STREnGth_M
Strengthening EU
Road Transport R&I

Deliverable D2.1

Future research needs in road transport

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Summary sheet

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Summary

Devising future road transport is a long-term process and requires close collaboration in related research matters, between all stakeholders, in both the public and private sectors. The STREnGth_M project, a Coordination and Support Action (CSA) co-funded by the EC and directly linked to ERTRAC, is helping to address this matter, by promoting sustainable road transport in Europe and globally. This report presents the results of Task 2.1 “Identify future research priorities in road transport” within STREnGth_M, namely the **new ERTRAC Vision 2050** and **systemic research needs** derived from this vision. Built on stakeholder consensus, with partnerships and associations actively involved, these results were developed in a series of workshops and online consultations.

The new **ERTRAC Vision 2050** is shaped by the complex web of societal, technological, geopolitical, economical and environmental influences. At its core, mobility is recognized as a fundamental right, essential for individual freedom and societal participation. The Vision is structured around five key sub-visions, which are describing the desired situation in 2050 within Europe:

- Europe as the world leader for safe and sustainable road transport solutions.
- Seamless mobility of people and goods for the benefit of all EU citizens.
- All-round protection: safety and security.
- Environmental sustainability: energy and resource efficiency, decarbonisation and excellent air quality.
- Highly efficient and resilient road transport: a key element of the European mobility system.

Comparing the Vision to the status quo, the following **systemic research needs** have been determined. These complement the research needs identified by the focus areas of the existing ERTRAC Working Groups, without significant overlap:

- Ensure seamlessness of mobility services while staying cost effective
- Joint forces for a well-functioning digital mobility ecosystem for people and goods
- 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
- Encourage societal support for rapid changes and investments in road transport
- Fair global boundary conditions and reduced dependencies, to enable sustainability
- Holistic optimisation of resources by maximizing the use of renewable materials and energy
- 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 the resilience of the road transport system
- Data collaboration to support safe and secure fully connected road transport
- Advancing Europe's leadership in road transport innovation
- Attractive and innovative framework conditions for research and education
- Harmonised curricula and professional carrier development models for life-long learning
- Master global competition in a responsible and social way, and strengthen EU sovereignty

Together, the **Vision** and the **systemic research needs** form relevant input for the next ERTRAC Strategic Research Agenda (SRA), preparing thematic input for the next Framework Programme. They highlight the importance of collaboration among sectors, such as transport, energy, urban planning and the digital infrastructure. Only by impactful collaborative research, involving actors all along the value chain can these systemic research needs be addressed successfully. Sustained public-private partnerships and targetted investments are essential for positioning the EU as a leader in safe and sustainable road transport, and for driving innovation in a critical sector for the EU's sovereignty, security, industrial competitiveness and prosperity.

List of abbreviations and acronyms

Acronym	Meaning
2Zero	Towards Zero Emission Road Transport European Partnership
ALICE	Alliance for Logistics Innovation through Collaboration in Europe
CAD	Cooperative and Automated Driving
CCAM	Connected Cooperative Automated Mobility
CSA	Coordination and Support Action
D	Deliverable
ERTRAC	European Road Transport Research Advisory Council
EC	European Comission
EU	European Union
FP	Framework Programme
IoT	Internet of Things
M	Month
MRL	Manufacturing Readiness Level
MS	Milestone
ODD	Operational Design Domain
pkm	Passenger * kilometers
R&D	Research and Development
R&I	Research and Innovation
ROI	Return on Investment
RTO	Research and Technology Organisation
RTR	Road Transport Research
SDGs	Sustainable Development Goals
SM	Social Media
SRA	Strategic Research Agenda
SRIA	Strategic Research and Innovation Agenda
tkm	Tonne * kilometers
TRA	Transport Research Arena
TRL	Technology Readiness Level

V2I	Vehicle to Infrastructure
V2X	Vehicle to X (anything)
WG	Working Group
WP	Work Package

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1 Introduction

1.1 Project abstract and reference to the work plan

STREnGth_M is a coordination and support action (CSA) co-funded by the European Commission (EC) under the call for project proposals topic HORIZON-CL5-2022-D5-01-11. The objective of this topic is to promote sustainable road transport in Europe and at international level. This CSA will contribute to a further harmonisation of research and innovation activities and, therefore, to European strategies for future transport systems. The action should also help reduce the time to market of new mobility solutions, by stimulating a wider participation in EU activities and supporting worldwide dissemination of the results therefrom. In addition, this CSA will support climate action and air quality improvement in line with the Green Deal's objectives and contribute to the United Nations (UN) Sustainable Development Goals.

The STREnGth_M project will contribute to the planning of research and innovation in Europe by identifying future research needs in the field of road transport, by updating and supporting the coordination of strategic research agendas and roadmaps in the field, and by facilitating continuous exchange between road transport research related Horizon Europe partnerships and platforms. Further, STREnGth_M will analyse research, innovation and cooperation capacities in Member States, explore funding instruments at national and regional levels, and assess national and regional roadmaps. Within STREnGth_M, the global progress of electric mobility will be tracked whilst measuring the feasibility of innovative solutions for prospective and emerging markets in Africa, Asia and Latin America. Thus, STREnGth_M will strengthen existing and even forge new links between European, national and regional programmes, and support structures for international cooperation task forces. The project partners will also identify barriers that may exist for the deployment of research results at European and international levels, and they will identify education and training actions to contribute to capacity building. In order to inform and engage the stakeholder community, policy makers and the civil society, the consortium will develop dissemination strategies and support the dissemination and organisation of European and international road transport research related events. This way, the dissemination of the contribution from road transport to the realization of the European Green Deal targets and the Paris Agreement can be ensured. Via the establishment of the Multiplier Group, the engagement of the various stakeholders will be facilitated during the project.

Designing road transport for 2050 is a long-term process that requires collaboration between all stakeholders in both the public and private sectors. Flexibility and adaptability to emerging technologies and societal changes are key to ensuring the success of such activities. However, only appropriate investment in research and development for existing and emerging transport technologies can help meet societal and economical goals.

Moreover, designing road transport in Europe for the future involves considering a wide range of factors, including sustainability, technological advances, population growth, urbanization and the environment. Therefore, thorough and consistent research and innovation planning is essential.

1.2 Related STREnGth_M Work Package and Task

In line with the goal of the STREnGth_M project, Work Package 2, entitled “Research and Innovation Planning”, has the objectives to:

- Ensure harmonized research and innovation plans in order to strengthen the European road transport research arena and Europe’s future transport systems
- Identify future research needs in road transport
- Layout the plan needed for the roadmapping activities at the ERTRAC Working Group level
- Support ERTRAC Working Group (and CO2 Evaluation Group) activities
- Facilitate cooperation between ERTRAC and road transport research related Horizon Europe partnerships
- Support the Horizon Europe mid-term review of the partnerships’ Strategic Research and Innovation Agendas.

This work package is divided into three tasks, with each of these tasks having a deliverable at their ending:

- Task 2.1: Identify future research priorities in road transport (M1-M22);
- Task 2.2: Update and coordinate strategic research agendas and roadmaps in the field of road transport (M1-M36);
- Task 2.3: Facilitate exchange between road transport related platforms and partnerships (M1-M36).

1.3 Objectives and scope of this report

The primary objective of this report Deliverable D2.1 is to give the context, method and findings of Task 2.1 “Identify future research priorities in road transport”. This task focused on developing a common vision of the future EU road transport system, identifying systemic research challenges and defining systemic research needs. The report contributes to the STREnGth_M project Milestone 16 “Future research needs”.

1.4 Connection to European Technology Platforms, Horizon Europe Partnerships and Stakeholder Associations

As reported on the ERTRAC website, the STREnGth_M CSA is directly connected to ERTRAC, the European Technology Platform (ETP) for Road Transport, as recognized and supported by the European Commission. However, other partnerships and associations have been actively involved throughout the Task to create a broad consensus. These are, for example, the 2ZERO Partnership, the CCAM Partnership, EARPA, EUCAR, CLEPA and POLIS.

2 Method of Task 2.1

Task 2.1 “Identify future research priorities in road transport” has been conducted within a three-step top-down process, complementing the bottom-up-approach by the ERTRAC Working Groups (WGs). The main results, **firstly a common vision of the future EU road transport system, secondly systemic research challenges and thirdly systemic research needs,** were derived in a series of workshops and online consultations, each building systematically upon the previous one:

The vision seeks to answer: How should European road transport look like by 2050? Once the vision is defined, the next step poses the question: How does the current state compare to this vision, and what systemic challenges prevent progress? This question is used to identify the challenges and obstacles to achieving the vision. From there, the systemic research needs ask: What critical topics must be researched to overcome these challenges and realize the vision? This structured flow ensured that each step builds on the findings of the previous one, creating a coherent path from thinking the future to actionable research plans.

In order to facilitate collaboration, associations and partnerships around STREnGth_M have been actively invited and involved throughout the process. Broad involvement was enabled by the combination of on-site kick-off workshops, where an initial framework was established, and subsequent online consultation phases, which allowed for comprehensive feedback and refinement. Representatives from key organizations, associations and partnerships, including e.g. ERTRAC, 2ZERO, CCAM, CLEPA, EARPA, EUCAR and POLIS, were actively engaged in this process. In order to bring together a good number of competent people with an excellent overview of EU road transport research, invitations to the physical workshops were sent to the Executive Group, Office Director, all Working Group (co-)leaders and the Supporting Institutions Group within ERTRAC, the Executive Board of the 2Zero Association, the Administration Board of the CCAM Association as well as to all contributors to STREnGth_M Work Package 2.

Vision workshop: The Vision Workshop was structured as a two-day event to kick-off the rethinking of the existing ERTRAC Vision 2050, which was published in 2018 and used as a starting point in the workshop. To create the atmosphere of visionary thinking, RWTH prepared several introductory steps, presenting a summary of the EC Sustainable and Smart Mobility Strategy, a recapitulation of the existing ERTRAC Vision 2050 and a keynote speech by an invited professor in transportation design. To align for a coherent vision in this interdisciplinary team, participants of the workshop agreed on a set of common values in form of attributes, which describe the character of road transport in 2050. They represent shared beliefs and ideals and foster unity among the stakeholders.

In the process of vision creation, understanding and integrating external influencing factors is critical. A vision that is informed by these elements can effectively anticipate changes and build adaptability into strategic planning. To make sure that interrelations to other sectors, future technological opportunities and trends as well as geo-political developments are considered in the vision, brainstorming sessions were conducted collecting factors to be covered. With these aspects in mind, the group revised the structure of the existing ERTRAC Vision and defined five key thematic areas (sub-visions), while the second day of the workshop focussed on re-

thinking, re-evaluating and refining the individual elements of the vision within these key thematic areas. The workshop concluded with planning online consultations and regular status updates to further broaden stakeholder engagement and guarantee transparency.

Online consultations involved, in a first step, those invitees to the workshops who could not attend physically. In a second step, these consultations were open to all members of the ERTRAC Plenary, representing a broad range of actors in road transport from academia and research providers, the automotive industry and energy suppliers to stakeholders from road infrastructure, cities and regions, national bodies and road user organisations.

Workshop on systemic research challenges: Based on the five key thematic areas (sub-visions) of the new vision, participants derived systemic challenges as a preparatory step for the workshop. This was done by comparing the vision to the status quo for each part of the vision. This process allows for the identification of specific barriers, inefficiencies and technical or regulatory limitations that must be addressed to achieve the desired status. The systemic challenges follow a standardized template to ensure uniform detail and clarity. This template establishes a link to the relevant vision item by comparing it with the current state. The template reads as follows:

- *"In order to [vision item], we must overcome [challenge] while considering [key contextual factors or conditions]."*

Within the workshop, challenges were added, refined and ranked with regard to their urgency and systemic relevance. Each participant had a limited number of points to distribute for the ranking. Another online consultation ensured consensus. The challenges were subsequently filtered for systemic perspective and clustered based on thematic similarities or content tags. Based on their content, overarching headings have been identified. These headings, along with the challenges and tags, formed the foundation for developing systemic research needs. An example of this process is illustrated in Figure 1.

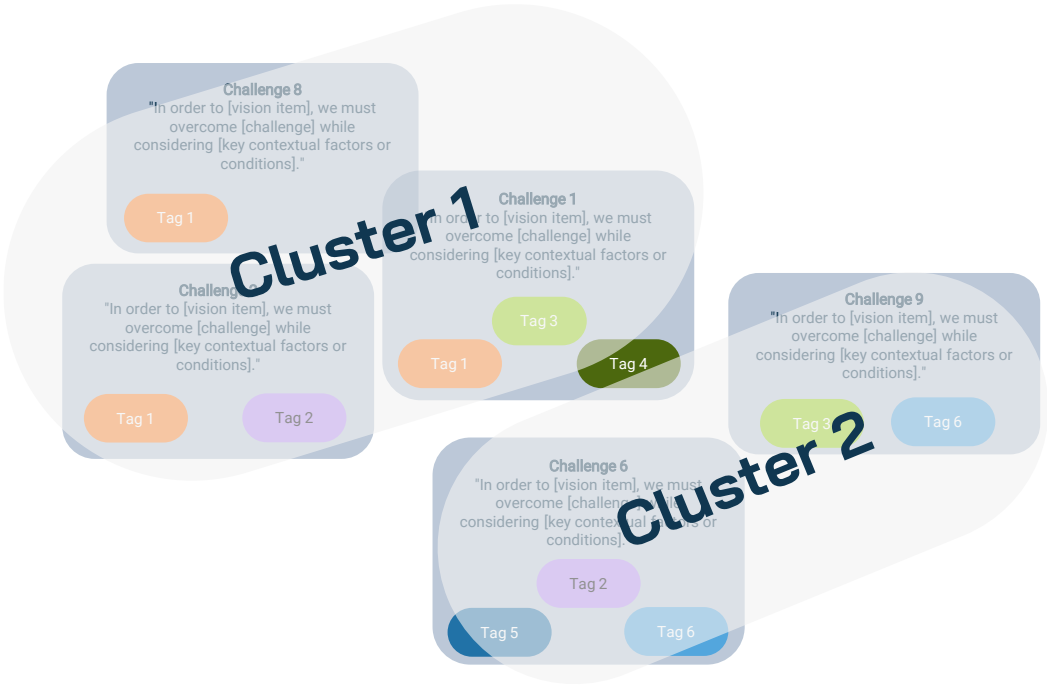

Figure 1: Content-clustering of systemic challenges to derive headings for the research needs

Workshop on systemic research needs: Participants of the third consecutive workshop agreed on these headings as the basis for the derivation of systemic research needs. They started phrasing, whilst on-site, key questions and expected outcomes for eight out of 15 identified research needs. This was followed by an online consultation with 13 responsible persons kindly coordinating the convergence and detailing of at least one research need each. This was done making use of a one-page template, summarizing the research need in key questions and formulating expected impacts:

- **Research Need Summary:** This section describes the R&I issues that need to be tackled in order to bring about the expected impacts. It contains key questions that give direction to the corresponding research.
- **Expected Impacts**: A brief summary of the potential impacts of the research findings on the field of science, society, industry, economy or other relevant areas. These are wider long-term effects enabled by the outcomes of the projects.

As a next step, these identified systemic research needs were reviewed in another online consultation with all ERTRAC Plenary members and analysed for interdependencies. The resulting one-pagers will serve as input for the next Strategic Research Agenda (SRA) by ERTRAC.

2.1 Results of Task 2.1

The results of the described method are a consistent vision for the future of EU road transport as well as 15 clearly identified systemic research needs supporting this vision. The structured approach that was followed ensures that research needs align with the overarching vision and address key challenges effectively. The research needs, described in the next chapters, are built on stakeholder consensus, enhancing the relevance of the proposed research directions. This top-down process complements the bottom-up approach of the ERTRAC Working Groups, ensuring that both strategic vision and the systemic research needs drive the development of a robust, responsive research agenda for the future of road transport in the EU.

3 A common vision of the future EU road transport system in 2050

3.1 Context and projection

The new Vision 2050 is shaped by a complex web of societal, technological, geopolitical, economical and environmental influences that demand a forward-thinking approach. At its core, this vision recognizes mobility – the capability to move people and goods from A to B – as a fundamental right, essential for individual freedom and full societal participation. Road transport is a vital enabler of social interaction and economic opportunity. It holds the highest share of total EU passenger transport use with 82% of overall pkm in 2018 [1] and the second highest share in the total EU freight transport with 24.9 % of overall tkm in 2022 (after maritime freight transport with 67,8% of overall tkm) [2].

In a society characterized by accelerated technological development, shifting demographics, and changing social values, the expectations and needs of road transport users are changing. By 2050, the mind-sets of users may be heavily influenced by factors such as digitalization,

personalization and climate consciousness [3]. Younger generations are placing more emphasis on work-life balance and on personal well-being, having purposeful experiences [4]. This is likely to influence their mobility choices. The status linked to car ownership may shift towards valuing access to advanced, eco-friendly, seamless mobility solutions, such as car-sharing and automated mobility services [5]. This is likely to drive demand for personalized, greener, more resource-efficient solutions. Younger generations increasingly value community spirit, purpose and societal equality [3, 4], highlighting the importance of diversity and inclusivity in transport solutions. Particularly as demographic shifts introduce higher demands for inclusion [6], an inclusive and accessible approach to transport will be crucial. Road transport must then not only be environmentally sustainable, but also equitable, ensuring that all segments of society benefit from safe, reliable and affordable mobility options. To enable this, younger generations expect technology to contribute positively to their communities, as they see technology as a natural extension of their lives [7].

As shown for society, the accelerating pace of technological advances is also reshaping the economy, the environment and global legislation in profound ways. Economically, technology leadership fuels growth, productivity and opens new markets. Rapid innovation in AI, automation and connectivity is altering job markets, necessitating ongoing education and skills development [8]. Environmentally, new technology can assist in energy efficiency and carbon reduction. Legislative bodies worldwide struggle to keep pace. The rapid integration of advanced technologies requires balanced, proactive approaches to regulation, sustainability, and economic restructuring to ensure equitable benefits across societies.

Global developments are increasingly reshaping the importance of competitiveness for the EU, as shifting geopolitical landscapes, technological leadership and economic power demand a proactive approach. The rapid rise of emerging markets, advances in technology spearheaded by global players, and the push for sustainability are intensifying the need for the EU to innovate and maintain a competitive edge in an increasingly multipolar world.

The new Vision 2050 embraces these influencing factors, setting a clear path towards a future in which mobility is accessible, sustainable and integrated into the changed landscape of 2050. For this, the previous ERTRAC Vision 2050, published in 2018, served as a blueprint. However, given the significant changes since then, it became essential to rethink the vision to reflect these new realities.

3.2 Common values

Adapting to the new circumstances given in the year 2024, common values for the future of road transport have been discussed by the stakeholders involved in the process according to the described method. The values listed in Table 1 support a vision that addresses environmental, societal, economical needs as well as resilience. Values such as sustainability, efficiency, and safety reflect a commitment to responsible and effective practices, while health, seamlessness and user-focus underscore the importance of well-being and acceptance. Emphasizing accessibility and inclusivity ensures that diverse needs are considered. The values of affordability and resilience underline a commitment to creating efficient and robust solutions. Trustworthiness in areas such as data security and privacy is paramount, while the values

competitiveness, sovereignty, and global relevance aim to boost international standing. By integrating these values, a vision could be developed that is both ambitious and grounded in actual needs.

Table 1: Common values for the new Vision 2050

Values (Road transport will be…)
Sustainable
Efficient
Safe
Healthy
User-focussed (considering the changed mindset)
Accessible, inclusive (for diversity in the EU population)
Seamless
Affordable
Resilient
Trustworthy (data security, privacy)
Competitive, sovereign, globally relevant

3.3 External influencing factors

As highlighted in the method and in the context of this vision, understanding and integrating external influencing factors is critical in shaping a vision. These factors - technological advances, geopolitical developments, social trends, and cross-sector interdependencies - define the broader context in which transport solutions operate.

Technological advances (see Figure 2) are transforming road transport. Innovations such as autonomous or highly automated driving, electric mobility, blockchain or advanced data analytics enable smarter, safer, and more user-centric mobility solutions. However, implementing these technologies requires infrastructure and regulatory support to address challenges amongst other technologies related to data privacy and cybersecurity.

Geopolitical factors (see Figure 3, left), including resource access, energy security, and trade conflicts, also play a critical role in shaping the feasibility of long-term transport strategies. Access to essential raw materials, such as lithium and cobalt for battery production, is fundamental for scaling-up electric mobility, while energy supply stability underpins the viability of electric-powered systems. Trade conflicts and supply chain disruptions can threaten these goals, highlighting the need for energy independence and resource security to ensure resilience.

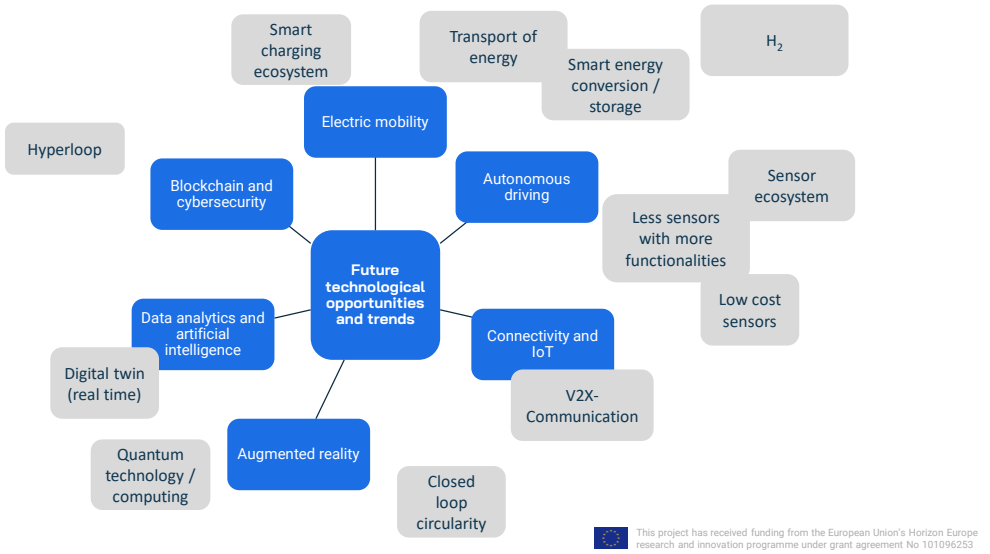

Figure 2: Future technological opportunities and trends

Social and economic trends (see Figure 3, right) are reshaping transport demands and expectations. Urbanization and increasing climate consciousness are driving demand for low-emission, resource-efficient transport models. Additionally, regulatory pressures and changing consumer values necessitate systems that are inclusive, accessible, and environmentally responsible. Urban centres, for example, require transport solutions that are not only efficient and adaptable to densely populated environments, but also have a good connection to rural areas.

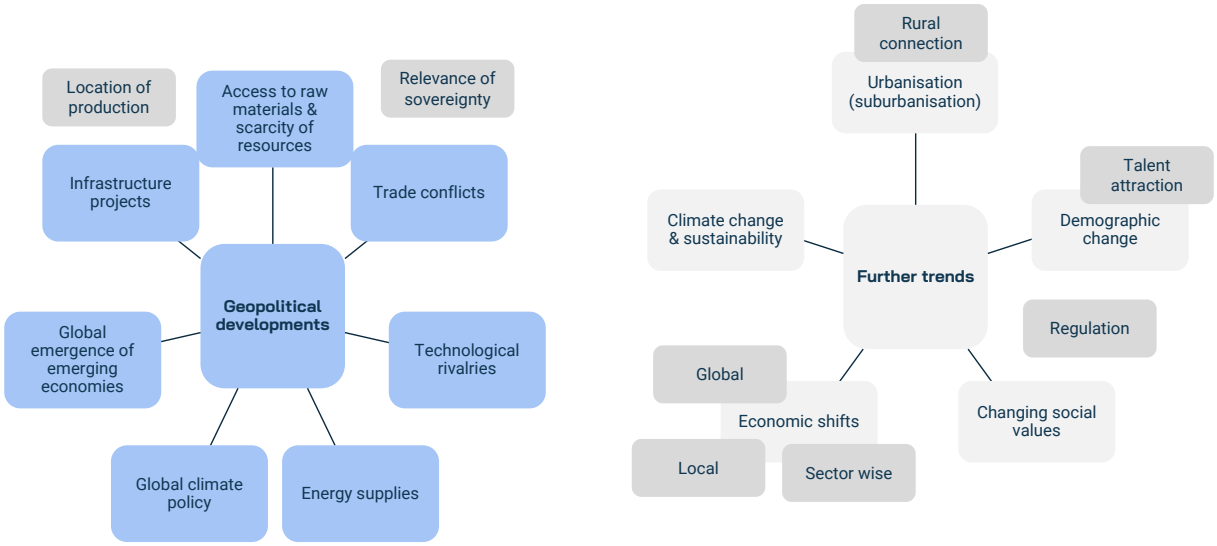

Figure 3: Relevant geopolitical developments and further trends

The transport sector's interconnections (see Figure 4) with the finance, legislation, energy, telecommunications, materials and education sectors emphasize the importance of cross-sector collaboration. Financial investment enables the development of infrastructure and supports innovation, while energy sector stability is crucial for advancing electric mobility and renewable energy integration. Telecommunications and data providers enable real-time data exchange and connectivity, which are essential for smart mobility solutions such as highly automated

driving. Material providers secure essential resources, and the education sector supplies the skilled workforce needed to drive these technological advances.

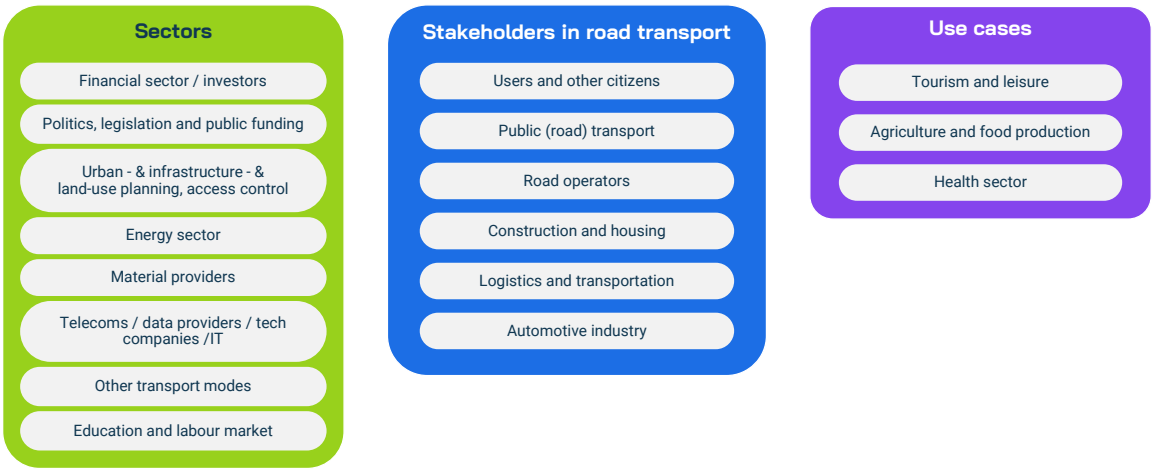

Figure 4: Interrelations of road transport with other sectors

3.4 Vision content & structure

Given this context, these values and external influencing factors, the resulting new Vision 2050, adopted by the ERTRAC Plenary on 24th June 2024, addresses major challenges such as climate change, air quality, demographic shifts, resource limitations, road safety and global competition.

3.4.1 Overall structure

In Figure 5 the structure of the new vision, which is organized as a matrix, structured across five distinct sub-visions, is illustrated. Each sub-vision is closely connected to the thematic areas of the ERTRAC Working Groups.

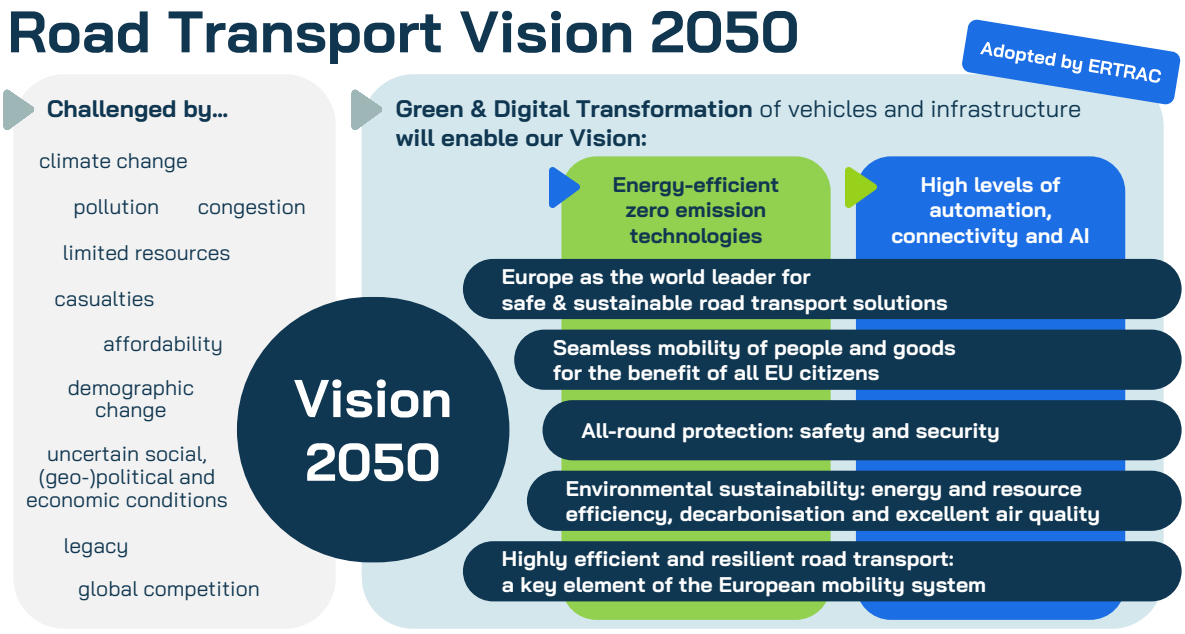

Figure 5: The ERTRAC Vision 2050

The Vision is structured around five key sub-visions, each of them defined by a vision statement and items describing the status quo in 2050:

- Europe as the world leader for safe and sustainable road transport solutions.
- Seamless mobility of people and goods for the benefit of all EU citizens.
- All-round protection: safety and security.
- Environmental sustainability: energy and resource efficiency, decarbonisation and excellent air quality.
- Highly efficient and resilient road transport: a key element of the European mobility system.

The vision outlines ambitious goals, such as global leadership in road transport solutions, seamless mobility, safety and security, environmental sustainability as well as efficiency and resilience. It emphasizes multimodal transport solutions, digital assistants and services as well as healthy mobility options.

The matrix also highlights key enablers - shown in the vertical bars - such as energy-efficient zero emission technologies and high levels of automation, connectivity and AI. These crucial elements in the green and digital transformation are currently addressed by the 2Zero and CCAM Partnerships. To realize this vision, several additional enablers are necessary, including secure access to the digital world across Europe, effective cooperation amongst stakeholders, technology, regulatory support and organizational changes. To highlight the relevance of this, cross-cutting enabling factors are addressed in a dedicated part of the vision.

Additionally, the vision emphasizes challenges, including e.g. climate change, road safety, demographic shifts and global competition. These challenges frame the complex environment in the pathway to achieve th ERTRAC vision for road transport in 2050.

The vision, described in detail in the following sections, aims to describe a sustainable, efficient and inclusive transport system that addresses critical environmental, economic and societal challenges, preparing for the upcoming EU Research Framework Programme (FP10).

3.4.2 Europe as the world leader for safe & sustainable road transport solutions

Vision: “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**.

- **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.

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

Vision: "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** offerings, satisfying 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.

* "Multimodal" referring to all modes of transport

- **Mobility concepts for people and goods are optimized to ensure 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.

3.4.4 All-round protection: safety and security

Vision: "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.

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

Vision: "Climate-neutral, zero pollution road transport satisfying circular economy and resource efficiency needs."

- **Zero pollution from road transport, i.e.:**
  - Rate of road transport-related air, water and soil pollution reduced to levels no longer considered harmful to health and natural ecosystems*.
  - **Significantly reduced noise emissions**.
  - **Transparent accounting schemes of residual emissions** from the complete life cycles of vehicles and infrastructure recognised as internalised costs of transport.
- **100% renewable energy and sustainable** 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 infrastructure.
  - **Resource efficient vehicle production** with minimum environmental impact.
  - **Circular economy** for vehicles and infrastructure – based on the 9Rs (refuse, rethink, 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.

* Definition of “zero pollution” according to EU Action Plan “Towards a Zero Pollution for Air, Water and Soil” [9]

** ”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 [10].

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

Vision: “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.

3.4.7 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.

4 Systemic research needs

4.1 Relevance of systemic perspective

As described in Chapter 2, Task 2.1 complements the efforts in the ERTRAC WGs with a cross-cutting approach. This systemic perspective gives insights amongst others in the complexity and dependency of the developments of the individual components of road transport.

4.2 Identified systemic challenges

Identifying challenges from the new Vision 2050 involved systematically comparing the current state of the transport system with the vision to highlight gaps and areas needing transformation, following the proposed template sentence. Each systemic challenge is associated with a specific sub-vision and is ranked based on urgency and systemic relevance. The introduction of content tags was used to analyse frequently mentioned topics within the systemic research challenges. All challenges have been catalogued and are included in the Appendix. Table 2 shows an excerpt.

Figure 6 presents the identified tags, with each standing for a covered topic. The recurrence of these tags underscores their significance and highlights the need for an integrated approach. This visual summary indicates that solutions for road transport must address multiple and diverse dimensions to be impactful.

Table 2: Excerpt of systemic challenges for "Seamless mobility of people and goods…"

Index (not ranked)	Challenge	Urgency	Systemic relevance	Tags
1	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.	7	2	Affordability; Society; User

2	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.	1	6	Affordability; EU unity; Platform
3	To promote sustainable mobility and illuminate the environmental impact and total cost of all modes of transport for users, we must eliminate intransparent 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.	3	3	External costs; User; Environmental impact

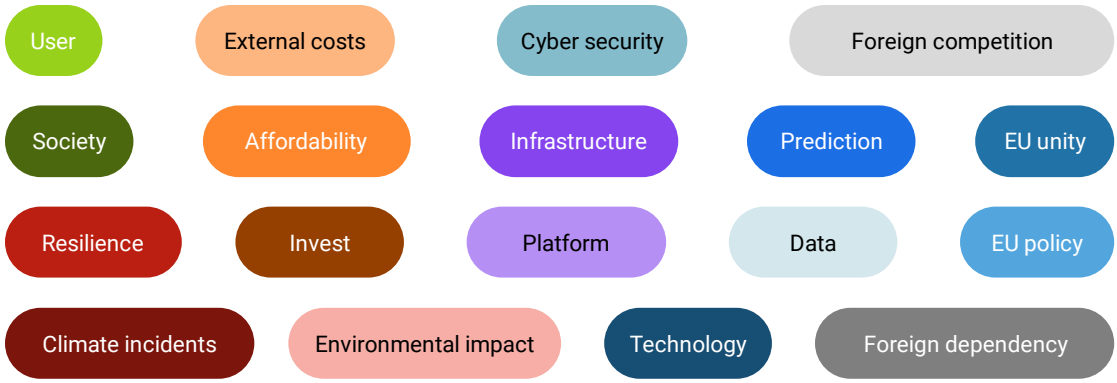

Figure 6: Tags, showing repeatedly addressed topics

4.3 Derived systemic research needs

The systemic research needs (see Table 3), developed on the basis of the identified challenges, are designed to complement the focus areas of the ERTRAC Working Groups by adding overarching topics. While the WGs address specific research areas, the systemic research needs provide broader themes that support these efforts, overarching without overlapping significantly with the specific areas of the WGs. This integrative approach ensures the WGs benefit from a holistic framework aligned with a shared vision while maintaining their distinct focus areas.

Table 3: Identified systemic research needs

Index	Systemic research need titles
1	Ensure seamlessness of mobility services while staying cost effective
2	Joint forces for a well-functioning digital mobility ecosystem for people and goods
3	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	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

As described in detail in chapter 2, each research need consists of two parts: a research need summary, in which key questions outlining the topic are formulated, and an expected impacts paragraph, pointing out the long-term effects on road transport that are expected. All systemic research needs have been catalogued and are included in the Appendix. Given here is an exemplary systemic need, addressing the challenge to ensure seamlessness while staying cost effective.

EXEMPLARY RESEARCH NEED: "ENSURE SEAMLESSNESS OF MOBILITY SERVICES WHILE STAYING COST EFFECTIVE

Research Need Summary:

- How to determine which public vehicles and services best meet rural and peri-urban transport needs with irregular demand, economic viability, and 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 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.

4.4 Interdependency of systemic research need

The identified systemic research needs (grey boxes - titles shortened) in road transport are strongly interconnected (see Figure 7), with insights and outputs from one research need feeding into others. The domains - Environmental, Societal and Governance - do not operate in isolation. Instead, they form a network where each research need supports the others. The arrows between research needs illustrate how outputs and insights from one area act as essential inputs for other areas, showcasing the systemic perspective.

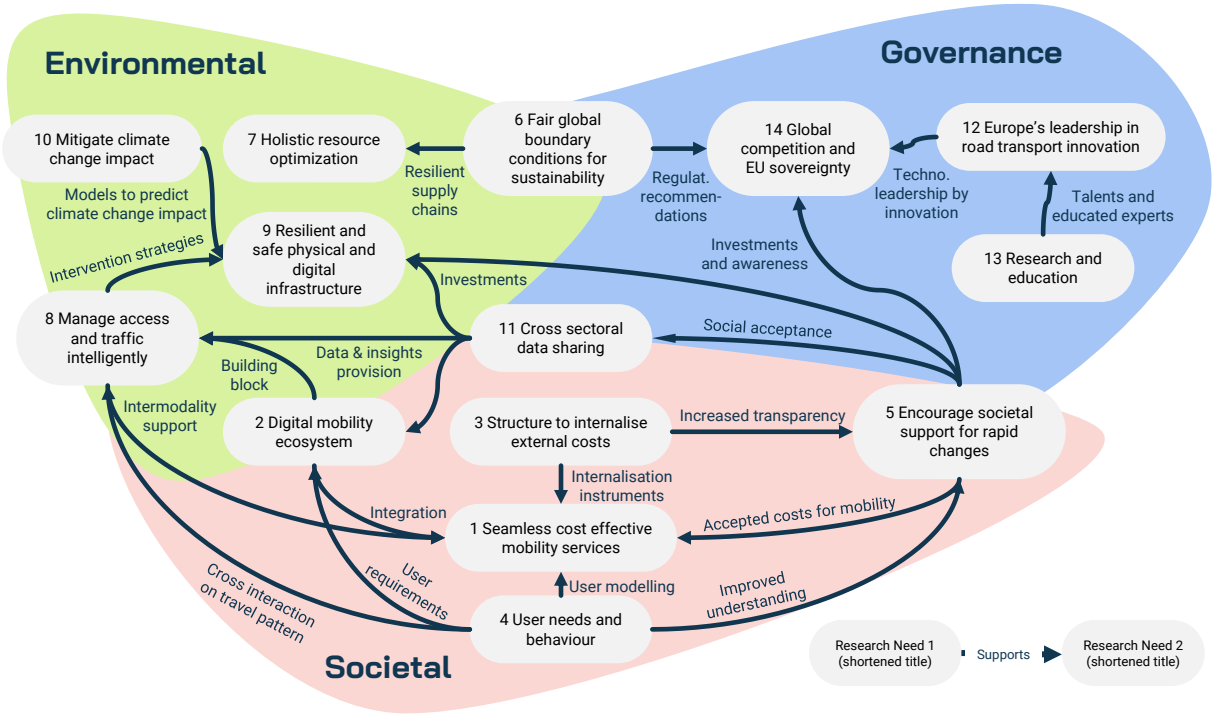

Figure 7: Interdependencies between research needs (research need titles shortened)

By mapping these interdependencies, the framework proposes a coordinated approach to advancing road transport, ensuring that each research need contributes to a sustainable, user-centred, and competitive transport ecosystem. The Environmental domain focuses on research aimed at sustainability, resource optimization and climate impact mitigation. The Societal domain encompasses research needs in the context of user behaviour, inclusivity, and mobility service accessibility. Governance research needs are geared towards regulatory frameworks, international competitiveness, and educational systems.

5 Conclusion and outlook

In summary, Task 2.1 followed a structured three-step process with broad stakeholder involvement to come to a consensus on future road transport research needs at the transport system level. Based on three dedicated face-to-face workshops and subsequent online stakeholder consultations, first a common vision of the future EU road transport system was developed, which the ERTRAC Plenary adopted as the new ERTRAC Vision 2050. Comparing this vision to the current status of road transport in the EU, important challenges were identified in a second step. Finally, a set of 15 systemic research needs was derived from these challenges, with each of these research needs outlined in a number of key questions and completed by expected impacts of such research.

With their overarching, cross-cutting character, these systemic research needs provide input to the WGs and complement their research roadmaps, in which these groups describe more specific needs for research within their thematic areas.

Altogether the research needs and the new Vision form relevant input for the next ERTRAC SRA preparing thematic input for the next Framework Programme. The new ERTRAC Vision 2050 and the systemic research needs emphasize the importance of collaboration among sectors such as transport, energy, urban planning, and digital infrastructure. Only by impactful, leading, collaborative research involving actors all along the value chain can these systemic research needs be addressed successfully. Moving forward, sustained public-private partnerships and strategic investments are essential for positioning the EU as a leader in safe and sustainable road transport and for driving innovation in a critical sector for the EU's sovereignty, security and prosperity.

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7 Appendix

7.1 Systemic research challenges in relation to the sub-visions

Table 4: Systemic research challenges in relation to “Europe as the world leader for safe & sustainable road transport solutions”

HEADING	INDEX (NOT RANKED)	CHALLENGE	URGENCY	SYSTEMIC RELEVANCE	TAGS
Advancing Europe’s leadership in road transport innovation	40	To create an environment attractive for research and innovation, we must overcome the increasingly complex EU-funding system of innovation, research and deployment	7	2	EU policy; EU unity
Advancing Europe’s leadership in road transport innovation	44	To strengthen Europe's innovation potential, we must bridge the gap between research and market innovation, facilitating the final steps towards industrialization by developing better instruments for bringing innovation to the market.	2	2	EU policy; EU unity
Master global competition in a responsible and social way, and strengthen EU sovereignty	41	To secure Europe's global leadership, we must overcome Europe's dependency on raw materials by surpassing the barriers to material reuse and recycling, taking into account economic conditions and effort while considering the global dimension of value chains economic partnerships and limitations imposed by European geology.	2	5	Foreign competition; foreign dependency; invest; EU unity
Master global competition in a responsible and social way, and strengthen EU sovereignty	45	To ensure that the core added value of vehicles is produced in Europe, we must meet the challenge of ensuring the economic viability of such production in Europe and the availability of the required workforce, while considering that other global regions are catching up with or even overtaking Europe in relevant technologies	3	0	Foreign competition; foreign dependency; EU unity

		and offer qualified workforce at relatively low hourly rates.			
Master global competition in a responsible and social way, and strengthen EU sovereignty	46	To establish mobility as a service (MaaS) and transport as a service (TaaS) models in Europe, we must compete against global companies capable of providing wide-reaching/supra-regional digital transport platforms and services, without the immediate need for profitability necessitating strategic responses that leverage European strengths in innovation, regulation and local market understanding.	2	1	Foreign competition; foreign dependency; platform; EU unity
Strengthen excellence in education and research in EU	42	To achieve global leadership in innovation and sustainability, we must meet the challenge of strengthening scientific excellence, while allowing leading scientists a greater degree of independence.	4	3	EU policy; EU unity
Strengthen excellence in education and research in EU	43	To provide excellence in education, research and training, we must overcome the challenge of introducing extensive reforms in the whole education systems of EU Member States, preparing people for a digitalised world and for global competition really following the paradigm of lifelong learning and significantly reducing reaction times for future reforms in our education system. We must consider that such reforms may face strong forces of inertia by defenders of the status quo.	1	3	EU policy; EU unity
Strengthen excellence in education and research in EU	47	To strengthen Europe's R&D, we must develop strategies to retain academic & engineering excellence in Europe.	0	0	EU policy; EU unity

Table 5: Systemic research challenges in relation to "Seamless mobility of people and goods for the benefit of all EU citizens"

HEADING	INDEX (NOT RANKED)	CHALLENGE	URGENCY	SYSTEMIC RELEVANCE	TAGS
Cost structure to internalise external costs and finance sustainability	3	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.	3	3	External costs; user; environmental impact
Cost structure to internalise external costs and finance sustainability	3.2	To create a transparent cost structure, we must reliably analyse and measure the resulting external costs and aggregate all necessary data.			Data; external costs
Cost structure to internalise external costs and finance sustainability	7	To fully include external costs (safety, health, pollution, damage to infrastructure) in the actual costs of road transport, we must establish an agreed cost structure and payment / charging system.	1	0	Affordability; external costs
Cost structure to internalise exter-	11.3	To adjust to new cost structures, we must develop new business models, business cases and communication.			Affordability

nal costs and finance sustainability					
Ensure seamlessness while staying cost effective	1	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.	7	2	Affordability; society; user
Ensure seamlessness while staying cost effective	8	To provide seamless connections to less populated areas, we must overcome the challenge of investing 98% effort to serve 2% of the population by finding an adapted and economical solution for less densely populated areas.	0	1	Affordability
Ensure seamlessness while staying cost effective; Joint forces for a well-functioning digital mobility ecosystem for people and goods	2	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 ensuring satisfying reliability and affordability requirements.	1	6	Affordability; EU unity; platform
Joint forces for a well-functioning digital mobility ecosystem for people and goods	5	To enable fully multimodal mobility as service, we must establish interoperable European digital platforms and digital ecosystems while considering homogenisation and connection of platforms and agreement on one form of ecosystem with agreed range of functions/features.	1	3	EU unity; EU policy; platform
Joint forces for a well-functioning digital mobility ecosystem for people and goods	9	To provide a good user experience, we must understand which policy actions are the strongest and most effective levers to enable change without over-regulating or reducing the users' autonomy.	0	0	EU policy; user
Improve the ability to understand and anticipate user roles, needs and behaviour based on existing and future values	2.2	To establish multimodal transport with its many (sustainability) benefits, we must identify and overcome the associated user inconveniences that prevent them from using it.			User
Improve the ability to understand and anticipate user roles, needs and behaviour based on existing and future values	4	To achieve intelligent solutions, we must better understand passenger and freight transport user needs, predict behaviour and how to overcome legacy situations.	2	3	User; prediction; data
Improve the ability to understand and anticipate user roles, needs and behaviour based on existing and future values	6	To achieve the acceptance of the backbone of urban mobility, we must tailor mobility to user needs and preferences and the willingness to pay while predicting the required capacity of transport, taking into consideration individual mobility will most likely remain the cornerstone of mobility even in 2050.	1	1	Prediction; affordability; user
Improve the ability to understand	10	To ensure seamless connections, intelligent solutions and information for users,	0	0	Data; user

and anticipate user roles, needs and behaviour based on existing and future values		we must integrate different data sources while overcoming the challenge of fragmented data landscape as well as tools and services.			
Improve the ability to understand and anticipate user roles, needs and behaviour based on existing and future values	11	To design efficient right-sized solutions more intelligently, we must understand what all means in different contexts: citizens, customers, businesses and safety.	0	0	User;
Improve the ability to understand and anticipate user roles, needs and behaviour based on existing and future values	11.2	To provide a good user experience we must understand the different roles of citizens and their corresponding needs.			Society; user

Table 6: Systemic research challenges in relation to "All-round protection: safety and security"

HEADING	INDEX (NOT RANKED)	CHALLENGE	URGENCY	SYSTEMIC RELEVANCE	TAGS
Data collaboration to support safe and secure fully connected road transport	31	To realize the vision of fully connected vehicles, road users and infrastructure, we must significantly enhance effective cross-sector cooperation ensuring seamless data sharing and integration across all stakeholders within the framework of regulatory boundary conditions and respecting legitimate business interests.	7	5	User; data
Data collaboration to support safe and secure fully connected road transport	33	To achieve safe, affordable, reliable physical and digital infrastructure, we must collect reliable data to describe and predict road transport system and user behaviour, and develop suitable performance indicators while considering the matters of cost, privacy and shared responsibility between different stakeholders, not least the combination of infrastructure, vehicles (of different kinds) and road users.	0	2	User; prediction; data
Protection against threats to system and passenger security	35	To ensure cyber-security we must prevent potential attacks/misuses on many digital access points while identifying and prioritising the cases with the highest risk for safety.	0	1	Cyber security; technology
Protection against threats to system and passenger security	39	To create all-round protection, we must ensure passenger and freight safety against robbery, theft, violence and vandalism.	0	0	
Protection against threats to system and passenger security	39.2	To achieve ubiquitous connectivity amongst all vehicles and road users through seamless real-time communication, data exchange and processing we must face challenges in data generation, access, availability andsophisticated processing via learning systems, and ensuring cybersecurity in an			User; cyber security; data; technology

		era, where quantum technologies may outpace current protective measures.			

Table 7: Systemic research challenges in relation to "Environmental sustainability: energy and resource efficiency, decarbonisation and excellent air quality"

HEADING	INDEX (NOT RANKED)	CHALLENGE	URGENCY	SYSTEMIC RELEVANCE	TAGS
Holistic optimisation of resources by maximizing the use of renewable materials and energy	12	To achieve the use of 100% renewable energy considering the demands of other sectors for such renewable energy, we must use available renewable energy effectively by reducing the absolute energy demand of the road transport system significantly while keeping balance with user's transport needs.	3	5	User; environmental impact
Holistic optimisation of resources by maximizing the use of renewable materials and energy	21	To provide truly energy and material efficient road vehicles, we must right-size passenger cars by providing intelligent solutions for the few cases in which the full transport capacity of today's cars is really needed (cut the peak without anybody noticing) while considering the irrational factors driving the interest in over-sized vehicles.	0	1	User; environmental impact
Holistic optimisation of resources by maximizing the use of renewable materials and energy	13	To provide affordable energy supply and associated services anytime and wherever required, we must distribute energy to the different locations considering the time-wise varying demands and deploy interoperable electric charging infrastructure at large scale all over Europe while considering peak demands, local regulations and the economic viability of such infrastructure.	6	2	EU policy; infrastructure; invest
Encourage societal support for rapid changes and investments in road transport	14	To accurately measure environmental impacts and progress through action, predict future scenarios or provide actionable information to users supporting the high rate of change, we must develop and implement accurate and comprehensive metrics for system assessment while ensuring the system measurement is without bias.	2	6	Society; prediction; invest
Encourage societal support for rapid changes and investments in road transport	16	To reach our vision for 2050, we must overcome the challenge of low historical rate of change by investing into the needed upstream infrastructure (energy and road system) while not expecting a soon ROI.	3	1	EU policy; invest; society; infrastructure
Encourage societal support for rapid changes and investments in road transport	17	To reach our vision for 2050, we must increase societal acceptance and willingness for a high rate of change without external disruptors (e.g. war).	2	2	Society
Fair global boundary conditions and reduced dependencies to enable sustainability	15	To achieve resource efficient vehicle production with minimum environmental impact, we must establish a level playing field on a global scale with limited influence of foreign local policies.	3	1	Environmental impact; foreign competition;

					foreign dependency
Fair global boundary conditions and reduced dependencies to enable sustainability	20	To create a sustainable, stable and safe energy supply in Europe, we must overcome the dependency on a single source of energy and on external conflict parties while securing efficiency and sustainability in energy by diversifying and homogenizing our energy portfolio with renewable and sustainable options.	0	2	Foreign competition; foreign dependency; environmental impact
Fair global boundary conditions and reduced dependencies to enable sustainability	22	To realize circular economy for vehicles and infrastructure based on the 9Rs, we must overcome the challenge of transitioning to new industrial business models and decoupling the volume of road transport from economic prosperity and perceived quality of life while considering that global competitors may follow different paradigms.	0	1	Environmental impact; foreign competition; affordability

Table 8: Systemic research challenges in relation to "Highly efficient and resilient road transport: a key element of the European mobility system"

HEADING	INDEX (NOT RANKED)	CHALLENGE	URGENCY	SYSTEMIC RELEVANCE	TAGS
Create resilient and safe physical and digital infrastructures	25	To design road transport resilient, we must overcome the challenge to create road transport infrastructure that is reliable and fail-operational at all times, while being affordable.	1	3	Resilience; infrastructure; affordability
Create resilient and safe physical and digital infrastructures	28	To improve the overall strength of the system, we must improve the climate resilience of individual system building blocks identifying and prioritising the areas with the greatest weaknesses.	0	1	Resilience; climate incidents
Create resilient and safe physical and digital infrastructures	30	To create a resilient road transport system, we must establish a unified approach to safeguarding against cyber-attacks, vandalism and abuse ensuring a consistent level of protection across all facets of infrastructure and digital interfaces.	0	0	Cyber security
Manage access and traffic intelligently	26	To implement adaptive and flexible traffic management, we must predict the transport demand by channelling all necessary transport tracking and infrastructure status information while ensuring user and data privacy and independence of global competitors.	0	3	User; data; prediction
Manage access and traffic intelligently	29	To implement intelligent and dynamic access regulation, we must overcome the challenge to not exclude users from access in general but provide access on a fair basis.	0	0	User; affordability

Predict and mitigate the impact of climate change on the road transport system	24	To create a truly resilient road transport system, we must predict and anticipate all the impacts of climate change on road transport infrastructure and users.	5	3	Prediction; resilience; climate incidents; infrastructure
Predict and mitigate the impact of climate change on the road transport system	27	To reduce the impact at all incident and disruptive levels, we must detect and track events (congestions, accidents, weather incidents…) in real time and predict such events as well as create technology (e.g. model-based) to derive precautions and mitigation strategies.	0	1	Prediction; resilience; climate incidents

7.2 Systemic research needs

7.2.1 Ensure seamlessness of mobility services while staying cost effective

Research Need Summary:

- How to determine which public vehicles and services best meet rural and peri-urban transport needs with irregular demand, economic viability and 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.

7.2.2 Joint forces for a well-functioning digital mobility ecosystem for people and goods

Research Need Summary:

- What are the steps to get towards an integrated digital ecosystem? How do interfaces look like across platforms? Which functionalities are needed for interoperability?
- How would an economically efficient solution look like with regards 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 can 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 & ecosystem for "purpose-driven services" (CO_2 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

7.2.3 Cost structure to internalise external costs and finance sustainability

Research Need Summary:

- 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.

7.2.4 Improve the ability to understand and anticipate user roles, needs and behaviour based on existing and future values

Research Need Summary:

- How to close the gap between what people say is important and how they actually behave?
- How can we differentiate between explicit user needs, and intrinsic user needs?
- How to understand the factors, mechanisms and real reasons why users won't 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 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 timely anticipate upcoming changes and created 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 behavior, highlighting the importance of HMI development and user-centric approaches

7.2.5 Encourage societal support for rapid changes and investments in road transport

Research Need Summary:

Technologies are evolving fast, inducing fast changes (economical & organizational) and bringing about the need for rapid changes and investments. For this we need societal acceptance. This 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 who?
- 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 objectives, and short-term objectives whose impact is society-related.

7.2.6 Fair global boundary conditions and reduced dependencies to enable sustainability

Research Need Summary:

- 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.

7.2.7 Holistic optimisation of resources by maximizing the use of renewable materials and energy

Research Need Summary:

- 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 since the design level (including material choice)?
- How to combine a right sizing approach with a predictive component reuse (2nd life) strategy to optimize the use of critical materials according to a holistic circular economy? What is the right balance between 2nd 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_2 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^{nd} life).
- Improved resilience of EU energy system, facilitated integration of renewable energy sources.
- Implementation of a paradigm shift in freight transport, emphasizing sustainable practices and consumer responsibility.

7.2.8 Manage access & traffic intelligently

Research Need Summary:

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 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 be the role 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 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 (SUMPs).
- 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.

7.2.9 Create resilient and safe physical and digital infrastructure

Research Need Summary:

Sustainable, safe, and resilient solutions for physical and digital infrastructure shall be designed at 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 it for the effects of all disruptive events, especially considering climate change, vandalism, abuse and terror attacks? How to prepare it for military attacks and military 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 intermodal mobility on overall resilience? How to support the resilience of the physical infrastructure by CCAM?
- How to develop maintainance 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 ofise validation tools and scenario databases?

Expected Impacts:

- Effective and cost efficient increase of safety and resilience of the physical and digital infrastructure.
- Solutions to handle vandalism, cyber security threats and 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.

7.2.10 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

Research Need Summary:

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 & 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.

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

Research Need Summary:

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?
- 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 asses 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.

7.2.12 Advancing Europe's leadership in road transport innovation

Research Need Summary:

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?
- 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 asses 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.

7.2.13 Attractive and innovative framework conditions for research and education

Research Need Summary:

- 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 programs?
- How must legislations 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.

7.2.14 Harmonised curricula and professional carrier development models for life-long learning

Research Need Summary:

- 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 in 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.

7.2.15 Master global competition in a responsible and social way and strengthen EU sovereignty

Research Need Summary:

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 sustainable look like, if travel goes via borders of the EU and further - e.g. to UK, US, India, 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, micro and industrial economy in the less developed country and 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.