-exposure).

Government/administration and *provision of infrastructure/public services* were the suggested responsible actors. Associated benefits included increased public pressure to improve product safety, reduced exposure to co-pollutants and increased public health literacy (understanding of exposures). Mentioned obstacles were the limited effectiveness of awareness campaigns and people's reluctance to change their behaviour. Generally, exposure avoidance can only be a (rather cheap and short-/medium-term) supporting measure. The public should not be responsible for avoiding exposure. In the long run, safe rubber products, bans on specific applications, or (individual) traffic reduction should be pursued.

Restricting tyre crumb rubber applications with high exposure risk for humans and the environment (e.g. in playgrounds, sports fields, landscaping/gardening etc.) was also highly rated in the expert survey (stakeholder-average score 16.1), and highly supported by all stakeholders, except *industry/ROI*, which considered it hardly effective. Workshop participants suggested

- banning applications with a high risk of exposing humans or the environment (crumb rubber in playgrounds, sports fields, floorings in gyms/pool surroundings, as filter/drainage materials etc.),
- conducting a risk-based evaluation (e.g. based on research in the above measure)
- ensuring (compulsory) risk-mitigation measures (e.g. certifying the physicochemical stability of crumb rubber materials, employing certified particle-retention units to retain emissions).

Government/administration and *industry/business* were considered responsible for implementation, which would require mainly *regulation, innovation, awareness,* and *research*. Again, upstream measures to ensure chemically safe tyres were considered a better long-term goal, but it would not prevent microplastic emissions. Precautionary restrictions were strongly recommended for scenarios exposing children and young people. Some obstacles to be considered comprise

- a lack of suitable substitutes for (crumb) rubber in sports,
- finding alternative uses and recycling options for waste tyres,
- resistance by recyclers due to economic interests,
- insufficient evidence to justify restrictions (more research needed on emissions & exposure risks).

Both **exposure avoidance** and a **restriction of crumb rubber applications** were rated as (highly) realistic and effective in the medium-term (5 to <10 yrs) and would be suitable intermediate measures, e.g. until the chemical safety of tyres is ensured and crumb rubber applications may be re-evaluated.

It is recommended to evaluate the implementation of restrictions based on research (in synergy with evaluating human exposure to particles & hazardous substances by end-of-life tyre applications) and taking into account the precautionary principle.

5.3.4 Pillar 5: Smart Technology Advancements

Smart technology in vehicles or traffic management can support the reduction of tyre wear emissions. Related highly rated measures (stakeholder-average scores 16.0) in the expert survey comprised:

- *avoiding stop-and-go traffic (harsh braking & accelerating), e.g. by enabling green waves, and*
- *promoting smart vehicles to optimise torque, acceleration, and deceleration behaviour (automatically or by pop-up driver information)*

The first measure was rated lower by *government/administration* (score 12.3), especially regarding effectiveness. It was, however, very highly rated by other stakeholders and considered to take effect in the short-term (<5 yrs). Smart vehicles were considered a medium-term (5 to <10 yrs) measure and equally supported by all stakeholders. To promote smooth traffic and reduce tyre wear, workshop participants would choose smart vehicles over smart traffic management, as the latter is frequently undermined by driving behaviour (e.g. drivers speeding and braking harshly). Other drawbacks mentioned were the high cost of smart infrastructure and the need to prioritise motorised traffic (i.e. by letting them pass first) over other road users (cyclists, pedestrians, trams etc.) for smooth driving. Smart vehicles can override the drivers' intent in favour of smooth driving (e.g. controlling torque, acceleration, deceleration etc.). Workshop participants suggested developing specific "eco-modes" to reduce tyre wear and the (compulsory) inclusion of such features in new cars. To ensure safety (and fair competition), international standards would be required. *Industry/business* and *academia* were considered responsible for the potential implementation. Enhanced driving safety and fewer accidents are noteworthy benefits, but drivers may feel less safe and patronised when the vehicle takes over control. Incentives may help to buffer the innovation cost or higher prices of smart vehicles, but people's habits, mindsets, or capacities may limit the use of "eco-modes".

It is recommended to promote research and development of smart vehicles as a forward-looking measure that supports tyre wear reduction and introduces many other benefits (e.g. increased safety, lower fuel consumption, less noise, lower CO_2 and other pollutant emissions etc.).

5.4 Emission Retention Measures

5.4.1 Pillar 6: Targeted Emission Retention and Mitigation

Overall, emission retention measures scored lower than emission reduction and risk reduction measures in the expert survey.

Targeted road dust collection, by expanding sweeping or optimising the locations, frequency, and timing of road cleaning, was the best-ranked emission retention measure (stakeholder-average score 15.9). It was very highly rated by *academia* and *industry/ROI*, but *government/administration* doubted the effectiveness and feasibility (score 13.1). Workshop participants suggested conducting a cost-benefit analysis, identifying relevant spatial and temporal hotspots through research, and focusing cleaning campaigns accordingly. *Government/administration* and *provision of infrastructure/public services* were considered responsible for implementation. A major obstacle identified is the financial burden for communities and public authorities (continuous expense), which may be eased by raising money through "polluter-pays"-oriented regulations, e.g. to account for tyre abrasion in motor vehicle taxes. Added benefits are the retention of other pollutants and particulate matter, less clogging of gullies, and the capture of littered waste (reducing microplastic pollution).

It is recommended to implement targeted, hotspot-based sweeping as a complementary and short-term effective measure, financed through dedicated mechanisms.

Optimal maintenance/cleaning of non-centralised road runoff collection/treatment facilities was rated very high by all stakeholders in the expert survey, except *government/administration* (score 11.5), which doubted effectiveness and feasibility.

It would, however, be a rather short-term measure to enhance the efficacy of already installed infrastructure and was supported by workshop participants who highlighted the benefit of retaining other pollutants.

Promoting roadside greenery along roads as wind-barriers and particle traps was very highly rated (stakeholder-average score 16.4-16.6) by *academia* and *industry/ROI* in the expert survey, but *government/administration* and *NGOs* strongly doubted the effectiveness and feasibility. Suggestions of workshop participants on operationalisation included

- mandatory roadside greenery where possible, and implementation within environmental compatibility assessment provisions for road construction, and
- providing clear guidelines (e.g. in road construction) on how to design effective green barriers (e.g. which plants to use etc.).

The actors considered responsible were government/administration and provision of infrastructure/public services, as implementation would mainly require regulation and construction/spatial planning activities, followed by innovation, research and standardisation. Green barriers would come with many positive external effects (e.g. for biodiversity & climate, as noise absorbers, to retain dust/pollutants/litter etc.). Encountered obstacles include space limitations, land ownership issues and the cost of construction/maintenance.

It is recommended to integrate green barrier requirements into road planning where possible and into environmental impact assessment frameworks, not least due to the many other benefits of increased greenery.

6 LIST OF ABBREVIATIONS

6PPD	N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (CAS 793-24-8)
6QDI	N-1,3-dimethyl butyl-N'-phenyl quinone diamine (CAS 52870-46-9)
7PPD	N-(1,4-dimethylpentyl)-N'-phenyl-p-phenylenediamine (CAS 3081-01-4)
BMLUK	Austrian Ministry of Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management
CLH	harmonised classification and labelling
CPPD	N-cyclohexyl-N'-phenyl-p-phenylenediamine (CAS 101-87-1)
DPG	N,N'-diphenylguanidine (CAS 102-06-7)
DPPD	N,N'-diphenyl-p-phenylenediamine (CAS 74-31-7)
EAA	Environment Agency Austria
FAIR	findable, accessible, interoperable, and reusable data
HMMM	hexamethoxymethyl melamine (CAS 3089-11-0)
IPPD	N-(1-methylethyl)-N'-phenyl-p-phenylenediamine (CAS 101-72-4)
PBT	persistent, bioaccumulative, toxic
PDs	phenylenediamines
PMT	persistent, mobile, toxic
PPDs	para-phenylenediamines
REACH	EU-regulation on the registration, evaluation, authorisation, and restriction of chemicals
ROI	*representation of interests*
SSbD	safe and sustainable by design
TMQ	polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (CAS 147-47-7)
UN WP.29	UNECE World Forum for Harmonization of Vehicle Regulations

7 LIST OF FIGURES

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ANNEX

Annex I

Table 21. List of the 17 action areas in the categories *emission reduction*, *emission retention* and *risk reduction*

category	action area no. and description
emission reduction	1: reduce (individual) **traffic** volume
emission reduction	2: optimise **tyres** for low wear (materials, design/dimensions etc.)
emission reduction	3: optimise tyre choice and maintenance for low wear (**tyre management**)
emission reduction	4: avoid emissions from **end-of-life tyre** utilisation
emission reduction	5: optimise **vehicles** (weight, smart vehicles etc.) and vehicle maintenance (wheel alignment etc.) to reduce tyre wear
emission reduction	6: foster a low wear **driving style**
emission reduction	7: optimise **roads** (surfaces, topology etc.) for low tyre wear
emission reduction	8: optimise **practices** regarding road dust, grit/salt application to reduce tyre wear
emission retention	9: equip **vehicles** with (tyre wear) particle collection systems
emission retention	10: foster particle retention at **roads** or roadsides to reduce wind drift (e.g. by porous asphalts, roadside greenery, constructed wind barriers)
emission retention	11: expand collection and treatment of **contaminated materials** from roads/roadsides (e.g. roadside greenery, snow, road dust, banquet/roadside soils)
emission retention	12: expand **runoff** collection from roads and sealed surfaces (in cities) and optimise treatment efficiency (for particles and chemicals)
risk reduction	13: ensure the retention of hazardous substances **leached** from tyres or tyre wear (at/near roads, in treatment facilities, from end-of-use tyre applications etc.) to avoid sinks becoming sources
risk reduction	14: reduce or avoid the use or presence of **hazardous substances** in tyres

category	action area no. and description
risk reduction	15: protect **environmental media** (soil, water, air etc.), sensitive ecosystems, and crops to minimise exposure of humans and biota (e.g., by limit values, buffer zones, monitoring etc.)
risk reduction	16: advance **risk assessment** to handle the complexity of tyre wear particles and related substances (incl. transformation products)
risk reduction	17: generate and provide knowledge on how to **avoid exposure** to empower individuals and to inform stakeholders (producers, legislators etc.)

Table 22. List of measures that were evaluated in the online expert survey.

category	action area / measure	description
emission reduction	action area 1	reduce (individual) traffic
emission reduction	measure	promote local sourcing
emission reduction	measure	shift freight transport from road to rail and ship transport
emission reduction	measure	shift personal transport from cars to public transport, walking, and cycling
emission reduction	measure	promote telework
emission reduction	measure	promote proximity of workplaces, housing, and shopping
emission reduction	measure	promote car-free holidays
emission reduction	action area 2	optimise tyres for low wear
emission reduction	measure	implement tyre-emission limits (e.g. Euro 7)
emission reduction	measure	implement a wear-based tyre labelling scheme (allowing informed consumer decisions)
emission reduction	measure	optimise tyre materials (formulation/composition) for low wear
emission reduction	measure	optimise tyre design (e.g. physical factors, weight, dimensions, rolling resistance) for low wear
emission reduction	action area 3	optimise tyre management, i.e., tyre choice and maintenance for low wear (optimal tyre choice regarding the dominant driving conditions, e.g. road types, driving speed, climate conditions; optimal tyre maintenance regarding tyre pressure, tyre alignment, usage duration, storage conditions/time etc.)
emission reduction	measure	provide "tyres as a service" for fleets or tyre leasing for individual vehicles to optimise tyre choice and maintenance
emission reduction	measure	inform/train consumers (drivers) on optimal tyre choice, maintenance and storage
emission reduction	measure	optimise tyre choice for the destination market (based on regional conditions: climate, road conditions, speed-limits etc.) involving tyre & automotive industry and retailers
emission reduction	measure	stop the use of winter tyres during summer (softer winter tyres generate more wear at higher temperatures)

category	action area / measure	description
emission reduction	measure	optimise storage (conditions, max. duration…) at producers and retailers (incl. second-hand) to avoid aging impacts on tyre wear
emission reduction	measure	optimise the tyre use phase (e.g. "expiry date") to avoid aging impacts on tyre wear (limiting also the second-hand tyre market)
emission reduction	action area 4	avoid emissions from end-of-life tyre utilisation
emission reduction	measure	avoid applications of tyre crumb rubber products in the environment (e.g. artificial turf, playground equipment, landscaping gardens/parks, fillers/embankments)
emission reduction	measure	avoid tyre (crumb) rubber modified materials exposed to the environment (e.g. asphalt, concrete, roofing materials, acoustic barriers along roads/railways)
emission reduction	measure	promote the retreading of tyres
emission reduction	action area 5	optimise vehicles and vehicle maintenance
emission reduction	measure	promote lighter (smaller) vehicles (without compromising safety)
emission reduction	measure	ensure optimal wheel alignment (e.g. by regular maintenance, sensors & maintenance pop-ups, automatic alignment in future?)
emission reduction	measure	"smart" vehicles to ensure optimum tyre pressure by automatic adjustment (depending on speed, terrain, load, traction conditions etc.) or maintenance pop-ups
emission reduction	measure	"smart" vehicles to optimise torque, acceleration & deceleration behaviour (depending on speed, terrain, load, traction conditions etc.) by automatic optimisation or pop-up driver information
emission reduction	measure	"smart" vehicles to optimise steering movement & curve behaviour (depending on speed, terrain, load, traction conditions etc.) by automatic adaptation or pop-up driver information
emission reduction	measure	"smart" vehicles to optimise driving speed (depending on curves, terrain, load, traction conditions etc.) by automatic adaptation or pop-up driver information
emission reduction	measure	"smart" vehicles with active suspension to reduce tyre wear (depending on speed, terrain, load, traction conditions etc.)

category	action area / measure	description
emission reduction	measure	promote autonomous driving to reduce tyre wear
emission reduction	action area 6	foster a low wear driving style
emission reduction	measure	reduce or optimise speed limits for low tyre wear (regarding road surface conditions and topography, curve radii/inclinations)
emission reduction	measure	ensure enforcement of existing/adapted speed limits (stricter controls)
emission reduction	measure	install traffic-calming (speed-limiting) construction measures
emission reduction	measure	avoid stop-and-go traffic (harsh braking & accelerating) by enabling green waves
emission reduction	measure	promote smooth traffic using dynamic speed limits according to traffic load
emission reduction	measure	educate drivers on smooth (low tyre wear) driving style (by information material, training etc.)
emission reduction	action area 7	optimise roads for low tyre wear
emission reduction	measure	identify/develop asphalt types for low wear (considering driving speed, climate, impacts of road dust & salt/grit)
emission reduction	measure	foster maintenance and repair of worn road surfaces and "upgrade" of terrain for low tyre wear
emission reduction	measure	optimise road planning to favour low tyre wear (e.g. curve radii and inclination, dimensions of de-& acceleration lanes, roundabouts vs. crossroads) considering road surface type, speed limits etc.
emission reduction	action area 8	optimise practices regarding road dust, grit/salt application
emission reduction	measure	evaluate/optimise the use of road salt vs. grit in winter to reduce tyre wear
emission reduction	measure	evaluate/optimise the use of grit (grit type, particle size/shape etc.) in winter to reduce tyre wear
emission reduction	measure	increase road cleaning to remove dust that may enhance tyre wear
emission retention	action area 9	promote equipment of vehicles with particle collection systems
emission retention	measure	equip vehicles with tyre housings to collect particles
emission retention	measure	equip vehicles with nozzle-collection systems at the wheels to collect particles

category	action area / measure	description
emission retention	measure	equip vehicles with electrostatic modules at the wheels to collect tyre wear
emission retention	measure	equip vehicles with filters (e.g. on the roof or in the front fascia) to collect suspended particles (while driving and/or when parked)
emission retention	action area 10	foster particle retention at roads or roadsides to avoid wind drift
emission retention	measure	promote roadside greenery (grass, bushes, trees etc.) as wind barriers and particle traps
emission retention	measure	install (or redesign existing) constructed barriers (e.g. walls, fences, nets) as wind barriers and particle traps
emission retention	measure	promote high embankments ("road-canyons") to favour particle retention along roads
emission retention	measure	install particle collecting/trapping road surfaces (e.g. porous or permeable pavements)
emission retention	action area 11	expand collection and treatment of contaminated materials from roads/roadsides
emission retention	measure	roadside greenery: expand the collection and appropriate treatment of materials (shed leaves, grass, cuttings etc.) and optimise management to retain tyre wear (e.g. when/how to cut trees/bushes?)
emission retention	measure	snow: expand the collection and treatment of snow from roads (incl. roadsides, pavements, parking lots etc.)
emission retention	measure	road dust: expand sweeping (include more roads, pavements, parking lots etc.) and optimise frequency, timing, locations (e.g. tyre wear "hot spots" or predicted wind/rain events)
emission retention	measure	optimise management of banquet materials and roadside soils to retain tyre wear (e.g. prevent wind/water erosion; optimise renewal-frequency to prevent tyre wear remobilisation)
emission retention	action area 12	expand runoff collection from roads and sealed surfaces (in cities) and optimise treatment efficiency
emission retention	measure	expand the network of road-runoff collection/treatment facilities from the local/decentralised to the centralised level
emission retention	measure	optimise the technical efficiency of road-runoff collection/treatment facilities to retain tyre wear
emission retention	measure	ensure the collection/treatment of stormwaters (no "overflow" emissions into the environment)
emission retention	measure	expand sealed-surface runoff collection (in cities) from the local/decentralised to the centralised level ("sponge city")

category	action area / measure	description
emission retention	measure	ensure optimal maintenance/cleaning of decentralised road-runoff (and snow) collection/treatment facilities to avoid (re)mobilisation or breakthrough of tyre wear particles
risk reduction	action area 13	ensure/enhance the retention of hazardous substances leached from tyres or tyre wear
risk reduction	measure	optimise the replacement frequency of banquet materials, roadside/buffer-zone soils to avoid leaching and breakthrough of hazardous chemicals
risk reduction	measure	add absorbers that retain hazardous substances, e.g. to (permeable) asphalts, banquet materials, roadside/buffer-zone soils
risk reduction	measure	ensure treatment efficiency for tyre-derived hazardous substances in facilities to collect/treat road-runoff or snow (e.g. infiltration swales, filter units, sedimentation/retention basins, wastewater treatment plants etc.)
risk reduction	measure	ensure maintenance/cleaning of decentralised road-runoff or snow collection/treatment facilities to avoid leaching and breakthrough of hazardous substances
risk reduction	measure	avoid the application of tyre crumb rubber as filter/drainage material (e.g. in stormwater and urban runoff management or in drainage layers for roads/railways/landfills etc.) to avoid leaching of hazardous substances
risk reduction	action area 14	reduce or avoid the use or presence of hazardous substances in tyres
risk reduction	measure	total ban of hazardous substances in tyres, based on human and environmental hazard and risk assessments for single substances or groups
risk reduction	measure	restrict hazardous substances in tyres, e.g. by means of concentration limits or migration limits, based on human and environmental hazard and risk assessments for single substances or groups
risk reduction	measure	promote safe-and-sustainable-by-design practices (e.g. consulting on chemical hazards in a trusted environment, installation of chemical substitution centres, subsidising production of non-hazardous alternative substances etc.)
risk reduction	measure	increase transparency: indicate the identity (not necessarily the contents) of all substances used in the tyre and declare known/potentially hazardous substances

category	action area / measure	description
risk reduction	action area 15	protect environmental media (soil, sediment, water, air etc.), sensitive ecosystems, and crops to minimise exposure of humans and biota
risk reduction	measure	establish limit values for tyre wear in environmental media (e.g. soil, sediment, water, air etc.) coupled with monitoring programmes
risk reduction	measure	establish limit values for tyre-related hazardous substances or transformation products in environmental media (e.g. soil, sediment, water, air etc.) coupled with monitoring programmes
risk reduction	measure	prevent the use (e.g. agriculture, landscaping) or disposal of (potentially) contaminated materials in the open environment: e.g. sewage sludge, (composted) roadside greenery, snow from roads, roadside soils, soils/sediments/filter materials from decentralised road-runoff treatment facilities etc.
risk reduction	measure	install sufficient buffer zones or constructed/green barriers to ensure the protection of sensitive ecosystems or agricultural produce near roads
risk reduction	measure	avoid negative ecological effects of emission-retention measures (e.g. roadside-greenery, retention ponds etc.) as organisms may consider these contamination hotspots attractive habitats
risk reduction	measure	conduct targeted monitoring studies to ensure the efficacy of measures to retain tyre-related emissions (e.g. wind barriers, roadside greenery, buffer zones/stripes, runoff collection/treatment systems etc.)
risk reduction	measure	establish long-term monitoring programmes for human exposure (e.g. respiratory, dietary) to tyre wear particles and related hazardous substances (incl. transformation products)
risk reduction	action area 16	advance risk assessment to handle the complexity of tyre wear particles and related substances (incl. transformation products)
risk reduction	measure	ensure that human and environmental hazard and risk assessment captures the complexity of tyre-related substances (e.g. mixture effects, transformation products, unintentionally present substances)
risk reduction	measure	ensure the suitability of human and environmental hazard and risk assessment for (tyre wear) particles (what works for chemicals doesn't necessarily work for particles)
risk reduction	measure	understand the degradation of tyre particles and the release of hazardous substances in different environmental media to evaluate persistence and long-term leaching behaviour

category	action area / measure	description
risk reduction	measure	understand the leaching/transformation/degradation of tyre-related hazardous substances in environmental media and biological fluids to evaluate risk
risk reduction	measure	understand the uptake, behaviour and fate of tyre wear particles in humans
risk reduction	action area 17	generate and provide knowledge on how to avoid exposure to empower individuals and to inform stakeholders (producers, legislators etc.)
risk reduction	measure	assess the impact of mobility behaviour (e.g. cycling/walking/jogging along roads, driving in cars etc.) on human exposures to tyre-derived particles & hazardous substances and derive recommendations
risk reduction	measure	assess the distribution of tyre-derived particles & hazardous substances on/within food plants and persistency during meal preparation to derive recommendations for consumers (e.g. washing, peeling, cutting off roots/greens, cooking etc.)
risk reduction	measure	evaluate human exposure to particles & hazardous substances by end-of-life tyre applications (e.g. crumb rubber in playgrounds/turf fields, flooring & mats, gardening/playground equipment etc.) and derive recommendations
risk reduction	measure	evaluate additional non-tyre sources of exposure to particles & hazardous substances, e.g. from rubber materials applied in food-contact, households, work environments, leisure (e.g. climbing shoes etc.) and derive recommendations

Annex II

Expert Panel - Tackling Tyre Wear and Associated Chemical Risks

Do. 27. November 2025, 09:00 am - 05:00 pm

DemoCenter Pier 50, Brigittenauer Lände 50-54/Staircase 6,
1200 Vienna and online

Agenda

Moderation: Philipp Hohenblum, *Environment Agency Austria (EAA)*

08:30 – 09:00	**REGISTRATION & WELCOME COFFEE**
09:00 – 09:15	**Welcome and Opening** Thomas Jakl, *Austrian Ministry of Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management* **Background & Aim of the Workshop** Helene Walch, *Environment Agency Austria*
09:15 – 10:15	**TALKS** **Fate of Tyre-Related Chemicals Across Different Time Scales** Bettina Seiwert, *Helmholtz Centre for Environmental Research (UFZ), DE* **Risk Management: Chemicals in Tyres (REACH Dossier PPDs)** Patrick Zweers, *National Institute for Public Health and the Environment (RIVM), NL* **Occurrence and Environmental Fate of Classical and Emerging Pollutants in Tyre Rubber Microplastics from Sports Fields and Playgrounds (online)** Maria Llompart, *University of Santiago de Compostela, Centre for Cross-disciplinary Research in Environmental Technologies (CRETUS), ES*

10:15 – 10:25	**COMFORT BREAK**
10:25 – 11:20	**BREAKOUT GROUPS** (2 discussion groups per topic) **Topic 1:** Chemicals and Risk Assessment **Topic 2:** Awareness and Exposure Avoidance (incl. end-of-life tyre applications)
11:20 – 12:00	**TALKS** **State of Knowledge – Tyre Wear Emissions During the Use-Phase** Kathrin Müller, *Hochschule Fresenius, DE* **URBANFILTER - Tyre Wear Retention in Road Runoff** Johannes Wolfgang Neupert, *Technical University Berlin, DE*
12:00 – 13:00	**LUNCH BREAK**
13:00 – 13:45	**BREAKOUT GROUPS** (2 discussion groups per topic) **Topic 3:** Distribution via Dust and Measures at or near the Road **Topic 4:** Runoff collection/retention and treatment
13:45 – 14:45	**TALKS** **Reducing the Impact of TRWP Emissions by Understanding Their Nature and Environmental Dynamics (online)** Bogdan Muresan, *Gustave Eiffel University, FR* **Addressing Tyre Wear Through Vehicle Design, Operation and Control (online)** Jenny Jerrelind & Lars Drugge, *KTH Royal Institute of Technology, SE* **Mobility Transition: Targeted Measures to Limit Tyre Wear and Environmental Damage** Dieter Schmidradler, *Verkehrswende, AT*
14:45 – 15:15	**COFFEE BREAK**
15:15 – 16:00	**BREAKOUT GROUPS** (2 discussion groups per topic) **Topic 5:** Tyre – Vehicle – Road – Driving Behaviour **Topic 6:** Mobility Transition & Traffic Reduction
12:00 – 13:00	**Wrap-Up Breakout Groups** **CLOSING**

Annex III

Figure 29. Ranking of all measures by stakeholder-average total score, parts II–IV (continuation of Figure 5)

Ranking of All Measures by Stakeholder-Average Total Score (Part II)

TOTAL SCORE*)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups: academia	gov./adm.	ind./ROI	NGO	stakeh. average	level of expertise: gut feeling	≥well inf.
assess the distribution of tyre-derived particles & hazardous substances on/within food plants and persistency during meal preparation to derive recommendations for consumers (e.g. washing, peeling, cutting off roots/greens, cooking etc.)	15.2	16.4	13.2	16.3	16.8	15.7	15.5	15.1
ensure optimal maintenance/cleaning of decentralised road-runoff (and snow) collection/treatment facilities to avoid (re)mobilisation or breakthrough of tyre wear particles	15.6	16.4	11.5	16.6	18.0	15.6	16.1	15.4
evaluate additional non-tyre sources of exposure to particles & hazardous substances, e.g. from rubber materials applied in food-contact, households, work environments, leisure (e.g. climbing shoes etc.) and derive recommendations	15.1	16.1	13.3	16.2	16.8	15.6	14.1	15.4
identify/develop asphalt types for low wear (considering driving speed, climate, impacts of road dust & salt/grit)	16.3	17.2	14.9	17.6	12.7	15.6	16.3	16.4
reduce or optimise speed limits for low tyre wear (regarding road surface conditions and topography, curve radii/inclinations)	15.4	15.9	14.5	13.8	18.2	15.6	14.3	15.8
avoid the application of tyre crumb rubber as filter/drainage material (e.g. in stormwater and urban runoff management or in drainage layers for roads/railways/landfills etc.) to avoid leaching of hazardous substances	16.3	18.1	14.4	14.7	14.8	15.5	17.2	15.5
optimise tyre choice for the destination market (based on regional conditions: climate, road conditions, speed-limits etc.) involving tyre & automotive industry and retailers	15.6	15.6	15.9	15.6	14.3	15.4	15.8	15.5
foster maintenance and repair of worn road surfaces and "upgrade" of terrain for low tyre wear	15.7	16.7	15.2	15.6	13.8	15.3	15.8	15.7
ensure the collection/treatment of stormwaters (no "overflow" emissions into the environment)	15.1	15.7	12.2	15.8	17.5	15.3	16.9	14.2
smart vehicles to ensure optimum tyre pressure by automatic adjustment (depending on speed, terrain, load, traction conditions etc.) or maintenance pop-ups	15.5	15.7	15.4	15.7	14.3	15.3	15.4	15.6
restrict hazardous substances in tyres, e.g. by means of concentration limits or migration limits, based on human and environmental hazard and risk assessments for single substances or groups	15.4	15.7	15.7	13.3	16.3	15.2	15.8	15.3
ensure enforcement of existing/adapted speed limits (stricter controls)	15.2	15.8	13.0	14.6	17.5	15.2	13.9	15.7
ensure optimal wheel alignment (e.g. by regular maintenance, sensors & maintenance pop-ups, automatic alignment in future?)	15.7	16.5	15.0	15.5	13.8	15.2	15.9	15.6
optimise the technical efficiency of road-runoff collection/treatment facilities to retain tyre wear	15.1	15.7	11.6	16.0	17.5	15.2	16.0	14.6
conduct targeted monitoring studies to ensure the efficacy of measures to retain tyre-related emissions (e.g. wind barriers, roadside greenery, buffer zones/stripes, runoff collection/treatment systems etc.)	15.2	16.3	14.1	15.6	14.7	15.2	12.0	15.9
ensure maintenance/cleaning of decentralised road-runoff or snow collection/treatment facilities to avoid leaching and breakthrough of hazardous substances	15.1	15.6	13.1	17.0	14.8	15.1	15.6	14.8
educate drivers on smooth (low tyre wear) driving style (by information material, training etc.)	14.8	14.6	11.9	16.8	17.2	15.1	11.8	15.9
promote lighter (smaller) vehicles (without compromising safety)	15.3	16.2	14.8	13.7	15.8	15.1	14.9	15.6
smart vehicles to optimise driving speed (depending on curves, terrain, load, traction conditions etc.) by automatic adaptation or pop-up driver information	15.2	15.7	14.7	14.9	14.3	14.9	14.6	15.4
shift freight transport from road to rail and ship transport	15.0	15.3	14.7	14.6	14.8	14.8	14.7	15.4
increase transparency: indicate the identity (not necessarily the contents) of all substances used in the tyre and declare known/potentially hazardous substances	13.9	14.2	12.9	14.4	17.7	14.8	15.4	13.6

Source: Environment Agency Austria

ENVIRONMENT AGENCY AUSTRIA

Ranking of All Measures by Stakeholder-Average Total Score (Part III)

TOTAL SCORE*)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups				stakeh. average	level of expertise	
		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
expand sealed-surface runoff collection (in cities) from the local/decentralised to the centralised level ("sponge city")	14.4	14.9	10.1	16.3	17.5	14.7	14.4	14.5
add absorbers that retain hazardous substances, e.g. to (permeable) asphalts, banquet materials, roadside/buffer-zone soils	14.4	14.9	12.4	16.4	15.0	14.7	14.7	14.2
equip vehicles with nozzle-collection systems at the wheels to collect particles	13.6	13.1	14.8	12.2	18.5	14.6	14.1	13.3
prevent the use (e.g. agriculture, landscaping) or disposal of (potentially) contaminated materials in the open environment: e.g. sewage sludge, (composted) roadside greenery, snow from roads, roadside soils, soils/sediments/filter materials from decentralised road-runoff treatment facilities etc.	15.6	16.8	15.6	11.9	14.2	14.6	14.7	15.7
establish limit values for tyre wear in environmental media (e.g. soil, sediment, water, air etc.) coupled with monitoring programmes	14.4	15.5	12.6	15.9	14.3	14.6	12.3	14.8
install sufficient buffer zones or constructed/green barriers to ensure the protection of sensitive ecosystems or agricultural produce near roads	14.5	15.6	12.9	13.8	16.0	14.6	11.4	15.1
increase road cleaning to remove dust that may enhance tyre wear	14.6	14.7	15.6	13.8	14.0	14.5	14.3	14.9
smart vehicles to optimise steering movement & curve behaviour (depending on speed, terrain, load, traction conditions etc.) by automatic adaptation or pop-up driver information	14.6	15.1	13.9	14.8	14.3	14.5	14.1	14.9
establish long-term monitoring programmes for human exposure (e.g. respiratory, dietary) to tyre wear particles and related hazardous substances (incl. transformation products)	14.5	16.3	12.3	15.3	14.2	14.5	10.7	15.3
ensure treatment efficiency for tyre-derived hazardous substances in facilities to collect/treat road-runoff or snow (e.g. infiltration swales, filter units, sedimentation/retention basins, wastewater treatment plants etc.)	14.6	15.7	12.0	15.4	14.8	14.5	13.9	14.9
provide "tyres as a service" for fleets or tyre leasing for individual vehicles to optimise tyre choice and maintenance	14.2	14.4	14.3	12.8	16.3	14.5	14.9	14.0
promote local sourcing	14.1	14.4	12.7	15.2	15.5	14.4	14.4	13.8
establish limit values for tyre-related hazardous substances or transformation products in environmental media (e.g. soil, sediment, water, air etc.) coupled with monitoring programmes	14.9	17.3	12.9	12.9	14.5	14.4	12.1	15.5
install traffic-calming (speed-limiting) construction measures	14.6	16.3	11.7	12.5	16.2	14.2	12.6	15.3
install particle collecting/trapping road surfaces (e.g. porous or permeable pavements)	14.6	15.7	11.3	15.2	14.2	14.1	12.2	16.4
expand the network of road-runoff collection/treatment facilities from the local/decentralised to the centralised level	13.7	14.3	10.2	14.3	17.5	14.1	13.4	13.9
optimise road planning to favour low tyre wear (e.g. curve radii and inclination, dimensions of de-& acceleration lanes, roundabouts vs. crossroads) considering road surface type, speed limits etc.	14.3	14.6	13.6	15.2	12.7	14.0	14.6	14.0
optimise management of banquet materials and roadside soils to retain tyre wear (e.g. prevent wind/water erosion; optimise renewal-frequency to prevent tyre wear remobilisation)	14.4	15.2	8.0	17.5	15.3	14.0	15.5	13.7
promote roadside greenery (grass, bushes, trees etc.) as wind barriers and particle traps	14.9	16.4	10.4	16.6	12.7	14.0	13.8	15.8

Source: Environment Agency Austria

ENVIRONMENT AGENCY AUSTRIA

Ranking of All Measures by Stakeholder-Average Total Score (Part IV)

TOTAL SCORE*)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

measures	all responses	stakeholder groups: academia	gov./adm.	ind./ROI	NGO	stakeh. average	level of expertise: gut feeling	≥well inf.
optimise the replacement frequency of banquet materials, roadside/buffer-zone soils to avoid leaching and breakthrough of hazardous chemicals	13.6	14.7	10.5	15.4	15.0	13.9	13.3	13.8
equip vehicles with tyre housings to collect particles	12.9	12.6	13.3	11.2	18.5	13.9	14.0	12.3
equip vehicles with electrostatic modules at the wheels to collect tyre wear	12.8	12.8	13.3	10.8	18.5	13.8	12.8	12.8
smart vehicles with active suspension to reduce tyre wear (depending on speed, terrain, load, traction conditions etc.)	13.8	13.9	14.1	12.7	14.3	13.8	14.4	13.5
install (or redesign existing) constructed barriers (e.g. walls, fences, nets) as wind barriers and particle traps	13.7	14.5	8.5	16.7	15.0	13.7	12.4	14.7
avoid tyre (crumb) rubber modified materials exposed to the environment (e.g. asphalt, concrete, roofing materials, acoustic barriers along roads/railways)	14.5	15.8	14.8	10.4	13.2	13.5	15.2	14.1
promote proximity of workplaces, housing, and shopping	12.6	12.6	12.4	11.4	17.3	13.4	11.6	14.1
roadside greenery: expand the collection and appropriate treatment of materials (shed leaves, grass, cuttings etc.) and optimise management to retain tyre wear (e.g. when/how to cut trees/bushes?)	13.9	15.3	10.4	13.5	14.3	13.4	14.1	13.7
optimise the tyre use phase (e.g. "expiry date") to avoid aging impacts on tyre wear (limiting also the second-hand tyre market)	12.6	11.8	15.6	9.2	16.7	13.3	16.0	10.7
promote the retreading of tyres	13.8	14.7	14.6	9.4	14.3	13.2	15.6	12.8
evaluate/optimise the use of road salt vs. grit in winter to reduce tyre wear	13.5	14.1	11.8	14.0	12.0	13.0	15.1	12.2
optimise storage (conditions, max. duration...) at producers and retailers (incl. second-hand) to avoid aging impacts on tyre wear	12.9	13.4	16.5	8.4	13.0	12.9	14.5	12.0
snow: expand the collection and treatment of snow from roads (incl. roadsides, pavements, parking lots etc.)	13.4	15.1	11.5	10.3	14.3	12.8	14.6	12.4
evaluate/optimise the use of grit (grit type, particle size/shape etc.) in winter to reduce tyre wear	13.3	14.0	11.5	12.6	12.0	12.6	14.6	12.2
ban of hazardous substances in tyres, based on human and environmental hazard and risk assessments for single substances or groups	12.1	11.9	12.7	10.3	14.7	12.4	13.6	11.8
avoid negative ecological effects of emission-retention measures (e.g. roadside-greenery, retention ponds etc.) as organisms may consider these contamination hotspots attractive habitats	12.0	12.2	10.3	12.9	14.0	12.4	9.8	12.2
promote car-free holidays	10.6	10.5	10.7	7.5	19.3	12.0	10.5	10.6
promote autonomous driving to reduce tyre wear	12.7	13.5	12.3	12.0	9.7	11.9	12.8	12.6
promote high embankments ("road-canyons") to favour particle retention along roads	13.0	15.3	8.4	14.0	8.7	11.6	10.4	14.9
equip vehicles with filters (e.g. on the roof or in the front fascia) to collect suspended particles (while driving and/or when parked)	9.9	9.3	8.1	9.3	18.5	11.3	9.8	10.0

Source: Environment Agency Austria

Annex IV

Further Measures Ranked Highly (Score ≥16) by Industry/ROI

TOTAL SCORE*)

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

		stakeholder groups					level of expertise	
measures	all responses	academia	gov./adm.	ind./ROI	NGO	stakeh. average	gut feeling	≥well inf.
evaluate human exposure to particles & hazardous substances by end-of-life tyre applications (e.g. crumb rubber in playgrounds/turf fields, flooring & mats, gardening/playground equipment etc.) and derive recommendations	16.2	17.0	14.9	16.9	16.8	16.4	15.4	16.4
educate drivers on smooth (low tyre wear) driving style (by information material, training etc.)	14.8	14.6	11.9	16.8	17.2	15.1	11.8	15.9
smart vehicles to optimise torque, acceleration & deceleration behaviour (depending on speed, terrain, load, traction conditions etc.) by automatic optimisation or pop-up driver information	16.1	16.1	15.8	16.8	15.3	16.0	15.0	16.6
install (or redesign existing) constructed barriers (e.g. walls, fences, nets) as wind barriers and particle traps	13.7	14.5	8.5	16.7	15.0	13.7	12.4	14.7
ensure optimal maintenance/cleaning of decentralised road-runoff (and snow) collection/treatment facilities to avoid (re)mobilisation or breakthrough of tyre wear particles	15.6	16.4	11.5	16.6	18.0	15.6	16.1	15.4
assess the impact of mobility behaviour (e.g. cycling/walking/jogging along roads, driving in cars etc.) on human exposures to tyre-derived particles & hazardous substances and derive recommendations	16.0	16.9	14.6	16.6	17.2	16.3	13.4	16.7
promote roadside greenery (grass, bushes, trees etc.) as wind barriers and particle traps	14.9	16.4	10.4	16.6	12.7	14.0	13.8	15.8
implement a wear-based tyre labelling scheme (allowing informed consumer decisions)	15.7	15.8	14.5	16.4	17.5	16.0	16.0	15.6
add absorbers that retain hazardous substances, e.g. to (permeable) asphalts, banquet materials, roadside/buffer-zone soils	14.4	14.9	12.4	16.4	15.0	14.7	14.7	14.2
ensure that human and environmental hazard and risk assessment captures the complexity of tyre-related substances (e.g. mixture effects, transformation products, unintentionally present substances)	16.2	16.7	15.3	16.4	17.7	16.5	14.8	16.5
ensure the suitability of human and environmental hazard and risk assessment for (tyre wear) particles (what works for chemicals doesn't necessarily work for particles)	16.2	16.4	15.7	16.4	17.7	16.5	15.2	16.5
assess the distribution of tyre-derived particles & hazardous substances on/within food plants and persistency during meal preparation to derive recommendations for consumers (e.g. washing, peeling, cutting off roots/greens, cooking etc.)	15.2	16.4	13.2	16.3	16.8	15.7	15.5	15.1
promote telework	16.2	15.8	16.5	16.3	17.8	16.6	16.3	16.0
expand sealed-surface runoff collection (in cities) from the local/decentralised to the centralised level ("sponge city")	14.4	14.9	10.1	16.3	17.5	14.7	14.4	14.5
evaluate additional non-tyre sources of exposure to particles & hazardous substances, e.g. from rubber materials applied in food-contact, households, work environments, leisure (e.g. climbing shoes etc.) and derive recommendations	15.1	16.1	13.3	16.2	16.8	15.6	14.1	15.4
promote smooth traffic using dynamic speed limits according to traffic load	16.0	16.8	13.0	16.2	17.2	15.8	13.2	16.9
optimise the technical efficiency of road-runoff collection/treatment facilities to retain tyre wear	15.1	15.7	11.6	16.0	17.5	15.2	16.0	14.6

Source: Environment Agency Austria

Figure 30. Further Measures that were well-ranked (score ≥16) by industry/ROI.

Further Measures Ranked Highly (Score ≥16) by Academia

*) numbers represent sum score regarding effectiveness, implementation & timeframe (highest score=best measure)

	TOTAL SCORE*)							
	all responses	stakeholder groups				stakeh. average	level of expertise	
measures		academia	gov./adm.	ind./ROI	NGO		gut feeling	≥well inf.
assess the impact of mobility behaviour (e.g. cycling/walking/jogging along roads, driving in cars etc.) on human exposures to tyre-derived particles & hazardous substances and derive recommendations	16.0	16.9	14.6	16.6	17.2	16.3	13.4	16.7
implement tyre-emission limits (e.g. Euro 7)	17.0	16.8	16.8	17.8	17.7	17.2	15.8	17.4
prevent the use (e.g. agriculture, landscaping) or disposal of (potentially) contaminated materials in the open environment: e.g. sewage sludge, (composted) roadside greenery, snow from roads, roadside soils, soils/sediments/filter materials from decentralised road-runoff treatment facilities etc.	15.6	16.8	15.6	11.9	14.2	14.6	14.7	15.7
promote smooth traffic using dynamic speed limits according to traffic load	16.0	16.8	13.0	16.2	17.2	15.8	13.2	16.9
ensure that human and environmental hazard and risk assessment captures the complexity of tyre-related substances (e.g. mixture effects, transformation products, unintentionally present substances)	16.2	16.7	15.3	16.4	17.7	16.5	14.8	16.5
foster maintenance and repair of worn road surfaces and "upgrade" of terrain for low tyre wear	15.7	16.7	15.2	15.6	13.8	15.3	15.8	15.7
promote safe-and-sustainable-by-design practices (e.g. consulting on chemical hazards in a trusted environment, installation of chemical substitution centres, subsidising production of non-hazardous alternative substances etc.)	16.2	16.6	15.4	15.8	18.7	16.6	16.4	16.2
avoid applications of tyre crumb rubber products in the environment (e.g. artificial turf, playground equipment, landscaping gardens/parks, fillers/embankments)	16.3	16.5	17.3	13.5	16.8	16.1	15.9	16.5
ensure optimal wheel alignment (e.g. by regular maintenance, sensors & maintenance pop-ups, automatic alignment in future?)	15.7	16.5	15.0	15.5	13.8	15.2	15.9	15.6
optimise tyre design (e.g. physical factors, weight, dimensions, rolling resistance) for low wear	16.4	16.4	15.8	17.0	15.8	16.3	16.4	16.4
ensure the suitability of human and environmental hazard and risk assessment for (tyre wear) particles (what works for chemicals doesn't necessarily work for particles)	16.2	16.4	15.7	16.4	17.7	16.5	15.2	16.5
ensure optimal maintenance/cleaning of decentralised road-runoff (and snow) collection/treatment facilities to avoid (re)mobilisation or breakthrough of tyre wear particles	15.6	16.4	11.5	16.6	18.0	15.6	16.1	15.4
promote roadside greenery (grass, bushes, trees etc.) as wind barriers and particle traps	14.9	16.4	10.4	16.6	12.7	14.0	13.8	15.8
assess the distribution of tyre-derived particles & hazardous substances on/within food plants and persistency during meal preparation to derive recommendations for consumers (e.g. washing, peeling, cutting off roots/greens, cooking etc.)	15.2	16.4	13.2	16.3	16.8	15.7	15.5	15.1
conduct targeted monitoring studies to ensure the efficacy of measures to retain tyre-related emissions (e.g. wind barriers, roadside greenery, buffer zones/stripes, runoff collection/treatment systems etc.)	15.2	16.3	14.1	15.6	14.7	15.2	12.0	15.9
install traffic-calming (speed-limiting) construction measures	14.6	16.3	11.7	12.5	16.2	14.2	12.6	15.3
understand the uptake, behaviour and fate of tyre wear particles in humans	16.2	16.3	15.4	17.6	17.8	16.8	14.5	16.6
establish long-term monitoring programmes for human exposure (e.g. respiratory, dietary) to tyre wear particles and related hazardous substances (incl. transformation products)	14.5	16.3	12.3	15.3	14.2	14.5	10.7	15.3
promote lighter (smaller) vehicles (without compromising safety)	15.3	16.2	14.8	13.7	15.8	15.1	14.9	15.6
shift personal transport from cars to public transport, walking, and cycling	15.8	16.2	15.0	15.8	17.8	16.2	15.4	16.5
evaluate additional non-tyre sources of exposure to particles & hazardous substances, e.g. from rubber materials applied in food-contact, households, work environments, leisure (e.g. climbing shoes etc.) and derive recommendations	15.1	16.1	13.3	16.2	16.8	15.6	14.1	15.4
smart vehicles to optimise torque, acceleration & deceleration behaviour (depending on speed, terrain, load, traction conditions etc.) by automatic optimisation or pop-up driver information	16.1	16.1	15.8	16.8	15.3	16.0	15.0	16.6
inform/train consumers (drivers) on optimal tyre choice, maintenance and storage	15.9	16.1	16.2	15.1	16.5	16.0	15.5	16.1

Source: Environment Agency Austria

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Figure 31. Further Measures that were well-ranked (score ≥16) by academia.

Annex V

Topic 2: Exposure Avoidance and End-of-Life Tyres

Promote Retreading of Tyres

In the expert survey *promoting the retreading of tyres* was not considered very useful for tackling tyre wear and related chemicals of concern (see Figure 16). However, as retreaded tyres will also wear and release chemicals, it may be resource-efficient and a viable recycling option for end-of-life tyres (see also page 58). The workshop participants suggested

- chemically safe materials as a basis for retreading and tyres designed for retreading
- research on the lifetime and wear-resistance of retreaded tyres in relation to costs (e.g. savings on materials vs. costs for collection/inspection of tyres for retreading etc.)
- stimuli to promote retreading and economical transitions (e.g. incentives/disincentives or quotas for public fleets)
- awareness raising among customers
- new business models for the tyre industry (manufacturers, retailers, recyclers)
- collection & inspection of casing (use criteria, e.g. age, no damages)
- technical quality standards, certification & labelling systems ensuring performance, safety, and independent quality control of retreaded tyres.

The implementation would mainly require *regulation* followed by *awareness-raising*, *innovation*, *research*, *incentives,* and *certification/labelling*. The stakeholders considered responsible were *industry/business* and *government/administration*. Ten participants suggested positive external effects of retreading, and three considered it neutral. Resistance was not expected to dominate. The expected benefits and obstacles are given in Table 23.

Table 23. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing measures to promote retreading of tyres.

positive external effects	encountered obstacles/resistance
• increased sustainability (resource efficiency, circular economy, environmental footprint, less waste) • innovation stimulus (e.g. longer-lasting tyre casings) • chance to strengthen regional economy (collection/inspection, retreading-services) • support for developing countries • lower CO_2 emissions by retreading vs. production/disposal of new tyres (e.g. incineration)	• investment/cost for retreading facilities • too expensive (labour cost of collection/inspection/retreading) compared to new tyres • competition for end-of-life tyre materials: they should rather be used as a resource in the manufacturing of new tyres • market obstacles: lack of awareness and negative perception (e.g. quality concerns) • resistance from industry (selling less new tyres) • organisational hurdles: varying quality of used casings, structured collection/sorting needed • regulatory and standardisation gaps (lack of internationally harmonised guidance)

Monitor Human Exposure

Establishing long-term monitoring programmes for human exposure (e.g. respiratory, dietary) to tyre wear particles and related hazardous substances (incl. transformation products) did not score very high in the expert survey (stakeholder-average score: 14.5, see Figure 23). Only *academia* rated this measure very high (16.3), followed by *industry/ROI* (15.3). Workshop participants shared the following ideas on implementation:

- specify parameters & matrices for long-term monitoring and standardise (or use standardised) sampling & analytical methods
- use the momentum to take the problem seriously and promote research to establish limit-values
- direct stable public funding into long-term biomonitoring studies
- provide necessary data for health databases and define indicators for hazardous effects related to tyre wear particles & chemicals
- monitor various populations: control group, different exposure scenarios (e.g. urban/rural, occupational exposure, vulnerable groups), differentiate exposure routes (inhalation, ingestion)
- international/global data are needed; ensure the integration with existing monitoring frameworks and international data sharing.

Government/administration and *academia* were considered equally responsible for long-term monitoring campaigns. *Research*, *standardisation*, *awareness* and *regulation* were rated as most needed for implementation. Ten participants expected positive external effects of monitoring and three voted “neutral”, while resistance was not expected to dominate. The benefits and obstacles mentioned are given in Table 24.

Table 24. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing long-term monitoring programmes for human exposure.

positive external effects	encountered obstacles/resistance
• better understanding of exposure risks and pathways for informed action, e.g. future decisions/regulations • identification of additional risk factors and effects (e.g. traffic-related co-pollutants)	• financial burden • difficult to regulate and lack of standardised methods • difficult to find control groups (ubiquitous exposure)

Annex VI

Topic 3: Distribution via Dust and Measures at or Near the Road

Installation of Emission Retaining Roads

Emission retaining roads may be designed by

- *installing particle-collecting/trapping road surfaces (e.g. porous or permeable pavements), or*
- *adding absorbers to (permeable) asphalts that retain hazardous substances.*

Both measures did not reach scores ≥16 in the expert survey (see Figure 18 & Figure 21). Suggestions by workshop participants revealed that such measures would still require significant research & development:

- doubtful if it works, better collect dust & runoff by technical or biological retention
- find a proven solution: absorbers have a limited lifespan (e.g. ZOAB, used in the Netherlands, deteriorates with frequent frost)
- develop such surfaces, define the minimum lifetime and maintenance requirements and implement porous asphalt
- include new road surface type/absorbers in the guidelines and quality regulations for the use of asphalt under specific conditions (e.g. *Guidelines and Regulations, RVS, for Road Construction* in Austria, factsheets of the *Research Association for Road and Transport Engineering, FSGV*, in Germany).
- install such surfaces in new constructions or when roads need to be replaced (delayed effectiveness).

Government/administration and *provision of infrastructure/public services* were considered equally responsible for the potential implementation. The most needed tools for implementation are *innovation*, *research*, *construction/spatial planning* and *regulation.* Four participants expected positive effects to dominate and three participants the encountered resistance. A major anticipated positive effect is the capture of particulate and other co-pollutants. Obstacles are the high cost and delayed effect (time to replace road surfaces), technical limitations (resistance to wear and frost), potentially increased road & tyre wear by porous asphalt and increased noise.

Optimise Management of Banquet Materials and Roadside Soils

The *management of banquet materials (and roadside soils)* can be *optimised to retain tyre wear and related chemical emissions*, e.g by

- *preventing wind/water erosion of banquet materials (roadside soils),*
- *optimising the renewal frequency of banquet materials (roadside soils) to prevent tyre wear remobilisation and to avoid leaching and breakthrough of hazardous chemicals, or*
- *adding absorbers that retain hazardous substances (e.g. to banquet materials, roadside, or buffer-zone soils*).

These measures were not rated very high in the expert survey, except by *industry/ROI*, which considered them very good options (see Figure 18 & Figure 21). These measures were considered to require great efforts, considering the length of roads. As regards the potential implementation, ideas were to identify the lifetime and optimal renewal frequencies and integrate renewal into roadside management.

Government/administration and *provision of infrastructure/public services* were the responsible actors suggested, with *innovation*, *construction/spatial planning, regulation* and *administration* being requirements for implementation. One participant associated these measures mainly with positive external effects, three with obstacles/resistance, and two voted neutral. A positive effect may be increased road safety due to better maintenance. The obstacles mentioned included labour intensity and cost as well as high amounts of waste soil (treatment costs) and suggest that there are better solutions.

Prevent the Use or Disposal of (Potentially) Contaminated Materials in the Open Environment

Preventing the use (e.g. agriculture, landscaping) or disposal of (potentially) contaminated materials in the open environment: e.g. sewage sludge, (composted) roadside greenery, snow from roads, roadside soils,

soils/sediments/filter materials from decentralised road-runoff treatment facilities etc. was not highly ranked in the expert survey (see Figure 23). Workshop participants suggested that the use/disposal of contaminated materials should be banned, and clear regulations should indicate exemptions. This would require effective controls and fines. *Regulation* and *administration* would be most needed, and *government/administration* was considered responsible. Three participants expected positive external effects, three voted neutral, and one considered resistance/obstacles dominant.

The benefits include a healthier environment and better control of what is disposed of in the environment, the main obstacle mentioned was an increased bureaucratic burden and high additional costs (analysing materials, waste management/treatment cost etc.).

Annex VII

Topic 5: Interactions – Tyre, Vehicle, Road, Driving

Promote Lighter (Smaller) Vehicles

In the expert survey, only *academia* rated the *promotion of lighter (smaller) vehicles (without compromising safety) to reduce tyre wear* quite high (score ≥16), the other stakeholders were more critical. Workshop participants mentioned the following ideas to operationalise this measure:

- generate a lucrative market (consumer desire for lighter/smaller vehicles), inducing industry-driven innovations, using new materials & technologies
- promote smaller/lighter cars, e.g. by limiting the number of large parking spaces in cities and offering a greater number of small spaces, or by defining zones which only compliant cars are allowed to enter.
- change people's mindset (status symbols etc.) by awareness-raising or incentives ("lighter" is probably more accepted than "smaller")
- regulate vehicle weight by class/type (prohibiting excessively heavy vehicles) in combination with international standards on safety, and ensure the execution of laws
- autonomous driving allows for lighter (smaller) vehicles, while keeping safety standards high

- weight reduction is always a goal of industry; lowering top-speed limits could help reduce the weight of cars without compromising safety.

The suggested primary implementation needs comprise *awareness raising*, *incentives,* and *regulation*, supported by *innovation*, *standardisation*, *certification/labelling*, and *disincentives*. *Government/administration* and *industry/business* were considered the main responsible actors. The implementation of this measure was considered quite beneficial (beyond tyre wear) by seven participants and associated mainly with difficulties by two participants. Details on these perceptions are given in Table 26.

Table 25. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing measures to promote lighter (smaller) vehicles to reduce tyre wear.

positive external effects	encountered obstacles/resistance
• general benefits of optimal tyre-vehicle-road-driving interactions (Table 14) • less space needed for parking (in case vehicles are also smaller)	• measure opposes the trend of increasing vehicle size (e.g. popularity of SUVs) • economic benefit of selling big/heavy and more expensive cars • hard to change people's mindset or perception: a big car is a status symbol for many people (ego issues), and heavy cars are associated with safety • for many use cases, there is a need for larger (heavier) vehicles; restrictions may cause unjustified disadvantages (e.g. larger families, transporters etc.) • lack of technology and innovation to significantly reduce weight without compromising safety

Annex VIII

Topic 6: Mobility Transition and Traffic Reduction

Reduce Freight Transport on the Road

Reducing freight transport on the road, e.g. by shifting it from the road to rail and ship transport, or by promoting local (regional) sourcing, was not given high priority in the expert survey (see Figure 9). Workshop participants had the following ideas regarding the potential implementation:

- direct public infrastructure investment to promote a shift, e.g. enhance the competitiveness of rail transport by increasing the capacities for freight transport and the flexibility of rail transport
- consider which goods are suitable for which kind of transport and ensure effective logistics (transport mix is always required)

- introduce taxes or fees for freight transport on the road and incentives for rail or ship transport
- develop standards and regulations for public procurement to use local/regional products and clearly define “local/regional”
- raise awareness of consumers for local/regional seasonal food
- provide economic stimuli to promote local/regional sourcing (counteracting low wages in other countries & low transport costs).

For the implementation of this measure *regulation*, *construction/spatial planning, disincentives* and *incentives* were rated as most important. The suggested responsible actors were *government/administration* and *industry/business*, followed by *provision of infrastructure/public services*. The implementation of this measure was associated with positive external effects by four participants s and considered “neutral” by one participant. Expected concerns and benefits are listed in Table 26.

Table 26. Potential positive external effects (beyond tyres) and encountered obstacles/resistance when implementing measures to reduce freight transport on the road.

positive external effects	encountered obstacles/resistance
• general benefits of traffic reduction measures (Table 18) • local sourcing benefits the local economy • more social sustainability (frequent precarious employment conditions of truck drivers as opposed to train drivers; fair wages through locally sourced products) • greater auto-sufficiency through regional/local sourcing (less dependence on other countries and impacts of political instability etc.)	• not possible for all goods • rail transport is less flexible and not competitive with road transport • resistance of stakeholders and big economic players wanting to maintain profits • lack of rail infrastructure; cost for expansion • lack of political will (if industry is “burdened” with restrictions)

Adapt/Enforce Speed Limits

Adapting driving speed to lower tyre wear may be achieved by

- *reducing/optimising speed (e.g. regarding road surface conditions & topography, curve radii/inclinations)*
- *ensuring the enforcement of existing/adapted speed limits (stricter controls)*
- *installing traffic-calming (speed-limiting) construction measures*.

All these measures did not achieve a stakeholder-average score ≥16 in the expert survey (see Figure 13), but the last one was highly rated by two stakeholders (*academia* and *NGOs*). Two workshop participants shared specific recommendations on these measures: focusing them on areas with high tyre wear emissions, forming political will, and reducing speed limits with strict enforcement. *Regulation*, *awareness-raising*, *disincentives*, *administration*, and *construction/spatial planning* were rated as most important for potential implementation, and *government/administration* and *provision of infrastructure/public services* were identified as the main responsible actors. Three participants associated positive external effects with the potential implementation, and one participant considered it neutral. Positive effects mentioned were those given in Table 18. Expected obstacles comprise the perceived loss of personal freedom of drivers and some extra travel time, the lack of acceptance of lower speed limits, and the lack of political will (fear of losing voters).

Educate Drivers on Smooth Driving

Educating drivers on smooth (low tyre wear) driving style (e.g. by information material, training etc.) did not reach a stakeholder-average score ≥16 in the expert survey (see Figure 13), but *industry/ROI* and *NGOs* rated it very high. Two workshop participants shared the following suggestions regarding the potential implementation: foster awareness raising on the environmental impact of tyre wear and the education/training of learner drivers on smooth driving in driving lessons and exams. This is already part of the lessons but could be intensified. Considering the requirements for implementation, *awareness raising* was ranked top, followed by *regulation, administration, incentives*, and *disincentives*. *Government/administration* and *representations of interest* were considered the main responsible actors. Three participants assumed positive external effects of implementation, and one participant voted "neutral". The mentioned benefits correspond to Table 18. Since driving lessons (at least to some extent) already educate drivers, the measure may not be very effective.

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