



# Strategic Research Agenda

## Input to 10<sup>th</sup> EU Framework Programme

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## Disclaimer

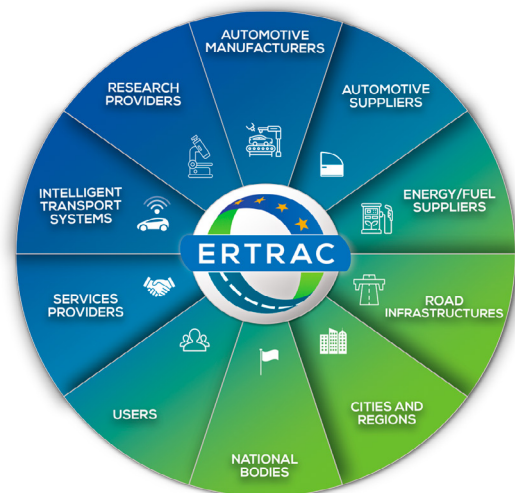
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## Reminder about the author

ERTRAC is the European Technology Platform gathering together all the actors within Road Transport Research. Its uniqueness lies in its public-private, multi-stakeholder nature: involving industry, academia and research providers together with public authorities at national and local levels. ERTRAC works in close cooperation with the European associations that represent the different components of road transport. It has also developed collaboration with other European Technology Platforms. Of course, the work of ERTRAC is also organised alongside the needs and recommendations from the European Commission services.



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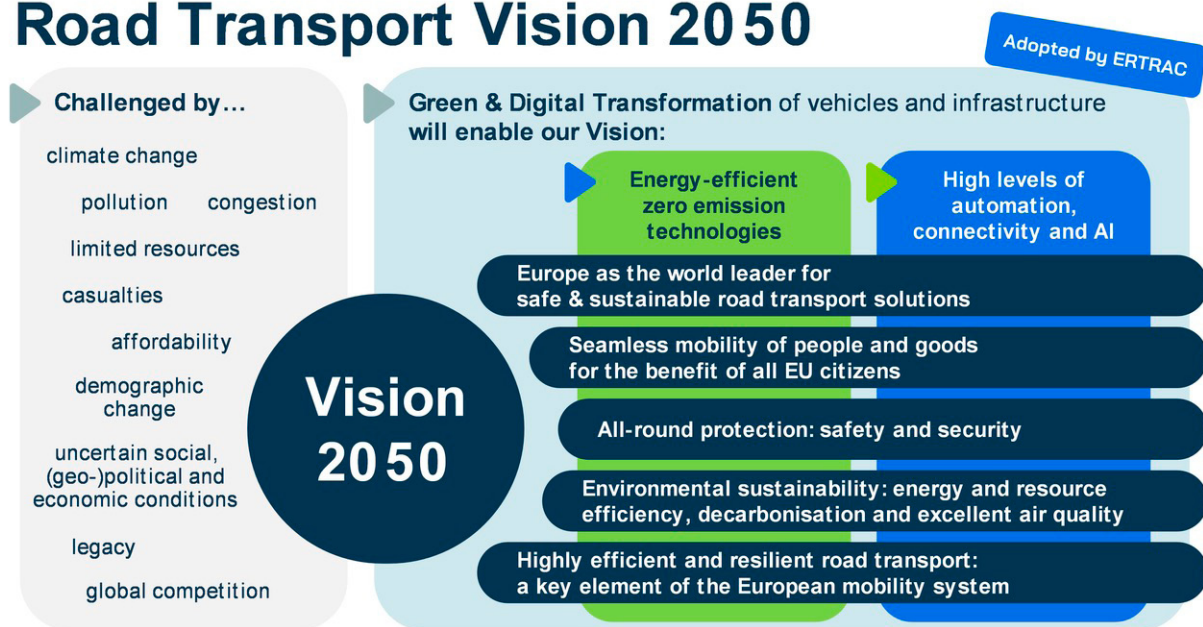
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# Introduction

The Strategic Research Agenda (SRA) is the key document of ERTRAC to prepare the next European Research Framework Programme. The previous version was published in 2018 in preparation for the Horizon Europe Programme. This new version supports the development of the 10<sup>th</sup> EU Framework Programme (FP10); therefore, it provides Innovation challenges and Research and Development topics for the timeframe 2028-2035.

The document is structured in seven chapters based on the latest Vision of ERTRAC<sup>1</sup>, which provides long-term objectives for the improvement of road transport until 2050. **This approach is a way to anchor the road transport system research work into the societal needs of Europe.** Compared to the previous version, this new SRA looks closer at the Green and Digital transformation of the transport system, through the application of energy efficient zero emission technologies plus high levels of automation, connection and artificial intelligence (AI). Potential impacts of the research work needed are also mentioned in this document, as well as some consideration of the barriers to deployment of the research and innovation results and the framework conditions for the organisation of such research.

## Road Transport Vision 2050



**Figure 1. The ERTRAC Vision 2050<sup>1</sup>**

Thus, in preparation of FP10, ERTRAC highlights the important opportunities from the upcoming innovations in road transport: major transformations are underway in the European mobility system, with electrification, automation, digitalisation and the circular economy. **Europe must act together in order to exploit the potential of these transformations:** to develop Europe-wide solutions answering societal needs, reestablish technology leadership and maintain research excellence, production and jobs in the Union.

One important remark is that these research efforts must be undertaken in the short and medium-term, in order to obtain market introduction from 2035 onwards, and become mass market thereafter, transforming the complete system by 2050. **So, there is a direct link between the research work to be done during the 10<sup>th</sup> EU Framework Programme and the achievement of the transport objectives of the ERTRAC Vision for 2050.**

<sup>1</sup>See the "Future Research Needs in Road Transport", STREnGth\_M project, Deliverable 2.1, December 2024, [https://www.ertrac.org/wp-content/uploads/2025/06/STREnGth\\_M-D2.1-Future-Research-Needs.pdf](https://www.ertrac.org/wp-content/uploads/2025/06/STREnGth_M-D2.1-Future-Research-Needs.pdf)

ERTRAC also calls for a well-balanced, technology neutral funding programme, addressing the different levels of research and development activities: from fundamental, long-term research to applied research and up to support for deployment. Supporting implementation of innovative products and services will have a key role for topics such as electrification and automation, where user involvement and testing in real conditions are critical aspects. **European pre-competitive collaborative research has a very high added-value since it brings together the many private and public stakeholders who are involved in transport:** working together, developing partnerships and implementing cross-sectoral collaboration - these are important assets to speed-up the transformation process in Europe.

Therefore, ERTRAC welcomes the preparation within the next EU Multi-Annual Financial Framework of a European Competitiveness Fund that will include both a continuation of the Horizon Europe programme to fund R&D and additional support tools to accelerate the market deployment of innovation. In the field of road transport, it is expected that a new Partnership will be implemented to coordinate R&I efforts and support the competitiveness of the European automotive sector: This comes as a concrete action in the context of the “**Industrial Action Plan for the European Automotive Sector**” published by the European Commission in 2025. The EC has set up an expert group on “European Union Research and Innovation for the automotive sector (EURIAS)” to provide input to this initiative. While being very supportive of the setup of this Partnership, ERTRAC calls to ensure that it will be complemented by continuous funding for Road Transport Research in the standard Work Programmes of Horizon Europe to address R&I needs that will not be fully covered by the Partnership. The new ERTRAC Strategic Research Agenda presented below offers a comprehensive input and can serve as a source of R&I topics for both the future automotive Partnership and the standard programme.

## Executive Summary

The Strategic Research Agenda (SRA) outlines ERTRAC’s Vision for the European road transport system in 2050 and summarizes the road transport research topics derived from this Vision. These are intended as input for the 10th EU Framework Programme (FP10) covering the timeframe 2028-2035. The SRA emphasizes the need for transforming the European road transport system and for re-gaining leadership in safe, sustainable mobility through innovation, digitalisation, and circular economy principles by fostering a robust ecosystem that supports sustainable growth.

Research topics with particular potential to drive transformative change are highlighted under the respective headlines of the ERTRAC Vision 2050 in the following:

### Europe as the world leader for safe and sustainable road transport solutions

To reinforce Europe’s leadership in road transport innovation, attractive framework conditions for research and education are needed, along with harmonised curricula and career models for life-long learning, while mastering global competition in a socially responsible way that strengthens EU sovereignty and competitiveness. For 2028–2035, research should focus on the following areas: urban mobility in international cooperation, developing guidelines, programmes and hubs for capacity building, knowledge exchange and financing concepts aligned with EU institutions. Furthermore, a global assessment framework for Infrastructure–Vehicle Cooperation (IVC) is needed that integrates economic, safety, environmental and quality-of-life impacts, compatible with existing tools, fairly allocating costs and benefits, and supporting climate-neutral, data-driven traffic management. In addition, a focus has to be given to digitalised battery research using advanced multi-scale, multi-physics and AI-supported models and digital twins to optimise materials and accelerate development from cell to pack level. Finally, a circular automotive economy is needed, based on digital infrastructure as well as reverse supply chains, circular business models, design for circularity and robust standards for reused and refurbished components to enhance Europe’s resource sovereignty.

## **Seamless mobility of people and goods for the benefit of all EU citizens**

Research topics aim to promote seamless mobility by integrating various transport modes (i.e. walking, cycling, shared and public transport, private modes) both physically – through the creation of multimodal hubs - and digitally – underlining the importance of robust data infrastructure and secure data sharing among stakeholders. Appropriate land use and public space distribution as key-enablers for seamless mobility are suggested to be studied. The agenda stresses understanding diverse EU contexts, from urban, peri-urban to rural areas, to design efficient multimodal systems for travel of people, but also for the movement of goods. Impacts of higher-level automation and infra-vehicle communication on seamless transport should be part of the research too.

## **All-round protection: safety and security**

ERTRAC puts emphasis on enhancing road safety through Connected Cooperative Automated Mobility (CCAM) technologies, particularly in rural areas where a significant portion of road fatalities occurs. The SRA also calls for fostering the digital transition in safety verification and validation to enhance significantly the coverage of safety-relevant scenarios while accelerating development times. Reliable, harmonised data is needed for this transition as much as for predictive road safety management and for the evidence-based prioritisation of road-safety measures. Road safety in a circular economy is included as another challenge that future research needs to address. It also emphasises cyber-physical security and civil preparedness, aiming at resilience against potential disruptions or attacks.

## **Environmental sustainability: Energy and resource efficiency, decarbonisation and excellent air quality**

The ERTRAC SRA highlights the necessity of transitioning towards a sustainable road transport including zero pollutions and 100% renewable energy and materials. Research is required on energy infrastructure, vehicle concepts, societal support and all related technologies of the mobility products. The development and use of digital tools like AI is emphasised to support all phases of life of systems, from the development to the use phase up to the end-of-life. Circularity and recycling are a key topic for research. Furthermore, the SRA discusses innovative approaches to electric energy delivery systems that support demand-responsive mobility models tailored for rural areas.

## **Highly efficient and resilient road transport: a key element of the European mobility system**

The SRA prioritises creating resilient physical infrastructures (including charging/ refuelling) capable of adapting to future vehicle generations while fostering cross-sector coordination between transportation systems. Key areas include developing predictive maintenance strategies using AI-driven monitoring tools alongside innovative materials designed for durability and reduced carbon footprints in road construction. Moreover, it seeks to integrate next-generation vehicles with smart infrastructure solutions that optimize traffic management effectively across various environments, ensuring sustainable operations amidst evolving technological demands.

## **Cross-cutting enabling factors and systemic research needs**

Effective governance frameworks are essential for fostering collaboration among diverse stakeholders involved in sustainable mobility initiatives across Europe. The SRA promotes co-creation practices involving public authorities, private stakeholders and citizens during the development aimed at enhancing the transportation systems' resilience. Furthermore, it highlights the importance of training programs designed to equip stakeholders with necessary skills while establishing harmonized evaluation methodologies across regions ensures consistent impact assessments related to environmental sustainability.

The ERTRAC SRA also identifies systemic road research needs, reflecting the complexity of the road transport system and interdependencies between individual research needs. These systemic research needs address amongst others the challenges to achieve seamless and inclusive transport by integrating



all modes in planning and payment systems while aligning stakeholder interests. To foster sustainable mobility, the need for transparent cost structures is included that account for external costs, ensuring competitive pricing for eco-friendly options. Other systemic research needs include creating a digital mobility ecosystem, understanding user behaviours, encouraging societal support for rapid changes, optimizing the use of resources through renewable materials, managing traffic intelligently, enhancing resilience against climate change impacts, and developing new approaches to master global competition in a responsible and social way strengthening EU sovereignty.

Finally, the ERTRAC SRA also identifies barriers for the deployment of research results and gives clear recommendations for favourable framework conditions for R&I. These recommendations include speeding up the whole process from drafting calls for proposals to the start of related projects, having more focus in call topic descriptions, having a stronger focus on the realism of project objectives and considering to a larger extent the capability of project consortia to finally deploy project results in the evaluation phase of project proposals.

## 1. Europe as the world leader for safe and sustainable road transport solutions

### VISION 2050:

**“Europe’s road transport research and industry as the world leader in innovation, services and production.”**

- **EU industry driving the green & digital transformation of the road transport system with speed and agility.**
  - Major value creation through vehicle production, including vehicle software, in Europe’s value chain.
  - *Resilient supply chains, particularly the electronics supply chain* for European sovereignty and sustainability whilst including critical materials and components, such as those needed for permanent magnets, batteries and semi-conductors.
  - European network for customer-oriented transport and logistic services (*MaaS and TaaS made in Europe*) with the Physical Internet realised in logistics.
  - Competitive production and road transport services contributing significantly to the EU’s *prosperity*.
  - Mastering the transition of the automotive industry towards a *circular economy*.
- **Europe being home to a highly attractive, well-functioning job market in road transport.**
  - *Europe as the first choice* for world-leading researchers, innovators, experts, entrepreneurs and the skilled workforce, enabled by an established innovation eco-system in road transport.
  - *Excellence in education, research and training* for all required skills and competences.

## Relevant system research needs

Various System Research Needs have been identified, these are given in detail in Chapter 7. However, those System Research Needs relevant to this topic of the 2050 Vision, that is, “Europe’s road transport research and industry as the world leader in innovation, services and production” are related to the necessity for:

- Advancing Europe’s leadership in road transport innovation
- Attractive and innovative framework conditions for research and education
- Harmonised curricula and professional career development models for life-long learning
- Master global competition in a responsible and social way to strengthen EU sovereignty and competitiveness.

## Research topics 2028–2035

### Urban mobility in international cooperation (UM)

Development of guidelines for the planning and implementation of programmes and hubs for capacity building, knowledge exchange and creation, encompassing different stakeholders, exploration of political, governance and financial solutions in coordination with EU services and public development banks for long-term impacts.

**Global assessment framework for benefit-driven use cases of Infrastructure-Vehicle-Cooperation (LDFT)**, which would combine the impacts in all domains: economics and business, safety for the drivers but also the other road users, environment (emissions, noise etc.), life quality (acceptance for drivers, impact on other road users etc.) etc. In particular, the impact on business and economics has to be considered carefully to:

- Develop a framework which is compliant with analyses and tools that are already used by the various stakeholders (Total Cost of Ownership (TCO) by OEMs, Life-Cycle Analysis (LCA) by road authorities).
- Make it possible to define the shares of investments and benefits between the stakeholders. This is a critical task as some stakeholders will have higher investments than others, and the process should be equitable to bring forward the real implementation of Infrastructure and Vehicle Cooperation (IVC).
- Implement a tool making it possible to apply this assessment in a practical way, for different stakeholders. For example, the particular issues of metropolises, where climate neutrality might be the most important factor, have to be taken into account. This implies that the assessment should make it possible to introduce weighting factors and provide decision making help. For example, cities would want an assessment of the status of the infrastructure and advice for decision making in achieving their climate neutrality. For example, “How should I invest or update my infrastructure to reduce the CO<sub>2</sub> emission in my city?”
- This research can then assess *how IVC can support proactive road traffic management that can facilitate transport planning, monitor and forecast energy requirements, predict accident risk and facilitate automation*. This will be accomplished by integrating real-time traffic data, infrastructure information and historical data, supporting real-time operations, maintenance and investment decisions.

Therefore, the core work will be defining proper measurements units and indicators, which will assess the expected impacts at all levels of the transport system and, in particular, some of which will accelerate decarbonization and bring positive effects on global health and safety.



### Leadership in Battery-technology using digital solutions (E&E)

Advanced, *virtual development of batteries* is one of the key pillars for strengthening position of the EU in the battery value chain. Therefore, in addition to the overarching digitalisation topics, a large leap forward is required in specific areas of the virtual development of batteries:

- Development of innovative, fundamental, multi-scale, multi-physics and AI supported models to enable accelerated optimisation of material combinations and interfaces, as well as for the design of electrodes and electrochemical cells;
- Development of innovative, scale-bridging approaches to successfully transfer key aspects from lower-scale models to continuum-scale multi-physics models applied in cell, module and pack engineering, as well as to advanced digital twins with an aim to boost the KPIs of prototypes and final products.

### Digital Infrastructure for a Circular Economy (C&C)

The automotive industry's transition to a circular economy relies on digital technologies, such as IoT, block-chain, AI and digital product passports, to ensure a circular economy value chain. However, the automotive sector is still facing a slow adoption of Digital Twins and Digital Product Passes, incomplete or outdated digital infrastructures enabling track and trace of components and vehicles for efficient EoL processes, or a lack of standardised data and interoperability across the different stakeholders. To overcome these challenges, among other aspects, research is needed on:

- Standardisation of Data Formats and Protocols as well as on Blockchain and Distributed Ledger Technologies;
- Digital Tracking and Tracing Technologies of Vehicles; or
- Advanced AI and Machine Learning for Component Health Monitoring, Dismantling, Sorting and Recycling.

### Reverse supply and value chains enhancing European's resource sovereignty (C&C)

The automotive supply chain is extensive and often global, making it difficult to implement circular practices consistently across all levels. Ensuring that all suppliers adhere to circularity principles and sustainability standards can be a significant challenge. This includes establishing a reverse logistics for EoL vehicles and value generating EoL strategies including reuse, remanufacturing or upgradability. Research should include:

- Business model innovations supporting circularity while ensuring consumer acceptances and market demands;
- Advance supply chain management complying with demands for circularity;
- Design and manufacturing for Circularity, uptaking secondary or green materials;
- Quality and Safety Standards for Reused, Repaired and Refurbished Components.

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## 2. Seamless mobility of people and goods for the benefit of all EU citizens

### VISION 2050:

“All people and goods can reach their destinations in a way that is healthy, safe, affordable, reliable and comfortable all across Europe.”

- **Seamless multimodal transport solutions available and attractive to all, giving users the freedom to choose.**
  - *Fully multimodal Mobility as a Service* offering, satisfying the requirements of affordability, reliability, resilience and overall trip quality.
  - Digital assistants & other services providing a *seamless experience to the user, including trip planning, pricing and payment*.
  - *Walking, cycling, collective and shared transport services forming the backbone of urban mobility*.
  - Motorised individual transport complementing this backbone where needed, e.g. giving access to mobility hubs.
  - Appropriate infrastructure supporting *healthy mobility, thanks to active modes* (walking and cycling).
  - *Information for the user* about the environmental impact and costs of all modes of transport, *including an indication of external costs*, encouraging sustainable mobility behaviour and supporting a “*pay as you use*” basis for mobility services throughout Europe.
  
- **Mobility concepts for people and goods are optimized to ensure the quality of life for all citizens.**
  - Geographic areas with different population densities *seamlessly connected* by optimal utilization of private and/or shared vehicles, public transport and convenient multimodality, supported by appropriate territorial integration and respecting the demographic, geographic, cultural and economic characteristics of different EU regions.
  - Connected and automated vehicles enabling *full inclusion of all users* in the mobility system, with a particular attention to children, people with reduced mobility and an ageing population.
  - *Smart multimodal logistics*, providing resilience and efficiency - including infrastructure capacity management for people and goods.
  - Intelligent solutions allowing the *rebalancing of land-use* thus improving the quality of life of citizens.

### Relevant system research needs

Various System Research Needs have been identified, these are given in detail in Chapter 7. However, those System Research Needs relevant to this topic of the 2050 Vision, that is, “Seamless mobility of people and goods for the benefit of all EU citizens” are related to the necessity to:

- Ensure the seamlessness of mobility services while staying cost effective
  - Join forces for a well-functioning digital mobility ecosystem for people and goods, based on harmonised and interoperable standards
  - Have a cost structure to internalise external costs and finance sustainability
  - Improve the ability to understand and anticipate user roles, needs and behaviour based on existing and future values.
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## Research topics 2028–2035

### Intelligent rebalancing of land-use and urban space (UM)

The recognised yet complex relationship between mobility and the built environment can be studied at two levels, in order to be optimised. Firstly, there is the meso and macro scale of zoning and land-use planning. This includes studying how to address the different timespans when planning roads, infrastructure and buildings, which require long-term planning and investment, in comparison to rapid developments in vehicles, technology, and approaches to mobility management. Secondly, there is the micro-level issue of managing urban space. In addition, it should be investigated how to promote sustainable developments that enable a high share of active modes and public transport, by understanding real-estate developers' incentives and enabling co-creation processes. This means considering rapid technological advancements, all types of mobility and the existing urban space to allocate to them all, without forgetting the urgency of climate adaptation and mitigation - integrating urban space design tools that support these objectives. Governance, policies and technologies to address both levels of action must be further explored.

### Seamless mobility for all across the diverse EU contexts (UM)

Multimodality is vital for seamless mobility. For seamless mobility to become a reality both the physical and digital integration of different transport modes is a prerequisite. For physical integration, this means interchanges and mobility hubs, where the different modes come together and can be easily combined. Digital integration relates to the integration of the different modes offered in a digital ecosystem, e.g. MaaS. It is paramount to consider the diversity of contexts across the EU when talking about multimodal lifestyles. In addition to taking into consideration the different demographic, socioeconomic and cultural characteristics of each context, this also entails considering peri-urban areas and lower-density settings more seriously. To do so, further research on how to design and implement efficient multimodal systems and further attract users in these areas is needed, addressing the use of private motorised vehicles when necessary or small and light electric vehicles (LEVs) as feeders for multimodal hubs, and the efficient integration with Public Transport, for example. Research is needed with a system-wide approach that includes vehicles, users, infrastructure and regulations, which ensures safety and includes consideration of in-between, peri-urban and lower density areas.

This also requires promoting a robust mobility data infrastructure, which, through European, scalable data spaces, can allow voluntary, sovereign and secure data-sharing for effective collaboration between relevant public and private stakeholders. This will entail further research on how to achieve real digital collaboration between cities and operators, encouraging data-sharing and developing data governance regulations that facilitate the task at hand, ensuring that MaaS priorities align with sustainability and societal challenges. Research should also support the development and integration of standard steps within the processes of transport planning that assess inclusivity and accessibility for all.

Research into SSH dimensions of multimodality such as affordability, and how cost structure, incentives and regulatory flexibility influence the usage of multimodal system, as well as demand-side instruments (cfr infra suggested activities on pricing and access management).

### Integrating active and healthy mobility in the multimodal transport system (UM)

Active mobility brings benefits at individual and collective levels, with positive impacts on individual's health and, at the same time, it is the cleanest way of moving around. Active mobility requires integration with public transport, as that is a key component of sustainable first and last-mile solutions. Furthermore, active transport solutions can support the delivery of goods through technological innovations, such as cargo e-cycles. To this end, it is necessary to strengthen research on how to improve planning, infrastructure and technology, supporting the integration of active modes and LEVs, in addition to exploring mobility management policies to support them, so that they become a priority in multimodal systems. Understanding how urban planning enables, supports or undermines active mobility is also necessary, considering the overall positive contributions to society, such as reductions in transport related pollution, the health and environmental benefits.

## Smart and multimodal freight and logistics (UM)

Urban logistics are a key component of mobility in cities. In addition, due to urbanisation and digitalisation there have been changes in delivery patterns, with deliveries becoming more frequent, smaller in size and direct to consumers. Improving coordination between businesses and public authorities should be researched, to mitigate negative impacts on the economy and society. How to better achieve cleaner deliveries should be investigated as well, focusing, for instance, on how to get businesses to adopt more eco-friendly practices, with the aim of achieving zero-carbon logistics. This includes further research on integrating lower and zero-carbon options as part of multimodal logistics solutions, including LDVs, new small vehicle classes and cargo bikes. Research is necessary to overcome barriers to achieving next generation LaaS ecosystems, to ensure seamless mobility for goods, and is necessary to optimise services and reduce congestion in urban areas as well as at urban-regional level.

The **impact of IVC on humans (drivers, road users, logistics and the population in general)** (LDFT) needs to be investigated, in terms of:

- The impact on truck drivers, including how the role of the truck drivers will change: it is necessary to understand what the driver can be doing to facilitate and prepare for the future. The impact is quantitative (because of the shortage of truck drivers and, therefore, the business side of the equation) and qualitative (what tasks can be done, acceptance of automation and/or even more the daily job of truck driver etc.).
- The safety of the redefined system.
- The role of the other workers in the whole ecosystem: for example, what will the impact on logistics workers, whose work will be more and more online, be? As a consequence, what will be the role of national road administrations linked to data management and analysis?
- How will the new energy carriers and technologies reshape the future logistics patterns? What will be the re-arrangement of fleets, how will workers and entities cope with change?

## Evolution of competitive European Large-Scale Demonstrations towards broader ODDs, higher speeds, supporting deployment, replication and innovation in balance with user and society demands (CAD)

Framework conditions for Large Scale Demonstrations. The target for such demonstration projects is that technical standardisation shall be supported and type approval, as well as road regulations and all operational aspects, standardised, interoperable vehicle-human-infrastructure interfaces, building on cooperation models between stakeholders required to address the logistics sector, shall be developed. Further, there must be demonstration to deliver a trusted framework for users and infrastructure, demonstrating value for users as well as mobility and logistics companies. Finally, the demonstration site shall have a sustainably improved situation after the project has ended, with good insights of the value streams for users and society, so prepare the stage for ideally directly following commercial deployment of parts of the services demonstrated.

## SAE L3/L4 driving on highways (CAD)

This use case is expected to deliver full highway driving from entry to exit and at up to maximum speed limits, including lane change, lane merge, tunnels and all types of roadworks. Degradation steps with lower speed and reduced functionality and minimum risk manoeuvre in a safe location would enable this.

During the research phase, use cases will focus on small-scale demonstrations with more complex traffic environment and activities. Furthermore, research use cases will include cooperative approaching scenarios such as vehicles, construction sites (more complex road works signalling) and motorway ends. Enhanced, AI-supported sensor data fusion, making use of Global Navigation Satellite Systems (GNSS), inertial sensor technology MEMS (Micro-ElectroMechanical Systems) and V2X, are also addressed. Infrastructure support will be investigated to develop a trusted framework. Motorway chauffeur with support of negotiations for on-ramp sections is included.



More example Use-Cases requiring further research, innovation and demonstrations are: L3/L4 vehicles commuting in mixed traffic, L4 truck safe hub-to-hub operation in mixed traffic between terminals, residential automated last-mile transport of people and goods, with regard to urban space sharing and curb management, on-demand automated shared shuttle services on routes in mixed traffic, automated municipal services plus services for highly automated driving in rural areas, enhancing inclusiveness.

### 3. All-round protection: safety and security

#### VISION 2050:

**“Safe and secure mobility for all road users at any time.”**

→ **No-one becomes the victim of a road crash anymore.**

- *Vision Zero* achieved: Zero fatalities nor severe injuries.
- *Nearly zero crashes and injuries* as a consequence of high levels of road safety culture all over Europe, making full use of various levels of automation and complementary safety functions as well as safe road infrastructure design principles.
- *High levels of in- and post-crash safety* in the remaining collisions.

→ **The security of citizens is ensured in both the digital and the physical world.**

- *Secured trustworthiness* of AI and data management in road transport as well as data privacy.
- *High levels of protection against crime and abuse* in road transport.
- The road transport system contributing to *civil preparedness* to military attacks.

#### Relevant system research needs

Various System Research Needs have been identified, these are given in detail in Chapter 7. However, those System Research Needs relevant to this topic of the 2050 Vision, that is, “All round protection: safety and security” are related to:

- Data collaboration to support safe and secure fully connected road transport

#### Research topics 2028-2035

##### Unleashing the potential of CCAM to enhance road safety in rural areas (CAD + S&S)

More than 50% of all EU road fatalities occur in rural areas and more than half of those fatalities are car occupants in collisions with other cars, commercial vehicles or with no other vehicle involved. These crashes could be avoidable, largely, by using CCAM technologies: Therefore, it is in rural areas where CCAM shows a particular potential to improve road safety significantly. At the same time, this domain presents the biggest challenge for the deployment of CCAM, combining high vehicle speeds with full traffic complexity, with, even in the long-term, limited coverage of digital infrastructure (mobile network, high-definition maps etc.). Accordingly, further research is necessary on enabling technologies to overcome these challenges, in technology integration and validation, as well as boundary conditions for viable business models for CCAM in rural areas. Once sufficient technology readiness will be achieved, demonstrations should also verify the positive contributions to inclusiveness and accessibility that are expected from CCAM in rural areas, including the accessibility of urban and peri-urban areas for the rural population.

### **The digital transition in safety verification and validation (S&S)**

For all levels of automation, virtual testing will move far beyond today's safety verification and validation schemes, with the efficient coverage of relevant scenarios in limited time. Research will have to address the verification and validation of new types of AI for safety-critical vehicle functions as well as the use of AI for digital twin-based validation methods. A European network of high-fidelity dynamic driving simulators will be useful both for testing systems in critical scenarios with the human in the loop and for deriving driver behaviour models, which can then be used for the virtual verification and validation of systems. Leveraging a predictive safety assessment framework, research should pave the way towards the ex-ante evaluation of all measures for collision prevention before their actual deployment.

Moreover, the availability of large data sets and new types of data sources (including event data recorders) should allow research to provide rapid feedback on the effectiveness of new safety technologies after their deployment in real traffic. This will facilitate informed policy making guided by evidence-based comparative effectiveness classification of safety measures. In addition, practical frameworks and toolkits are needed to enable timely, audible sharing of incident data while preserving GDPR compliance and data sovereignty. This will enable amongst others the accelerated learning of automated driving systems, in particular if applied to all sufficiently equipped motor vehicles on EU roads.

### **Predictive road safety management based on reliable, harmonised data (S&S)**

The availability of large data sets from multiple sources in the road transport system will in future facilitate in-depth crash causation analyses, rapid ex-post effectiveness analyses of new safety measures as well as the training and validation of AI-based safety systems. In addition, such data and their AI-based analysis will allow real-time predictions of road users' intentions and associated collision risks. This can draw from Surrogate Safety Measures (SSMs), measurable indicators of risk based on proximity, speed and similar kinematics. Once AI systems drawing from SSMs will have been established, targeted interventions can be made in an intelligent transport system, which do not have to be limited to the onboard activation of vehicle-based crash avoidance systems. Important challenges still need to be overcome, e.g. with regard to the accessibility, reliability, harmonisation and quality assurance of relevant data at a sufficient level of granularity, in particular from real-world incidents. In the long term, R&I should go beyond the above-mentioned use cases, demonstrate the feasibility of targeted real-time interventions and move towards the real deployment of such services.

### **Evidence-based prioritisation of road safety measures and their integration in a sustainable road transport system (S&S)**

In a transport system becoming safer and safer it will become harder and harder to safeguard the investments which are still necessary to actually move towards Vision Zero. Research needs to investigate why safety measures with proven effectiveness are not taken-up or taken-up in a suboptimal way and how barriers for their implementation can be removed or avoided. Social sciences can shed light on what sort of problems, countermeasures, target groups, processes etc. require what approach, including approaches that can shift long-term behaviour, increase the acceptance of measures and improve traffic safety culture. In combination with an evidence-based comparative effectiveness classification of different safety measures, this should allow for evidence-based prioritisation and implementation of measures for specific road safety issues. Research should also provide new concepts for and best practices of how to integrate such safety measures in a sustainable road transport system, so that the objective of zero-emission mobility and the Vision Zero in road safety ideally reinforce each other.

### **Cyber-physical security and civil preparedness (S&S)**

Road transport is of key importance for the daily lives of EU citizens and for the European economy. Therefore, the EU road transport system deserves special attention with regard to civil preparedness to military attacks and hybrid warfare. Security-related research should analyse how to increase the resilience of the road network against malicious, coordinated disturbances of important nodes and transport corridors.



The cyber-security of all elements of the road transport system needs to be enhanced, including its links to the energy infrastructure, to prevent system breakdowns as well as the misuse of connected vehicles. Applied research is needed amongst others on end-to-end and cyber-security for V2X communication systems, roadside and onboard units, and other software-defined vehicle subsystems including security validation methods, threat modelling, intrusion detection, standardised interfaces and secure over-the-air updates. How to realise effective cross-border operational threat intelligence in the EU and supply-chain integrity for critical components are additional high-level issues in this context.

Research should also investigate how hardware in infrastructure can be better protected against manipulation and how physical road infrastructure can be upgraded most efficiently to best support military mobility within the EU. Furthermore, research is needed to find energy efficient and fast encryption methods for data sharing in real-time applications. Finally, new concepts should be developed how road transport can effectively support in responding to and recovering from disasters and emergency situations within the EU territory. New types of civil special purpose vehicles combining vehicle technologies with robotics may be part such endeavours.

#### **Road safety in a circular economy (S&S)**

The evolution towards a circular economy in road transport must fully integrate road safety aspects. Research should investigate how material use can be reduced through the lightweight design of vehicles for specific operational environments. Major advances are needed in design for disassembly, repair, refurbishment and remanufacturing, while respecting road safety as the paramount concern. The same applies to all efforts towards closed material loops and increased longevity of both vehicles and road infrastructure with all their components, including virtual methods to predict the lifetime of safety-critical components. Moreover, repurposing of components and significantly enhanced upgradability should be considered as chances to bring in line the benefits of rapid market penetration of safety innovations with prolonged life cycles of vehicle hardware components, to support circular economy principles in road transport without compromising safety.

#### **Inclusiveness in occupant protection and human-technology interaction (S&S)**

With Vision Zero to be achieved by 2050, occupant protection and the design of human-technology interaction need to advance towards higher levels of inclusiveness and towards higher levels of automated driving. Highly adaptive restraint systems should account for new seating configurations, reclined postures and diverse occupant profiles, including women, children, elderly passengers and persons with disabilities. A stronger focus will have to be put on the avoidance of severe injuries and long-term impairments, in addition to the need for further significant reductions in fatality figures. AI boosted development methods and tools for restraint systems and crash structures, making use of virtual Human Body Models, can support the development of inclusive countermeasures for injuries which are not detected by crash test dummies. The crash compatibility of vehicles in different mass ranges (including new vehicle categories) is another inclusiveness issue to be addressed.

While advanced occupant monitoring systems will support adaptive restraint systems, future occupant monitoring systems and the application of more extensive and sophisticated AI will also enable new designs of human-technology interaction. Human-machine interfaces (HMI) should become highly adaptive to users' individual cognitive and physical states, in particular in mixed traffic with different levels of automation, avoiding distraction, balancing cognitive load and ensuring comfort, comprehension and the usability of vehicle functions for all population groups. The harmonisation of HMI designs may improve particularly the effectiveness of important safety functions. Virtual reality or AI-based tools should be further enhanced to study human-technology interaction in highly safety-critical manoeuvres.

### **Road safety on two wheels (S&S)**

The road safety of bicyclists and powered two-wheeler (PTW) riders remains a major concern, especially with the emergence of the many new forms of mobility (e.g. micromobility, including delivery robots) that also make use of limited public space and interact with active mobility (pedestrians and bicyclists). Regarding cycling safety, ageing cyclists' behaviour, single vehicle crashes and protective devices are important issues to address. A large-scale naturalistic cycling study could reveal in-depth insights in relevant issues of cycling safety and deliver valuable information on the effectiveness of safety measures. Regarding the safety of PTW riders, their needs have to be better integrated in the Safe System Approach, especially with regard to CCAM, and their safe interaction with other road users as well as appropriate road infrastructure design. The potential of electrification to improve their safety should also be further investigated and exploited. Inclusive and effective awareness rising and training campaigns are crucial to promote risk awareness and safe behaviour of two-wheeler riders and other road users interacting with them. Finally, sound modelling of riders in interaction with their two-wheelers will be crucial in better understanding safety issues related to riding dynamics. Knowledge transfer from motorsports to consumer bicycles / PTWs could be considered concerning limit speeds and manoeuvrability.

### **Infrastructure design for road safety across diverse urban and rural contexts (UM + S&S)**

Due to larger distances and lower walkability, there is more reliance on motorised modes in lower-density urban areas, such as suburbs, and in rural areas than in city centres. In combination with poorer infrastructure for pedestrians and cyclists, this can result in additional injury and fatality risks for these largely unprotected road users and in particular for children as well as the elderly. Therefore, it is important that research addresses these infrastructure issues (i.e. unsafe zebra crossings, lack of lighting and traffic lights or appropriate speed limits) with a context-sensitive design approach. New approaches should be investigated for road infrastructure design based on human factors, supporting the safer behaviour of all road users and, at the same time, facilitating the deployment of CCAM also in lower-density urban and rural areas. New standards for interoperability should consider how vehicles equipped with automated driving functions will operate in these environments. Virtual reality tools boosted by AI should be further developed to provide trustable solutions for safer infrastructure design across diverse urban and rural contexts.

### **Innovative tyre designs and telematics to increase vehicle safety and reduce emissions (E&E + S&S)**

The tyre is the only vehicle component in contact with the road, and tyre/road characteristics define the envelope of safe vehicle dynamics for any type of road vehicle. Tyre designs are challenged by the relatively high mass of battery-electric vehicles and by the high torques which electric motors can generate. Research should focus on optimising grip under various road conditions, rolling resistance, wear, particle emissions and noise emissions in real-world use cases. Sensors in tyres can provide valuable information about the tyre and road condition and will enable crucial functionalities and services for safety, predictive maintenance and automated driving. New sensing technologies and applications should be developed, as well as methods to exchange this information between vehicles, road-side systems and cloud services with a sufficient level of confidence. Smart materials and additional sensors in suspension and brake systems may support such applications.



## 4. Environmental sustainability: Energy and resource efficiency, decarbonisation and excellent air quality

### VISION 2050:

“Climate-neutral, zero pollution road transport satisfying circular economy and resource efficiency needs.”

→ **Zero pollution from road transport, i.e.:**

- The rate of road transport-related air, water and soil pollution is reduced to levels no longer considered harmful to health and natural ecosystems<sup>2</sup>.
- *Significantly reduced noise emissions.*
- *Transparent accounting schemes of residual emissions* from the complete life cycles of vehicles and infrastructures, recognised as internalised costs of transport.

→ **100% renewable energy and sustainable<sup>3</sup> materials.**

- *Renewable energy supply balanced between sectors* (transport, industry, households and services) *and between transport modes.*
- *Resilient energy supply* and associated services anytime and wherever required according to usage needs in road transport, with smart charging/refuelling infrastructure supporting seamless zero-emission mobility.
- *Energy and material efficient* road vehicles as well as physical and digital infrastructures.
- *Resource efficient vehicle production* with minimum environmental impact.
- *Circular economy* for vehicles and infrastructure – based on the 9Rs (refuse, re-think, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover).
- Availability of *affordable vehicles* for the mass market, following the idea of right-sizing, giving customers the freedom of choice regarding use cases and vehicle sizes.

### Relevant system research needs

Various System Research Needs have been identified, these are given in detail in Chapter 7. However, those System Research Needs relevant to this topic of the 2050 Vision, that is, “Environmental sustainability: energy and resource efficiency, decarbonisation and excellent air quality” are related to the necessity to:

- Convince society of the necessity for rapid changes and investments in road transport
- Have fair global boundary conditions and reduced dependencies to enable sustainability
- Enable the holistic optimisation of resources by maximizing the use of renewable materials and energy.

<sup>2</sup> Definition of “zero pollution” according to EU Action Plan “Towards a Zero Pollution for Air, Water and Soil”

<sup>3</sup> “Sustainable materials” meaning materials which can be produced in required volumes without depleting non-renewable resources and without disrupting the established steady-state equilibrium of the environment and key natural resource systems.

## Research topics 2028–2035

### Energy infrastructures for clean fuels and vehicles (UM)

Governance tools, standards, smart funding mechanisms and stable policy frameworks are needed to enhance cooperation and confidence amongst all stakeholders of the urban mobility value chains:

- Provide start-up support through pilot projects, reverse pitches, access to hardware, prototype facilities and operational data
- Establish proven concepts and pilot activities of Positive Energy Districts, encapsulating the complementary mobility measures, such as shared mobility configurations, vehicle access regulations and multimodal and energy hubs

### LEVs – new vehicle concepts for urban use (UM)

Research is needed collecting and analysing evidence of successes and failures, and the necessary social, ecological and planning frameworks, including user acceptance factors and diverse user requirements, to support the uptake and rollout of new and innovative LEVs. This includes:

- Enhancing infrastructure, assessing proper road placement, traffic codes and safety standards, and exploring the safety of interactions with <25 km/h vehicles in dedicated lanes
- Assessing the existing legal framework and safety standards for the production and testing of LEV vehicles, related batteries and electronics to enhance consumer safety
- While there are numerous positive impacts of LEVs, further researching the impacts of the sourcing and disposal of materials, especially in regard to the batteries, including end-of-life collection, recycling systems and the recovery/re-use of materials
- Continuing research to support the development of affordable and frugal (not over-engineered) L5, L6 and L7 (or above) vehicles, exploring use cases (for personal use and logistics), and optimising safety aspects when integrated with other traditional road users

### Raising awareness on the real environmental and other external costs (UM)

It is necessary to further research how to effectively raise awareness of the environmental and other external costs of each mode of transport, in addition to financial costs to the user and beyond EU legislative frameworks, such as CountEmissionsEU. It must be investigated how cost structures can be made more transparent and understandable for end users and decision makers. This can help to ensure that sustainability is economically competitive. For the urban context specifically, the societal cost of the use of space should be assessed.

### Holistic optimisation of resources by maximizing the use of renewable energy (LDFT)

- Understand public charging opportunities, costs and framework conditions (aligned with driving and rest time rules). How to optimize charging utilization (profitability) with charging point availability (charging congestion), as well as route optimization considering charging (book a time slot, book&pay).
- Cooperation of vehicles with local energy networks: location of vehicle flows compared to energy/grid vulnerability/hydrogen: identify additional charging/fuelling spots needed
- Validate the system business case of dynamic charging, including energy system impact: define the most fruitful use cases, build scenarios for willingness to invest etc.
- Alternative business cases for vehicle when standing still (loading, charging, driver resting etc.): distinguish key differences in requirements for trucks when compared to passenger cars
- Design business models for energy delivery, flow and storage to the transport sector and vice versa (V2G/hydrogen)
- Low-emission mobility for rural and regional contexts. Research on energy-efficient, demand-responsive mobility models for low-density areas, alongside charging solutions suited to constrained grid environments and dispersed populations



### Encourage societal support for rapid changes and investments in road transport (LDFT)

- What would incentivize change for different types of end-users and make them use/buy/pay for decarbonized transport?
- What would be Innovative logistics decarbonization pathways, e.g. new logistics schemes, EMS2 and IoT cargos, trailers (/driver) swapping?

### New battery and convenient charging opportunities for different use cases: urban charging, high power charging, power transfer technologies (E&E)

In order to challenge pure ICE vehicles without compromising performance, PHEV and BEV will need short/medium/long range batteries and fast-charging ability. Compact, light and affordable batteries with better tolerance to extreme temperatures will be needed for attractive and energy-efficient cars. Defining chemistry and developing solutions aimed at performance beyond current Li-ion capabilities will be a challenge. Energy efficient batteries and their production, considering preservation of available resources, are also areas for improvement.

*Impact:* increased uptake of PHEV and BEV in order to contribute to climate change mitigation, air quality improvement, sustainability/preservation of critical materials.

### Highly efficient, fully electric battery powertrains and vehicles cars (E&E)

In order to meet mobility needs for private customers and transport tasks as well as reduced GHG emissions, it will be necessary to develop electric vehicles utilising all the available potential of increasing efficiency. R&D needs to include energy efficiency gains by smart and connected driving functionalities, lightweight construction and components with the lowest energy needs. Research should, therefore, improve the efficiency of electric motor and power electronics, such as new semi-conductors.

*Impact:* Increased uptake of BEV in order to contribute to climate change mitigation.

### Improved road construction solutions and road surface technologies (E&E)

The research needs to focus on the use of new construction methods (such as connected solutions, new processes) to lower the related carbon/energy footprint and to create a better durability. Additionally, the road surface needs research to integrate new materials (bio-components), compounds (rubberized asphalt) and functionalities (CO<sub>2</sub> and/or particle-absorbing roads) to actively contribute to less CO<sub>2</sub> and to better air quality.

### Adaptation of road infrastructure for future vehicles and operations (E&E)

- Design and equipment of charging and fuelling infrastructure for the next generation of vehicles.
- Development of infrastructure for automated parking and charging of autonomous vehicles
- Road infrastructure monitoring, diagnosis and maintenance, including vehicle on-board monitoring.
- Smart adaptive operation of vehicles for preserving the road lifetime.
- Smart Infrastructure Access Programme (SIAP-infra), parking lots design and management.
- Logistics solutions for regional-urban freight coupling, including consolidation centres, micro-hubs, electric cargo platforms and coordinated delivery timing to minimise peak-time energy and air-quality impacts

*Impact:* reduced infrastructure cost, extended lifetime, harmonized European networks.

### European approaches for green energy supply (E&E)

The research needs to address the standardization of the still crowded mix of charging solutions and charging billing techniques, to create a harmonised, user-friendly charging ecosystem all over Europe. Another focus of research is the European strategy for energy policy and distribution to minimise the

overall energy demand in combination with a maximum share of green energy in the grid. Energy-aware fleet operations and charging optimisation require research on smart, grid-synchronised charging for mixed public and private fleets (including non-standard and heavy vehicles), with dynamic pricing, load balancing and integration with distributed energy resources.

#### **Renewable, low carbon advanced fuels: low-cost sustainable production, storage and distribution (E&E)**

A key ingredient to future decarbonisation of the transport system, especially in the transition phase towards full electrification, will be the availability of low carbon advanced fuels and blending components, both liquid and gaseous, e.g. those produced from biomass, synthetic fuels using green electricity. Their production may potentially remove existing CO<sub>2</sub> from the environment, may occur exterior to the vehicle or on-board, e.g. reformers and on-board CCS, and they may be used for chemical storage of electrical energy. Higher quality fuels may also have the advantage of providing improved vehicle efficiency and reduced emissions through better combustion. R&D challenges will include more energy and CO<sub>2</sub> efficient ways of production of traditional and new fuels. Novel ways of storing and distributing these fuels may be desirable and the infrastructure to allow them to be freely available where needed whilst minimizing further emissions.

*Impact:* Near zero CO<sub>2</sub> WTW, allows availability of low carbon energy for sectors whether suitable for electrification or not.

#### **Second life, recycling and recuperation of materials including energy balance (E&E)**

EV batteries need to be produced sustainably and have potential for use in stationary units (e.g. homes and other buildings, charging stations, power plant peak support) after use in vehicles. At the end of life, EV batteries need to be dismantled and have high potential for reuse of the materials. The value brought by second life, recycling and recuperation is significant for the vehicle total cost of ownership (TCO) standpoint. Challenges include research into sustainable production, development of cost-effective processes to produce energy supply units based on reused automotive batteries including standards and advanced cost and energy efficient processes to extract rare materials for reuse (aluminium, copper, nickel and cobalt). Advanced processes to treat non-recyclable components also need to be developed.

Develop harmonised LCA methods covering batteries, power electronics, sensors, automated-driving systems and digital infrastructure including end-of-life pathways, reuse strategies and circular-economy design.

*Impact:* Lifecycle CO<sub>2</sub> reduction and preservation of natural resources used in the production of the batteries, ensuring residual value of EVs.

#### **Minimising non-tailpipe emissions (E&E)**

Research into tyre/road and brake systems will contribute to reduce residual particulate emissions. Tyre-road-interaction models will help to optimise the abrasive behaviour in order to minimise particle creation. Materials, recycling and the behaviour of TRWP in the environment are core topics of research. Improving the wear performance is one way to reduce the wear particles emissions but there are other important elements to be taken into account, such as the road surface, driving style, traffic flow, vehicle design and weight.

The impact of TRWP (Tyre and Road Wear Particles) is not yet fully measured and understood. Research is needed to:

- Characterise more precisely TRWP (composition, quantify, biodegradability etc.);
- Adapt tyre conception to lower impact of TRWP.

Reducing the tyre noise generation correspond to the expectations of the city inhabitants.

The same relevance for research is given by the brake dust particles and how to mitigate them.



### Digitalisation, as a tool in development, production and use cases (E&E)

Digitalisation represents an overarching activity for accelerating the development of advanced powertrains; this is inherent at all TRLs. Significant advancements in digitalisation call for building-up knowledge and capabilities in the areas of modelling and simulation (besides CCAM and connectivity):

- Significant advancements are needed in predictive, multi-physics and multi-material models for simulating coupled transport, thermodynamics, electrochemistry, chemical kinetics, electromagnetics and material mechanics, as well as fatigue phenomena, to support the development of all types of electrified powertrains (generally applied at lower TRLs);
- The development of consistently scaled and computationally efficient models, e.g. reduced-order models, sharing as high a level of consistency with the detailed models as possible, is needed to enable high-fidelity system layout analysis and the application of the models in cyber-physical systems, e.g. Hardware-in-the-Loop (HiL) applications, as well as for on-line monitoring (applied at higher TRLs); The development of innovative interactions of AI and physics-based, detailed as well as reduced-order models, to further boost efficiency of the design space exploration are needed;
- The development of advanced, physics-based and AI supported digital twins (including SoX observers and EoL prediction functionality for batteries, fuel cells, electrical motors, inverters and other relevant components of electrified powertrains), which are applicable to on-board and off-line (cloud) applications, for on-line monitoring, virtual sensor functionalities, model based fault detection, model based predictive maintenance and for supporting health-passport functionalities, is needed with an aim to enhance reliability and safety whilst reducing TCO;
- The development of advanced, integrated and interoperable models of the entire PLM, including LCA is needed.
- Digital twins for environmental optimisation capable of modelling energy use, emissions, traffic flow, weather and grid constraints to support planning of air-quality measures, low-emission zones and renewable-powered transport hubs. Real-time environmental monitoring and data quality: Research on affordable, high-accuracy sensor networks for air quality, noise and micro-climate, integrated with traffic and mobility data for actionable interventions
- Definition of an digital environmental label for each vehicle to be communicated with the infrastructure in order to support geofencing
- Development of digital, AI-based traffic flow systems to reduce overall energy demand and to better plan infrastructure maintenance

*Impact:* strengthen of competitiveness, agility, sustainability and efficiency in the whole value chain from development to recycling.

### BEV / Battery safety and performance (E&E)

The increased requirements on performance indicators of BEV (including. PHEV, FCEV etc.) lead to concerns about the safety of the battery (thermal runaway) and capacity-losses over lifetime. Since increased power density is supporting sustainability (smaller batteries are required for the same range), the related risks need to be addressed. Research needs to focus on innovative, digital solutions (AI-based, adaptive) for BMS, TMS, battery monitoring and, especially, self-healing functionalities.

### Circular and fossil-free materials (C&C)

The circular economy is crucial for sustainability and material supply security, sovereignty and resilience, emphasizing closed-loop recycling of materials. However, the diversity of metal alloys, plastics and composites in transportation complicates recycling processes when ensuring the desired qualities of secondary materials. Developing purification technologies and designing materials tolerant to residual elements are essential for a widespread uptake of secondary, circular materials. Besides, to further defossilise the automotive sector, secondary polymer resources, such as bio-based materials, could offer a sustainable alternative to crude oil-based products but challenges, such as varying material properties and natural decomposition resistance, need to be addressed in future research.

### Efficient dismantling, sorting and recycling processes (C&C)

An economically viable circular economy requires highly cost efficient EoL processes. Significant efforts must be taken to shift from current manual labour intensive EoL processes toward semi- or fully automated systems. This shift will require the development, industrialization and scaling of large automotive dismantling and End-of-Life plants, which are capable of processing tens of thousands of end-of-life-vehicles at very low cost. Such an industrial EoL system must be flexible enough to handle various car brands, models and conditions. It would need to leverage advancements in autonomous reverse logistics, robotics, artificial intelligence and precision sorting technologies. Research is needed in particular on

- (Semi-)automated dismantling and high-efficient sorting processes; and
- advanced and high-throughput recycling technologies.

### Re-thinking vehicle development, production and life-cycle management (C&C)

Reflecting circular economy along the full life cycle of a vehicle, increasing product lifetime, saving natural resources and minimizing emissions, is adding another layer of constraints and complexity to the product development, product and life-cycle management. Besides a modular design impacting manufacturing processes, research is needed to account for upcoming EoL strategies already in the design phase implementing, e.g. through eco-design principles on material, part, subsystem and vehicle-level. In addition, repair and maintenance, including vehicle upgradability, must be ensured, demanding new product life-cycle management ensuring longer lifetimes. Within this context, research is needed on remanufacturing to restore high-value parts to their original specifications, this involves Refurbishing, Repair, Exchange, Upgradation, and/or Reuse of individual Parts and Components.

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## 5. Highly efficient and resilient road transport: a key element of the European mobility system

### VISION 2050:

**“Infrastructure and traffic management provide highly efficient road network services at competitive cost with minimized congestion, regardless of actual conditions and disturbances.”**

→ **Optimised usage of right-sized and cost-efficient infrastructure for environmental and economic sustainability.**

- *Intelligent and dynamic access regulation* for people and goods transport to sensitive areas.
- *Performance based standards* determining the access of freight vehicles to the road network and minimizing empty runs.
- *Adaptive and flexible traffic management*, across all transport modes, including peak loads and considering the interdependencies between mobility demand, infrastructure load and energy usage, based on the prediction of demand and V2I communication.
- Automated and *dynamic parking management integrated with smart bi-directional charging*.



→ **Delays are extremely rare.**

- Road transport system providing the *required capacity* to get people and goods safely to their destinations *in time*.
- *Affordable and resilient road infrastructure*, including the charging infrastructure, able to provide its functions even after disturbances and requiring minimum maintenance.
- *Construction and infrastructure maintenance practices mostly automated*, leading to cost-efficiency and minimal works related safety risks or congestion.
- *Predictive and anticipatory incident management* for all transport modes, aiming at resilience and minimised impact of all kinds of incidents and disruptive events.

### Relevant system research needs

Various System Research Needs have been identified, these are given in detail in Chapter 7. However, those System Research Needs relevant to this topic of the 2050 Vision, that is, “Highly efficient and resilient road transport” are related to the necessity to:

- Manage access and traffic intelligently
- Create resilient and safe physical and digital infrastructure
- Predict and mitigate the impact of climate change on the road transport system, especially when updating the ageing infrastructure, to ensure resilience of the road transport system

### Research topics 2028–2035:

#### Create resilient and safe, digital and physical, road infrastructure

- Develop redundancy models, failover strategies and cross-sector coordination between transport, energy and communications infrastructure to, for example, investigate how telecom outages, grid stress, extreme weather, sovereignty of tools, storage and cyber incidents affect road-network operations.
- Demonstrate and validate architecture, interfaces, systems and tools that integrate vehicles, roadside systems and environmental data: e.g., digital twins to support predictive traffic management, road-works coordination, incident impact modelling and optimization of speed, routing and lane allocation.
- Optimize road monitoring and maintenance related to higher weight of zero emission technologies: Road-asset condition monitoring and predictive maintenance: Develop scalable sensing, edge processing and AI-based diagnostic tools for pavements, bridges and safety systems. This includes integrating vehicle-generated data with roadside monitoring to reduce maintenance cost and disruption.
- Energy and capacity optimization for zero emission vehicles e.g. forecasting, planning methodologies and recommendations for charging and energy infrastructure along national and regional routes, aligned with grid constraints.

#### Create robust physical infrastructures

- Develop Smart Intelligent Access Programmes and Performance Based Standards (PBS): creation of win-win scenarios. First implementations and testing in restricted areas (cities, ports, dedicated networks like highways or even lanes of highways, etc.).
- Physical spaces and intelligent good handling: Smart and automated connected space management (e.g. parking lots, terminal and storage areas); automated load handling self- and / or remote manoeuvring, smart loading units, etc.
- Research related to road construction should be considered for the following areas:
  - ▶ Innovation in materials: road mixes for smooth, low rolling resistance and long-life roads, low-carbon concrete for green transition,
  - ▶ Increased use of recycled materials and (elements) of structures to reduce the carbon footprint of the road (strategies, methods, design, assessment),
  - ▶ Research into mitigation techniques: carbon absorbing surfaces, CO<sub>2</sub> absorbing concrete,
  - ▶ Innovative and test alternative mitigation or reducing risks techniques: adjacent road furniture and/or vegetation, porous surfaces, etc.

## Integration of the Next Vehicle generations with the infrastructure

- Software Defined Vehicle: Resilient, modular, and upgradable vehicle system architectures enabling long vehicle lifetimes, software updates, and rapid adaptation to disruptions (supply chain, energy, climate, cybersecurity) - validation of robustness under extreme and degraded conditions
- Adaptive and flexible traffic management and supporting functions to improve traffic and logistics/mobility services, including Tyres as a Service
- Interoperability across systems and borders: harmonised interfaces and operational procedures between road operators, ITS platforms and mobility providers to ensure consistent performance across Europe.
- Efficient multimodal freight logistics for competitive European industries: Synchronised longhaul-regional-urban freight, time-window optimisation, multimodal links and energy-efficient delivery patterns.
- Human-centred operational resilience: Include behavioural studies on driver response under degraded conditions, evacuation planning and communication strategies during network disruption.

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## 6. Cross-cutting Enabling Factors

Several technological, regulatory and organisational enablers need to be in place in 2050 to realise our vision, such as:

- **Secure access to the digital world across Europe for the benefit of all.**
  - *Connectivity provided everywhere needed and at any time needed* with stable connection and data rates (gaps bridged sufficiently).
  - *Cyber-security* features protecting against attack and misuse.
  - *Safe, affordable, reliable digital infrastructure across Europe* extended and adapted for automated vehicles and seamless mobility solutions.
  - Seamless and intuitive Human-Technology Interaction.
- **Effective cooperation of all stakeholders towards the common vision.**
  - *Cross-sectoral collaboration fully established with all relevant stakeholders.*
  - *Essentially harmonized legal frameworks* from EU for global use in road transport and *international standards supporting Europe's global competitiveness.*
  - Methods, processes and European policies *accelerating innovation* and managing road transport system complexity.

### Relevant system research needs

Various System Research Needs have been identified, these are given in detail in Chapter 7.

### Research topics 2028–2035:

#### Governance and regulations (UM)

Effective cooperation between all involved stakeholders is paramount in the context of mobility. From public authorities and institutions to public and private operators and service providers, without forgetting users, it is necessary to further investigate how to integrate their needs and interests when planning for more resilient and sustainable mobility. This entails research in the following areas.



- Develop and harmonise frameworks that enable effective collaboration at different levels. This includes cooperation at different scales, from enabling dataspace and data-sharing systems for mobility management, to boosting co-creation processes with citizens for the design of mobility policies.
- Exploring new governance frameworks and regulations for collaborative business models between public authorities, technology and mobility providers, logistics service providers, and real estate for data sharing and data-driven services.
- Skills, training and capacity-building. Research on scalable training frameworks for public authorities, SMEs and operators to deploy and manage advanced mobility systems.

#### Co-creation, user and public involvement (UM)

Effective collaboration and involvement of all stakeholders in the transport eco-system, with users, operators, authorities and the public. The development of tools to support implementation roadmaps, promoting the participation of all social groups, the co-design, co-implementation and co-evaluation of new services, and the adoption of more sustainable mobility habits

- Inter-disciplinary conceptual frameworks to support the set-up and deployment of AI and modelling tools for better policy making and improved service design
- Application of digital twins, AI image generators and other digital tools to help people visualise more sustainable transport networks and options
- Training and capacity-building programmes to apply co-creation and public involvement techniques in cities, tackling issues of available resources, time constraints and delivery of results.
- Harmonised evaluation and impact assessment. Common European methodologies are needed for assessing environmental impact, safety performance, socio-economic benefit and digital maturity, enabling consistent comparison across pilots and regions.
- Increasing the understanding of future business models and Total Cost of Ownership (TCO) through large-scale demonstrations, pilots of large number of vehicles and fleets during real operation in real environments.

#### European approaches for green energy supply (E&E)

Research needs to address the standardization of the still crowded mix of charging and renewable fuels solutions and billing techniques to create a harmonised, user-friendly (bi-directional) ecosystem all over Europe. The infrastructure evolution needs easily deployable, cost effective and interoperable charging stations as well as ultra high-speed charging stations. Another focus of research is the European strategy for energy policy and distribution to minimise the overall energy demand in combination with a maximum share of green energy in the grid (*vision: 100% fossil free energy*).

#### System perspective beside road transport (E&E)

There are certain system challenges to be addressed to achieve the vision, which cannot be solved by one stakeholder alone. Activities at an EU-level are recommended to address (at least):

- Renewable electricity generation capacity (inside and outside of Europe) .
- Net GHG-neutral Hydrogen and fuel production (inside and outside of Europe) .
- Technology and capacity of Carbon Capture and Storage (CCS) and Direct Air Capture (DAC) .
- Availability of raw materials and sustainable feedstocks (appraised in a life-cycle analysis perspective).

#### European AI and data ecosystem for safe and sustainable road transport (S&S)

Artificial Intelligence (AI) plays a major role in future services and digital value chains, not only in connected and automated driving, but also in intelligent mobility services. Strengthening European industries in the development and integration of AI technologies is a geopolitical necessity to avoid future strategic dependencies. A trustworthy and sovereign European AI and data ecosystem is essential in particular to enable secure, high-quality, and privacy-preserving data sharing across the mobility sector. Integrating advanced AI capabilities into the transport system will support predictive safety analytics,

AI-driven risk assessment, and real-time adaptation. To enable this, Europe must build on emerging European data space frameworks for mobility and CCAM in particular, ensuring that data platforms are federated, secure, and capable of supporting both operational and development-oriented use cases. To fully unlock this potential, Europe must also establish semantic and domain-adaptive frameworks for data interoperability, allowing datasets from different sources to be meaningfully combined, reused, and interpreted with minimal post-processing effort by end users. Such frameworks will significantly enhance data quality, reusability, and cross-domain consistency, reducing fragmentation and supporting continuous learning. However, major challenges remain regarding data accessibility, reliability, quality assurance, interfaces and continuous improvement of trained modules for applications, specifically in safety-critical domains, and the need for robust governance models to guarantee data sovereignty and ethical compliance. Research and innovation should therefore focus on developing federated, interoperable data platforms, standardised semantic models, and AI frameworks for real-time situational awareness and risk prediction, moving towards the real-world deployment of adaptive, AI-enabled safety and mobility services. This should include amongst others operational data-sharing frameworks with standard APIs and trust mechanisms that enable consistent exchange between different EU actors.

### **Advancements of the Key enablers for Connected and Automated Driving (CAD)**

The temporary or even complete hand-over of the driving task from a human to a machine in connected and automated vehicles requires the systems for environment perception, decision making and control to meet highest safety and performance standards, which, today, are still out of reach. Thus, further advancement in enabling technologies is essential for making CCAM ready for a wider market deployment, such as sensor components and networks, computing systems and control architectures with high reliability, fail-operation capabilities and efficiency, embedded software and artificial intelligence at the edge providing agile upgradability and self-learning capabilities, and communication infrastructures and cloud-based services for the gathering, exchange and analysis of critical data at high bandwidth, short latencies and highest levels of data security.

- Explore how non-terrestrial networks (NTN), particularly satellite systems, can enhance vehicle connectivity in areas with limited or no terrestrial coverage, and address wideband/broadband applications, ranging from essential safety and operational services to immersive experiences.
- Dynamic digital twin of traffic scenarios for vehicle automation as key enabler for highly automated driving especially in complex urban scenarios.
- Digital processes for automated logistics operations. Achieve standardized fully digital logistics processes from initiating an order to deliver, reporting and payment including EU and extra-EU enforcement and reporting by using AI and other technologies. This is a prerequisite to have automated logistics processes and cut administration and delays.
- Cyber-security and resilience, across the mobility continuum. Harmonised cyber-security methods and toolkits for vehicles, roadside infrastructure, cloud platforms and mobility applications, including tools for end-to-end validation. Priorities include threat modelling, secure OTA updates, public key infrastructure (PKI) management, harmonisation and coordinated vulnerability disclosure, as well as approaches to tackle supply-chain-complexity and cross-border challenges.



## 7. Systemic Research Needs

A system perspective gives insights into the complexity and dependency of the individual components of road transport. Comparing the current state of the European road transport system and the Vision given above, gaps of a systemic nature can be identified. Hence, research challenges in the system domain may also be identified. As with the format given above, these challenges can be identified as:

### Systemic research challenges

To ensure seamlessness and inclusiveness of transport, we must economically bridge transport gaps in less connected areas while balancing the overall system cost efficiency with different cost structures in rural and urban life and the preferences of users.

To create a seamless mobility experience, we must integrate all transport modes in planning, pricing and payment, harmonize disparate technological platforms and align stakeholders' interests while satisfying reliability and affordability requirements.

To promote sustainable mobility and illuminate the environmental impact and total cost of all modes of transport for users, we must eliminate untransparent cost structures by developing a pricing system that takes into account the external costs of a form of mobility and thus also ensures competitive pricing of sustainable modes with lower external costs.

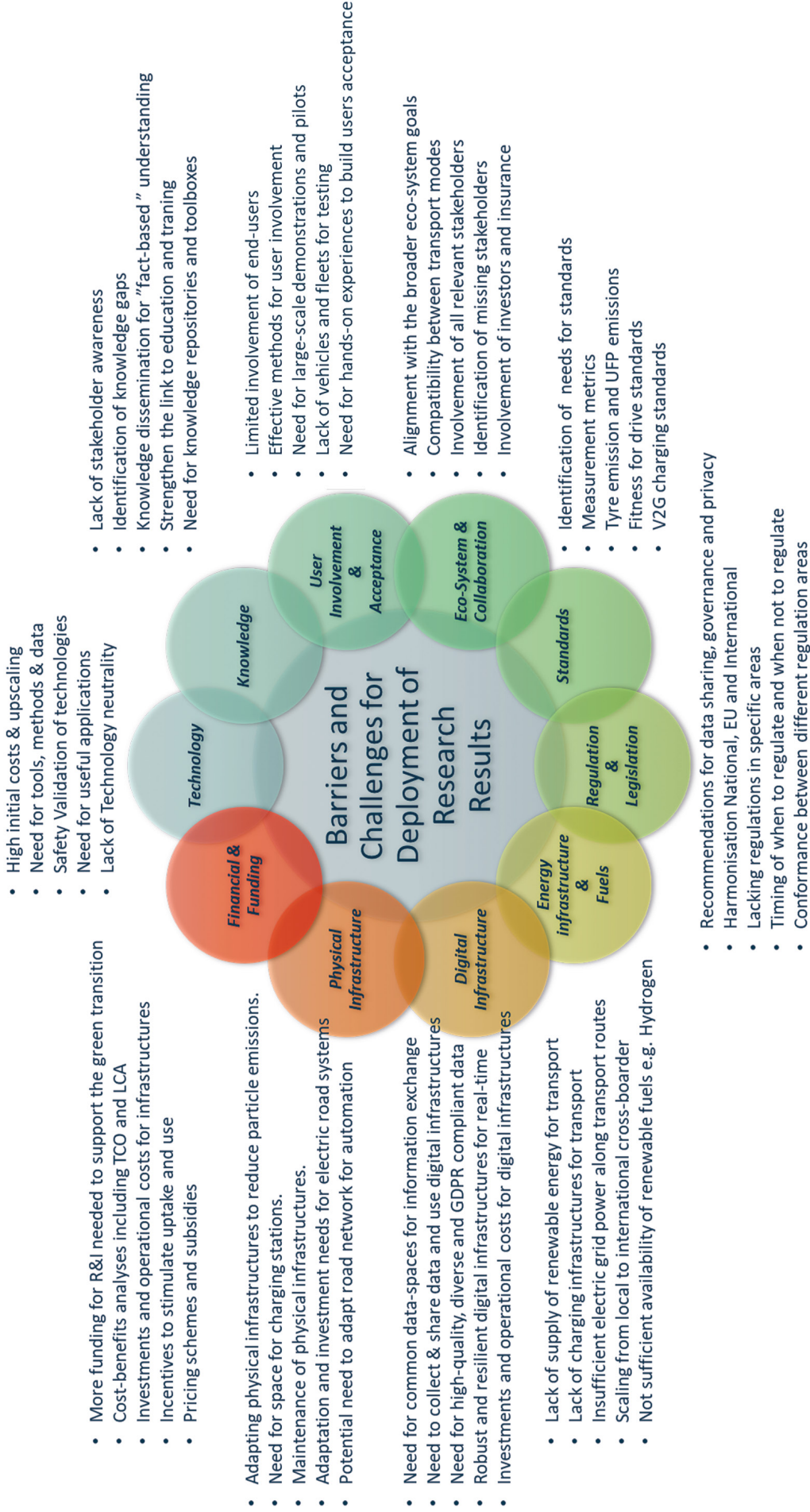
Hence the systemic research needs can be identified and listed as:

Index	Systemic Research Need
1	Ensure seamlessness of mobility services whilst staying sustainable and cost effective
2	Join forces for a well-functioning digital mobility ecosystem for people and goods
3	Define a Cost structure to internalise external costs and finance sustainability
4	Improve the ability to understand and anticipate user roles, needs and behaviour based on existing and future values
5	Encourage societal support for rapid changes and investments in road transport
6	Define Fair global boundary conditions and reduced dependencies to enable sustainability
7	Holistic optimisation of resources by maximizing the use of renewable materials and energy
8	Manage access and traffic intelligently
9	Create resilient and safe physical and digital infrastructure
10	Predict and mitigate the impact of climate change on the road transport system, especially when updating the ageing infrastructure, to ensure the resilience of the road transport system
11	Data collaboration to support safe and secure fully connected road transport
12	Advancing Europe's leadership in road transport innovation
13a	Attractive and innovative framework conditions for research and education
13b	Harmonised curricula and professional carrier development models for life-long learning
14	Master global competition in a responsible and social way, and strengthen EU sovereignty



The following recommendations have been identified.

- **Continued focus on R&I technology.** Technology innovation drives the potential of new solutions to meet the demands for the digital and green transition of the road transport system. It is also vital to strengthen and enhance the competitiveness of Europe, where technology innovation is a key enabler.
- **Improve the knowledge transfer of research results.** It is very important to ensure transferring results of research results, not only in new projects. Demonstration and pilots are efficient methods to further explain and disseminate results for the next phases in the development chain.
- **Increase user involvement and user dialogue.** It is of key importance to continue and strengthen the dialogue with the users of the solutions. This should ideally be a two-way dialogue to increase the understanding of user needs and to disseminate the results of research projects together with the users. Demonstrating results plays one important role to stimulate this dialogue.
- **Broaden the stakeholder eco-system engagement.** The digital and green transition of the road transport system gets increasingly integrated. New stakeholders continuously enter the eco-system as vehicles and infrastructure gets more integrated and new technology and knowledge emerges.
- **Ensure continued link to standardisation.** The European R&I projects provide a strong base to European and international standardisation.
- **Strengthen the link to regulation.** The regulatory framework plays a key role in deployment of solutions of road transport research results. Regulation can be a driver for the introduction of new technologies, especially when it acts on the end user, who needs to follow the rules without being restricted in their freedom.
- **Continue involvement with physical infrastructure.** It is important to continue the involvement and ensure a sound dialogue between the vehicle and road infrastructure stakeholders to enable understanding of needs and opportunities for further research and deployment of research results.
- **Improve the collaboration with energy infrastructure.** In the green transition of the road transport system the energy infrastructure stakeholders play an increasingly important role.
- **Strengthen digital infrastructures: Services & Data.** Future road transport solutions are increasingly depending on the digital infrastructure. Connectivity, Cloud, Services, AI etc. opens for considerable opportunities for further research and innovation. Hence it is of key importance to further strengthen the involvement of this sector in future re-search and innovation to enhance deployment of research results.



## 9. Framework conditions for research and innovation

The STREnGth\_M, “Stimulating road Transport Research in Europe and around the Globe for sustainable Mobility”, coordination and support action deliverable D1.1 examined the “Barriers for deployment of research results” (see Section 8 above). One of the recommendations there is, “Improve the funding schemes to support the digital and green transition – with focus on deployment of new technologies and the removal of the barriers. The transition of the road transport system will require significant financial support to strengthen the European road transport community and stakeholders, ... to increase industrial actors’ engagement.

- Speed up the whole process that precedes the start of EU research projects, from drafting calls for proposals to the completion of the grant agreement preparation phase, to make it easier for research projects to effectively address current challenges.
- Have more focus on call topic descriptions to make sure that significant progress can be made in these focus areas, rather than little incremental improvements in a broad range of research aspects that do not encourage deployment in the end.
- While ambition is important, have a stronger focus on the realism of project objectives the evaluation phase of project proposals, as project objectives that are ambitious, but not realistic to achieve, will not result in deployment.
- Consider to a larger extent the capability of project consortia to finally deploy project results in the evaluation phase of project proposals.

### ERTRAC SRA for FP10 – International Cooperation

European RD&I in road transport in the next Framework Programme is targeting an open, strategic and safe worldwide cooperation, promoting international collaboration to support pioneering technologies and funding innovation at all Technology Readiness Levels while safeguarding EU principles and competitiveness. RD&I cooperation with emerging countries is also within the European policies of pursuing international cooperation. Correspondingly, the development of strategic partnerships that will include international cooperation shall be part of the picture for the next Framework Programme to strengthen the cooperation in science and innovation for road transport.

The STREnGth\_M, “Stimulating road Transport Research in Europe and around the Globe for sustainable Mobility”, coordination and support action deliverable D1.2, “Roadmapping methods on European, Member State and international level” outlines the diverse mechanisms for defining road transport RD&I needs across different regions at the worldwide level:

- Considering the **RD&I focus on road transport** in the USA, the emphasis is on technology-driven solutions for intelligent transport systems, public-private partnerships and federal funding programs, combined with collaboration with the private sector. In Asia, the definition of the road transport RD&I needs is done with government-led initiatives (e.g., China 2035 Transportation Roadmap), in collaboration with academic institutions and smart city initiatives, the focus is on integrated planning and large-scale infrastructure projects.
- Considering the **stakeholder involvement in road transport** RD&I, the USA involves a wide range of stakeholders, including Federal Agencies, state and local governments, universities and private companies. In Asia, the drivers are the central government agencies with significant involvement of academic institutions and public-private collaborations.
- Considering **road transport RD&I on enabling technologies**, the USA focus is to be the frontrunner on advanced transportation technologies, including but not limited to connected vehicles and autonomous driving. In Asia, the emphasis is on technological solutions applied to smart city initiatives, electric mobility and sustainable transportation for people and goods.

In this landscape, **European RD&I activities in the next Framework Programme** should envisage agile and effective mechanisms for international collaboration, moving beyond liaison exchanges; digitalization is expected to play a role in facilitating the establishment of win-win collaborations.

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# Appendix

## Detailed Listing of the Systemic Research Needs and their Expected Impacts

### Ensure seamlessness of mobility services while staying cost effective<sup>4</sup>

#### Research Needs and Questions

- How to determine which public vehicles and services best meet rural and peri-urban transport needs with irregular demand, economic viability and have necessary infrastructure?
- How can operating zones and boundaries for mobility services be designed for short waiting times and economic sense?
- What are the requirements for seamless mobility services in different areas, and how can their organic development and growth be supported? How to create synergetic effects between private transport services with public transport?
- How can maximum mobility service be achieved with minimal resources, and what specific vehicles and infrastructure are needed?
- How can we assess and mitigate unexpected demand fluctuations or delays in mobility services?
- What measures ensure the safety and security of people and goods without reducing efficiency or increasing costs?
- How can we use insights from user acceptance models to design various mobility systems resilient to shifts within behaviour, to avoid costly retrofitting or dismantling?
- How to determine what measures and means will encourage companies and the public to implement and use seamless mobility services?

#### Expected impacts

- Design, construction or conversion of improved mobility services and related technologies, infrastructure and vehicles.
- Ensured reasonable operating costs for various user groups, with due consideration to safety, punctuality and high service availability.
- Mobility poverty in Europe is reduced to zero by 2050.
- Future competitiveness of Europe by accelerating the innovation process.
- Availability of required human resources within Europe with the growth in employment opportunities, particularly for highly skilled specialists.

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<sup>4</sup>This is related to the 2050 Vision topic “Seamless mobility of people and goods for the benefit of all EU citizens”



## Joint forces for a well-functioning digital mobility ecosystem for people and goods<sup>5</sup>

### Research Needs and Questions

- What are the steps to get towards an integrated digital ecosystem? How do interfaces look across platforms? Which functionalities are needed for interoperability?
- How would an economically efficient solution look like with regard to physical infrastructure?
- For which reasons are most current platforms not integrated (compared to Google maps)? What are the key factors to success of an integrated ecosystem?
- Are there any risks in integrating road transport into one ecosystem? How could they be mitigated?
- How does a highly accepted digital infrastructure and associated booking platform look like, one that actively supports inter-/multimodality by integrating planning, rescheduling and payment simply, quickly and customized to individual needs and preferences?
- How can heterogeneous and fragmented data be integrated to provide real-time travel information to users, and how can data be collected efficiently and reliably to better understand user's needs and corresponding services. How to acquire the necessary user-related data needed to provide user-friendly platforms and services without violating data protection laws?

### Expected impacts

- Harmonized and integrated platforms & ecosystems for “purpose-driven services” (CO<sub>2</sub> reduction, uptime, cost and inclusiveness) for all transport modes.
- Collaboration of all the stakeholders within the full digitalization process and their well defined tasks, together with the environment enabling a well-functioning digital mobility and logistics ecosystem.
- Secured interoperability of the different platforms – including interface standards.

## Cost structure to internalise external costs and finance sustainability<sup>6</sup>

### Research Needs and Questions

- What will serve as the fundamental framework for the cost structure? What kind and quantity of data is required? How can we identify them? What are the most suitable data aggregation techniques for effective data analysis?
- How can we include appropriately the external cost on different scales - total (country), average (expressed per performance unit) and marginal (for one additional performance unit)? How can we integrate associated costs, including safety, pollution, energy, maintenance and upkeep, that are not directly visible?
- What pricing system would be most suitable for addressing specific externalities and achieving competitive pricing for sustainable modes?
- What type of business model and communication strategy would be suitable for adapting to the emerging cost structure?
- What strategies can we utilize to measure the effectiveness of actions and monitor the progress of interventions?

### Expected impacts

- Agreed shared method for assessment of external costs and implementation of appropriate instruments for internalization.
- Novel business and communication models.
- Investments in the appropriate sustainable and technically feasible solutions.
- Rationalization in terms of optimizing transport costs. Ultimate cost / price reduction.
- Socially and ecologically beneficial / user-friendly transport options.

<sup>5</sup>This is related to the 2050 Vision topic “Seamless mobility of people and goods for the benefit of all EU citizens”

<sup>6</sup>This is related to the 2050 Vision topic “Seamless mobility of people and goods for the benefit of all EU citizens”

## Improve the ability to understand and anticipate user roles, needs and behaviour based on existing and future values<sup>7</sup>

### Research Needs and Questions

- How to close the gap between what people say is important and how they actually behave?
- How can we differentiate between explicit and intrinsic user needs?
- How to understand the factors, mechanisms and real reasons why users will not accept or embrace new and/or alternative solutions, especially environmentally friendly options?
- How to anticipate new and emerging aspects influencing alternative solutions and seamless mobility, like an increase in value of travel time?
- How to define, better understand and predict the potential shift of values for future generations and the impact on expectations, as well as increasing the awareness of current decision makers?
- How to determine and quantify the degree of freedom users would like to have for selecting mobility options and if these are actually used in travel planning?
- How to determine and validate acceptable travel tolerances, e. g. waiting times, length and duration of journey?
- How to ensure holistic transparency for individual mobility choices with regards negative or positive impact on energy transition and society?
- How to identify the most realistic and probable user needs through a predictive approach, which is able to evaluate the impact on current and future transport demand?

### Expected impacts

- Better overview/understanding of different types of users (individuals, groups of citizens, businesses etc.) to address their specific needs in providing viable solutions.
- Systems and solutions can be better tailored to meet user's needs and expectations.
- Beneficial changes in mobility habits contribute to achieving Green Deal goals.
- Advanced and innovative methods and tools are in use to anticipate, in time, upcoming changes and create flexibility to adapt policies (also in case of unforeseen developments).
- An improved understanding by policy makers and business developers for the systemic effects on the uptake of innovations including the individual and collective/societal user needs and driving forces.
- Improved ability to understand and anticipate user roles, needs and behaviour, highlighting the importance of HMI development and user-centric approaches

## Encourage societal support for rapid changes and investments in road transport<sup>8</sup>

### Research Needs and Questions

Technologies are evolving quickly, inducing fast changes (economical & organizational) and bringing about the need for rapid changes and investments. For this, we need societal acceptance. Thus research needs to take into account future demographic effects and economic, social, demographic and geographic differences.

- What are to society the positive and negative effects of road transport investments by taking into account the triplet people/planet/business?
- How high is the acceptable cost-increase for society to introduce innovative, greener, safer road transport solutions? What are the societal key acceptance factors for high change rate and investments with regard to road transport and how can acceptance be increased? Are there new forms of incentives (new quality of mobility)? Who needs to convince whom?

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<sup>7</sup>This is related to the 2050 Vision topic "Seamless mobility of people and goods for the benefit of all EU citizens"

<sup>8</sup>This is related to the 2050 Vision topic "Environmental sustainability: energy and resource efficiency, decarbonisation and excellent air quality"



- How can society be motivated for long term effects (e.g. in climate, competitiveness or resilience) and invests rather than short term success? How to implement in future policy, regulation and non-regulatory requirements?
- What impact have investments made to date had on climate change, and how can we measure these impacts accurately? How are these impacts disseminated effectively, credibly and trustworthily in society?

### Expected impacts

- Fostered societal support for rapid changes in road transport and investment in necessary infrastructure by gaining societal acceptance for significant changes.
- Substantial long-term environmental and societal benefits in alignment with the ERTRAC 2050 Vision.
- Provision of actionable information for society by accurate and comprehensive metrics for unbiased and regular system assessment.
- Overcome the low historical rate of change by investing in upstream infrastructure (energy and road system).
- Increased willingness to pay for stakeholders of road transport for investments for long-term and short-term objectives whose impact are related to society.
- Improved ability to understand and anticipate user roles, needs and behaviour, highlighting the importance of HMI development and user-centric approaches.

## Fair global boundary conditions and reduced dependencies to enable sustainability<sup>9</sup>

### Research Needs and Questions

- How to determine and validate the critical dependencies and boundary conditions hindering Europe's and global sustainability?
- How can Europe establish an ecosystem with resilient supply chains and technologies (for energy, products, materials etc.) so that fair conditions for business cases, circularity and sustainability can be achieved in Europe and globally?
- Which combination of measures can address the identified challenges in the most effective, fast and robust way?
- How to identify and implement solutions to reduce the import dependency from outside of Europe in terms of material, products and their related supply chains? What role can recycling and a circular economy play in this context?
- How to identify and implement technical solutions to reduce the energy dependency from outside of Europe while establishing a balanced, fair and sustainable mix of energy sources?
- How can we achieve a level playing field on a global scale?

### Expected impacts

- Fair boundary conditions to enable sustainable and diversified energy solutions and circular ecosystems in Europe by early assessment of the critical aspects, as described above
- Regulatory recommendations to support policy makers and businesses. The dependency on foreign energy and materials is reduced.

<sup>9</sup>This is related to the 2050 Vision topic "Environmental sustainability: energy and resource efficiency, decarbonisation and excellent air quality"

## Holistic optimisation of resources by maximizing the use of renewable materials and energy<sup>10</sup>

### Research Needs and Questions

- What are alternative sustainable materials to replace critical raw materials in key components of EV powertrain? How to obtain “free-critical raw materials” and “free-PFAS” batteries?
- How to solve the dilemma between integration/modularity enhancement and repair/recycling improvement at the design stage (including material choice)?
- How to combine a right sizing approach with a predictive component reuse (2<sup>nd</sup> life) strategy to optimize the use of critical materials according to a holistic circular economy? What is the right balance between second life reuse and recycling, considering technologies evolution and recycling processes?
- How to ensure an optimised renewable energy availability for all mobility modes, everywhere and in all conditions without any need for fossil energy to deal with peak demands?
- How could the demand of all sectors (industry, household, transport or services) be coordinated optimally?
- How to provide Transport as a Service according to a holistic approach that considers not only travel time and cost, but also the right energy request (i.e. minimum CO<sub>2</sub> emissions), to ensure a competitive and efficient use of energy along with responsible behaviours?

### Expected impacts

- European sovereignty on materials needed for industry is stronger and based on a sustainable approach.
- Enhancement of circular economy: component right sizing and reuse between different economic sectors (2<sup>nd</sup> life).
- Improved the resilience of the EU energy system, facilitated integration of renewable energy sources.

## Manage access & traffic intelligently<sup>11</sup>

### Research Needs and Questions

Intelligent and multimodal traffic management requires adaptive and flexible systems to predict transport demand and manage access dynamically. Ensuring data availability, accessibility and privacy is crucial for success. These research needs apply to multi- and intermodal systems.

- How can we maximise the impact of intelligent access, parking and traffic management, incorporating data made available due to regulatory obligations, while ensuring user and data privacy, but also circumventing the lack of certain data (e.g. active mobility data)?
- How can traffic flow models be improved to better predict transport demand and manage congestion for different modes and across different types of transport networks?
- What technologies and frameworks are needed to support real-time multi-modal traffic management and dynamic access control? How can adaptive traffic management systems be integrated with i) existing infrastructure, and ii) with future growing CAD capability in the fleet in co-existence with pedestrians, cyclists and non-CAD capable vehicles?
- What should the role be of connectivity and cooperative systems in ensuring integration of mobility services, also with existing infrastructure in urban and rural areas?
- How can user behaviour insights be used to intelligently influence travel patterns to answer to policy objectives?
- How can we ensure that the energy and material consumption of the traffic management system

<sup>10</sup> This is related to the 2050 Vision topic “Environmental sustainability: energy and resource efficiency, decarbonisation and excellent air quality”

<sup>11</sup> This is related to the 2050 Vision topic “Highly efficient and resilient road transport: a key element of the European mobility system”



in all its components is contributing to the overall climate neutrality of the transport system?

- Within the Vision's timeframe, the 431 Urban Nodes on the TEN-T will be important enablers for road transport innovation. How can urban nodes be further supported in their efforts for climate neutrality, more sustainability and liveability in a holistic way? How can we create more effective Sustainable Urban Mobility Plans (SUMP's).
- How to harmonise land use/spatial planning, housing and mix of other functions with transport solutions in the best way to maximise access while preventing further urban sprawl?

### Expected impacts

- Enhanced mobility, less congestion and more sustainability across mobility networks (long-distance, regional, local).
- Improved road safety due to the unburdening of the drivers in their driving tasks, creating conflict-free intersections and integrating road-safety related data in the management tools.
- Better cost-efficiency of the system and better compliance to regulations.
- Energy and material resource efficient traffic management systems.
- Better impact assessment and measurement of the implemented strategies, in view of climate, energy use, air quality, noise and social and economic targets.
- Better planning methods for Sustainable Urban Mobility Plans.
- Prevention of urban sprawl.
- Better integration of urban transport with long-distance transport.

## Create resilient and safe physical and digital infrastructure<sup>12</sup>

### Research Needs and Questions

Sustainable, safe and resilient solutions for physical and digital infrastructure shall be designed at a road transport network level to embrace the deployment of CCAM and be inclusive of areas not yet addressed.

- How to structure the network of the physical infrastructure and the architecture of digital infrastructure to make it truly resilient and fail-operational considering legacy infrastructural conditions?
- How to determine the weakest links in the chain of our physical and digital infrastructure?
- How to prepare infrastructure for the effects of all disruptive events, especially considering climate change, vandalism, abuse and terror attacks? How to prepare infrastructure for military attacks and military dual-use?
- How to design digital infrastructure resilient to cybersecurity threats especially considering robust and secure communication and data security?
- How to identify what infrastructural needs have to be prioritized in order to create the biggest leverage in resilience cost-efficiently?
- How to maximize the benefits on safety and resilience when deploying CCAM? How to increase the benefit of multi- and inter-modal mobility on overall resilience? How to support the resilience of the physical infrastructure by CCAM?
- How to develop maintenance strategies for a sustainable road infrastructure?
- How to best address the challenges of scaling and integrating CCAM technologies across diverse and complex environments?
- How to consider disruptive events in development and standardisation of validation tools and scenario databases?

<sup>12</sup>This is related to the 2050 Vision topic "Highly efficient and resilient road transport: a key element of the European mobility system"

## Expected impacts

- Effective and cost-efficient increase of safety and resilience of the physical and digital infrastructure.
- Solutions to handle vandalism, cyber security threats, military attacks and other disruptive events affecting physical and digital infrastructure.
- Updated, resilient, road network design for safe and efficient interactions of all road users.
- Updated road network maintenance strategies.

## Predict and mitigate the impact of climate change on the road transport system, especially when updating the ageing infrastructure, to ensure the resilience of the road transport system<sup>13</sup>

### Research Needs and Questions

Predicting and mitigating the impacts of climate change and renewing ageing infrastructure are critical for a resilient transport system. This involves anticipating future climate changes and developing measures to mitigate these impacts.

- How can we accurately predict the impacts of climate change on road infrastructure, and what preventive measures are required?
- What models, technologies and strategies are needed to detect, predict and mitigate events such as congestion, accidents and weather incidents in real-time?

## Expected impacts

Addressing these research questions will increase the resilience of the transport system and reduce vulnerability to climate-related disruptions. In the long term, this will lead to safer and more efficient infrastructure, with efficiency and effectiveness improvements for road operators positively impacting the economy and society.

- A truly resilient road transport system by anticipating the impacts of climate change on infrastructure and users.
- Low impact of disruptions by real-time detection, tracking and prediction of events, and model-based technologies for precaution and mitigation strategies.
- Implemented real-time capabilities for automated traffic management, particularly in response to acute environmental events.

## Data collaboration to support safe and secure fully connected road transport<sup>14</sup>

### Research Needs and Questions

Data identification, generation & processing:

- How to identify, acquire, clean, process and maintain data to support safe and secure road transport?
- How can society (including industry and academia) benefit from increased sharing of road transport-related data and meta-data?
- How can we identify, acquire, clean, process and maintain the necessary data and metadata to deliver societal gains in an efficient and sustainable way?

<sup>13</sup> This is related to the 2050 Vision topic "Highly efficient and resilient road transport: a key element of the European mobility system"

<sup>14</sup> This is related to the 2050 Vision topic "All-round protection: safety and security"



- How can data quality (reliability, robustness, accuracy, plausibility, security) and relevance (i.e. management of legacy data) be ensured?
- How to structure data access and maintain a secure data environment where intrusion events can be rapidly identified and acted upon – how will this change by 2050?

**Drivers & obstacles:**

- How to combat the obstacles and facilitate drivers for the generation, acquisition, processing, management and sharing of data?
- What are the challenges and limitations on data sharing that need to be addressed and overcome, and what could be the principles for data sharing?
- What incentives and business models can facilitate data sharing, especially in the context of limited financial incentives but significant societal gains?
- What regulatory frameworks and standardized protocols are needed to ensure secure, interoperable and ethically compliant data sharing while addressing concerns of privacy, liability and ownership.
- How to ensure benefits associated with data sharing support a more equitable Europe?

**Test & validation:**

- How can the data management associated with solution delivery be tested and validated?
- How could common evaluation methodologies across Europe ensure interoperability of mobility solutions?
- What are the necessary frameworks and tools needed to maximize gains from common evaluation methodologies?
- What scenarios (and scenario databases) should be used to reflect realistic and future oriented conditions to capitalize on common methods and tools for assess quality and impact of data collaboration?

**Risks & liabilities:**

- How are risks and liabilities distributed when decisions are made using data sets provided by multiple data owners (or third-party AI)?
- How will liabilities be distributed in a data rich environment?
- How can we secure traceability of data?

**Expected impacts**

- Societal gains: Increased collaborative data sharing, will enable the development of safer, more secure, more accessible and more efficient transport system solutions, and provide an enabler for an integrated digital ecosystem and a resilient infrastructure
- Energy reductions: Via innovative methods for collecting, storing, cleaning and processing data, the overall costs and energy demands associated with data management can be reduced.
- Business gains: Innovations in data management open up new internal EU business opportunities as well as export opportunities strengthening EU global competitiveness.

**Advancing Europe’s leadership in road transport innovation<sup>15</sup>**

**Research Needs and Questions**

**Culture:**

- How can we foster a culture of continuous innovation within the European road transport sector?
- What are the best practices for encouraging the collaboration and transfer of ideas between research institutions and the industrial sector?

<sup>15</sup> This is related to the 2050 Vision topic “Europe as the world leader for safe & sustainable road transport solutions”

- How can we accelerate the deployment of innovative solutions by overcoming regulatory constraints?

#### **Enabling technologies & innovation:**

- How can Europe capitalize on emerging enabling technologies to drive innovation in road transport?
- What emerging technologies will form the technical backbone of society and how can Europe capitalize on these?

#### **Production & resilience:**

- How can Europe enhance its innovation capabilities in production and mobility resilience?
- How can R&I activities serve to improve collaboration between manufacturers, suppliers and research institutions drive innovation in production?
- How can R&I facilitate increased resilience in the movement of people and goods?

#### **Obstacles & drivers:**

- How can we overcome obstacles and strengthen drivers for innovation in Europe?
- What are the drivers and obstacles to innovation in Europe and how do we strengthen or overcome these?
- How can we simplify access to public and private funding schemes that support innovation and what is the role of public-private partnerships?
- How can appropriate innovative ideas be identified and supported when attempting to propagate solutions to additional locations?
- How can we capitalize on innovation success in other regions and recreate the enablers for success?

#### **Innovation hubs:**

- How can we establish and support innovation ecosystems and hubs?
- How can we establish innovation hubs where cross-fertilization of ideas occurs early?
- How can we create a more fertile environment for innovative ideas and businesses?

#### **Future of business:**

- How can the future of business shape the innovation space and how can collaborative funded projects support innovation ambitions?
- How can we better assess the need to rapidly select or shut down innovative ideas or businesses of lower estimated value or success?
- How to identify and enable business models, such as 'as a service', and how to novel business models influence the innovation landscape?

#### **Expected impacts**

- **Global Leadership in Innovation:** Europe will become a frontrunner in road transport technologies, enhancing its global competitive edge.
- **Enhanced Service Quality:** Innovations will create more efficient, reliable, and user-friendly transport services, improving mobility for citizens.
- **Sustainable and Resilient Production and Mobility:** Innovative practices will ensure a robust, eco-friendly movement of people and goods, boosting economic growth and job creation.
- **Environmental Benefits:** Advancements in low-emission technologies and sustainable mobility will reduce the environmental impact, aiding Europe's climate goals and enhancing quality of life.



## Attractive and innovative framework conditions for research and education<sup>16</sup>

### Research Needs and Questions

- How to identify which investments are needed in the European research infrastructure (for academia, RTOs and industry) to attract highly skilled people within Europe and from outside, strengthening the research and education eco-system? Which models are feasible to finance those investments?
- How must public-private partnerships look like to allow and accelerate research along all TRLs and MRLs including blue sky research which is also impacting the quality of educational programmes?
- How must legislation in Europe and its Member States be adapted to allow testing and demonstration of new technologies on all scales under real-life conditions much quicker and more visible to the public?
- Which models and topics are attractive and suitable to strengthen the collaboration of Europe with less developed countries on education and research?

### Expected impacts

- Regained global competitiveness in research by creating an attractive research environment in the battle for the best talents world-wide with a welcoming research environment.
- Improved global competitiveness due to the attractive research environment, as investments in research and education frameworks are a decisive factor for economic growth
- More innovations developed and exploited in Europe, strengthening also the competitiveness of the European industry.
- Investments in education and research boost economic growth in less developed countries, creating new market potentials for the European road transport industry through increased exports. This enhances regional stability, securing natural resource supply chains for Europe.

## Harmonised curricula and professional carrier development models for life-long learning<sup>17</sup>

### Research Needs and Questions

- How to identify skills to be taught at university, in apprenticeships and in continuous industrial learning in view of the Vision 2050 objectives motivating young people?
- How can required skills be translated into innovative, attractive and European-wide harmonized curricula and educational programmes for the different levels of training and education?
- How can Europe's education schemes be reformed to enable an integrated life-long learning on all levels responding to volatile needs and to technological and social progress?
- How can professional carrier development models be rethought to make the road transport sector more attractive for skilled staff?

### Expected impacts

- With attractive curricula, innovative apprenticeships and continuous learning services highly skilled people with the right expertise will be available for the road transport sector enabling and accelerating future innovations.
- This directly impacts the competitiveness of the European road transport industry which is relying on excellence workforces along the value-chain.
- Highly skilled workforce is available for future innovations.

<sup>16</sup>This is related to the 2050 Vision topic "Europe as the world leader for safe & sustainable road transport solutions"

<sup>17</sup>This is related to the 2050 Vision topic "Europe as the world leader for safe & sustainable road transport solutions"

# Master global competition in a responsible and social way and strengthen EU sovereignty<sup>18</sup>

## Research Needs and Questions

Prosperity and quality of life are key to maintain social consensus and unity of Europe. As supply chains have shown limited resilience in the past and might be abused to compromise the EU's sovereignty, Europe must find a way to guarantee a sustainable level playing field in international business, which may include some degree of autarchy in key technologies, such as IT, logistics and production, along with the required competency and capacity of education, science and engineering. Until now, competitiveness has nearly always relied almost exclusively on growth strategies, however, this seems not sustainable. Hence the real question is how to find and transition to new competitive models that are both socially responsible and sustainable.

- How to more reliably determine what does EU sovereignty look like in 2050, in a world that is climate-changed?
- How to create a fair, level playing field in the EU and in other markets (including issues of social responsibility etc.)?
- How to make best use of regulation for global competitiveness and still achieving the sustainability targets?
- How to stay competitive with the mobility system and associated cost in the EU, compared to other countries?
- How do competitive business models and cost structures fostering sustainability look like, if travel goes via borders of the EU and further - e.g. to UK, US, India and China?
- How to handle foreign investments in critical EU assets without jeopardizing sustainability targets & sovereignty?
- What are the consequences of losing production capacity? How to determine what we must not lose?
- How to stay attractive for production businesses (energy prices etc.)? How to generate added value in the EU in future?
- How can collaborative research on-site strengthen both the micro and industrial economy in the less developed countries together with the competitiveness of the European industry?

## Expected impacts

- Competitive business models that are compatible with long-term sustainability goals
- A circular economy and diversified supply chains that minimise the need for the import of strategic and critical materials from single sources
- Prices for energy and (raw) material that ensure that Europe remains an attractive business place for the production of essential technologies and achieves the sustainability targets.
- Regulation that makes foreign investments in EU attractive, while preventing to turn this into political power.

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<sup>18</sup>This is related to the 2050 Vision topic "Europe as the world leader for safe & sustainable road transport solutions"





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