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D4.3 Transport research agenda

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Abbreviations

AI	Artificial Intelligence
ANP	Analytical Network Process
CO_2	Carbon Dioxide
EU	European Union
EU 27	European Union in the period 2007-2013 with 27 member states
EV	Electric Vehicle
ICT	Information and Communication Technology
IMO	International Maritime Organization
IT	Information Technology
ITS	Intelligent Transport Systems
I2V	Infrastructure to Vehicle
MaaS	Mobility as a Service
NGO	Non-Governmental Organization
R&D	Research and Development
TEN-T	Trans-European Network - Transport
V2I	Vehicle to Infrastructure
WP	Work Package

Executive summary

The mobility system is about to change in a fundamental way. Technological innovation, political decisions and new mobility concepts as well as social and economic trends lead to a system transformation. As the future transport system will differ from today, research has to be adapted to upcoming requirements of this new system. The present deliverable provides therefore a blueprint of a new and holistic research agenda, consisting of key research and innovation pathways for the future as well as blind spots beyond mainstream research that aim to support a system transformation and re-organization of the mobility system consistent with political goals of the European Union.

The present research agenda takes into account two main streams of trends, which define the main R&D needs in transport for the future:

1. *Internal trends* of the transport system: revolutionary technological developments will lead to a fundamental change of the transport system affecting supply side, markets, mobility services and vehicles. Form and effects as well as related risks and opportunities of these trends are still unknown.
2. *External trends* affecting the transport system: the trends come along with pressure to redesign the system to address climate change, emission problems, high density in cities, health and safety issues. Those trends lead to risks and a need to react, also providing opportunities for Europe to shape and improve the transport system.

In this respect, shaping the transformation of the transport system to cope with the predicted developments will be the main issue in the future. R&D will play a key role here, as it is crucial in analysing and understanding the problems, developing solutions as well as enabling transformation as guided development of the transport system towards a desired direction. In addition, funding for R&D will be the political instrument of directing innovation and development towards addressing both the mentioned internal and external issues.

To conclude, the identified research fields within the present research agenda are part of different dimensions, such as science, policy, society or the economy. However, all of them are depending and affecting more than one dimension, reflecting the complexity of the transport system. The change in turn is fundamental and more than anything else the precondition for achieving a transformation of the transport system, an energy revolution and the implementation of resource thinking is a cultural turn towards sustainability in its original sense of enabling our future.

1 Introduction

The overall objective of the INTEND project is to deliver an elaborated study of the research needs and priorities in the transport sector utilising a systematic data collection method. One of the main elements of the INTEND project is the review of pertinent literature (EU and international research projects including strategic research agendas, studies or roadmaps) in order to identify future technologies for each transport mode (road, aviation, rail, maritime) as well as infrastructure and transport systems which will be treated horizontally. The INTEND project will also review past futurology projects and recent futurology studies in order to present future mobility concepts. To ensure validity of the results, the Analytical Network Process (ANP) will be used to determine the prioritized elements in all clusters (technological advances, megatrends and political imperatives) for successful implementation and realization of key transport concepts of the future. Finally, INTEND will develop a transport agenda that will pave the way to an innovative and competitive European Transport sector. The project is driven by three main objectives:

- to define the transport research landscape
- to define the Megatrends and their impact on research needs
- to identify the main transport research needs and priorities

In order to enable a wide range of stakeholders to gain access to the results, INTEND will develop an online platform, the INTEND Synopsis tool that will be a dynamic knowledge base repository on the major developments in the transport sector. This will provide a visualisation of INTEND's main outcomes. The basis for the platform will be the Transport Synopsis Tool which has already been developed under the project RACE2050 coordinated by TUB. The repository will be updated and integrated into the INTEND website to provide a comprehensive picture of all forward-looking studies focusing on technological developments, megatrends and policies.

1.1 WP4 in the frame of the INTEND project

Global megatrends and socio-technical shifts in the transport industry are about to change the whole sector in a fundamental way. Besides future trends and weak signals affecting transport and their related research needs, it is necessary to face systemic change. New technologies and mobility concepts not only allow us to organize and optimize the transport system in a different way but will also provide solutions beyond traditional transport modes and thus change the transport market. Business opportunities for innovative operators will change the transport market and lead to a redesign of the transport system. In particular the field of system re-organisation has a need for research and development (e.g. in ICT, system operation or resilience). Thus, guidelines for a forward-looking transport sector need to be based on an understanding of the nature of such a systemic change and the research needs arising from it. The main objective of WP4 is to deliver directions for a forward-looking transport sector. The specific objectives include:

- To develop a sketch of the future transport system (D4.1)
- To identify gaps between ongoing R&D streams in the field of technologies and the development of the mobility system (D4.2)
- To deliver a blueprint on transport needs, priorities and opportunities – which include, in particular, blind spots beyond mainstream research (D4.3)

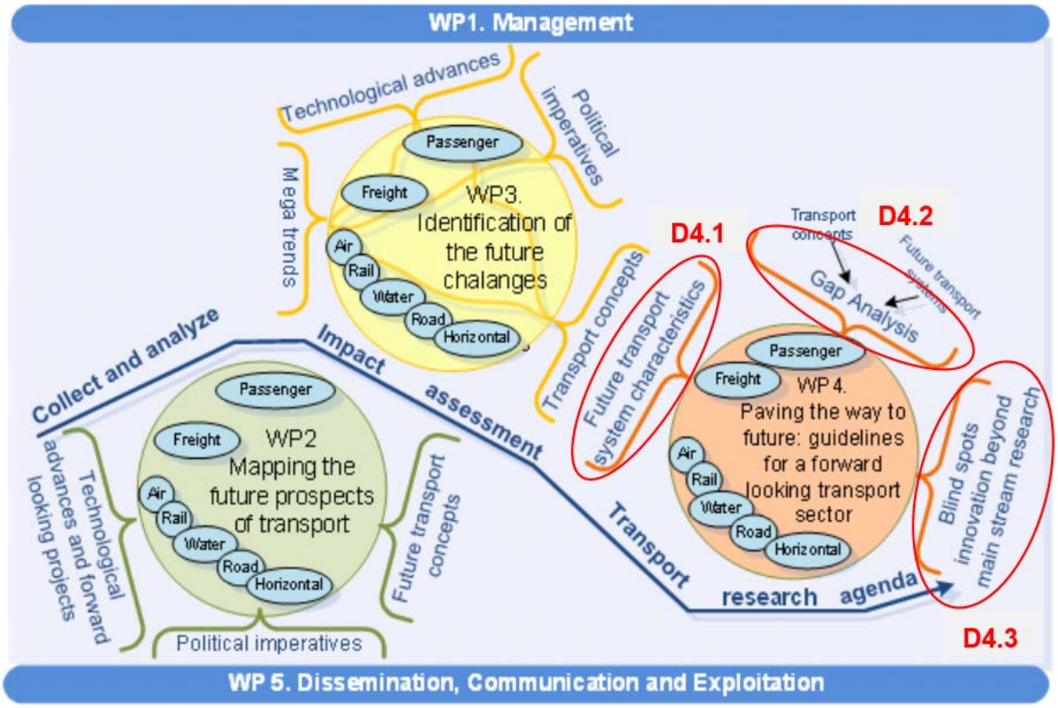

Figure 1: The INTEND workflow and relations of D4.3 with other work packages

1.2 D4.3 Transport research agenda

Based on the results from previous work packages and the preceding tasks in WP4, T4.3 aims to identify research needs, priorities and opportunities coming along with the transforming transport system (as characterized in detail in D4.1), resulting in a blueprint of a **transport research agenda (D4.3)**. Results of this task include in particular:

1. **Blind spots beyond mainstream research:** the inertia of the transport sector and the lasting effect of traditional research focus of the industry and policy-makers can create lock-in effects, which prevent innovation beyond mainstream research. T4.3 aims therefore to identify these blind spots, based on previous WPs and T4.1 results.
2. **Future priority research needs:** the combined effect of future technologies, global megatrends, including new market conditions, and strictly transport-related shifts asks to define a new research agenda that should not just address identified problems and gaps, but also show promising fields contributing to general social and economic development. Although, research needs revolve mainly around emerging technologies, megatrends, etc., the factors affecting the success and establishment of these technologies are not always related to the technologies themselves. Instead, these success factors could be related to other stakeholders. T4.3 will therefore look into needs for synergies and factors that will allow these research needs to become reality (e.g. new mobility paradigms), to achieve a more holistic outcome.

1.3 Organisation of the report

This report provides an analysis of future transport research needs and priorities, including key research and innovation pathways for the future. The report is divided into five chapters with Chapter 1 being the introductory, providing the purpose of this study. Chapter 2 presents the research approach and methodologies pursued in T4.3 with a special focus on the synthesis of the key results of different WP's within the INTEND project. Chapter 3 provides a broad overview of potential future research topics, including gaps and blind spots in transportation research. In Chapter 4, key results from the INTEND project are summarized and prioritized according to the urgency of actions needed in a research agenda for future transport research, focussing on a systemic transformation and re-organization of the mobility system towards sustainability.

2 Research approach and methodologies

The transport system is about to change due to political decisions, technological innovation, new mobility concepts and their interaction with society. Thus, research needs related to the future transport system will differ from today depending on the mentioned changes. T4.3 aims therefore to identify future priority research needs and opportunities coming along with the transforming transport system. In this final step, key results from the different work packages in the one-year research project INTEND were compared in a comprehensive synthesis and corresponding gaps and future fields of research were identified, including a set of blind spots in transportation research that go beyond mainstream research and that need to be given more attention in the future.

To approach the targets set in T4.3, the following research questions were conductive:

- *What policies is the European Union pursuing, in order to ensure long-term competitiveness of the transport sector and how are they correlating with trends in research and development?*
- *What are the blind spots in transport research that create lock-in effects and prevent innovation beyond mainstream research?*
- *What are the future research needs that may support social and economic development in Europe?*

To answer the first research question, a **literature analysis** was carried out, considering pertinent literature of the European Union about visions, goals and strategies of the future development of the European transport sector. The second and third research questions were answered through an interpretative process and **synthesis of the main outcomes** of all WPs with the key visions, goals and strategies of the European Union (as elaborated in the initial literature analysis in T4.3). This resulted in an identification of gaps and blind spots beyond mainstream research that further on formed the basis for the elaboration of a transport research agenda, showing promising fields of research that may have the potential to contribute to social and economic development in the future.

The following figure shows the approach pursued in the synthesis process of the key results elaborated in the one-year research process of the INTEND project in more detail and points out the different levels of analysis with the corresponding inputs from the INTEND WP’s that were considered in this final work step. The various analysis units are briefly described below.

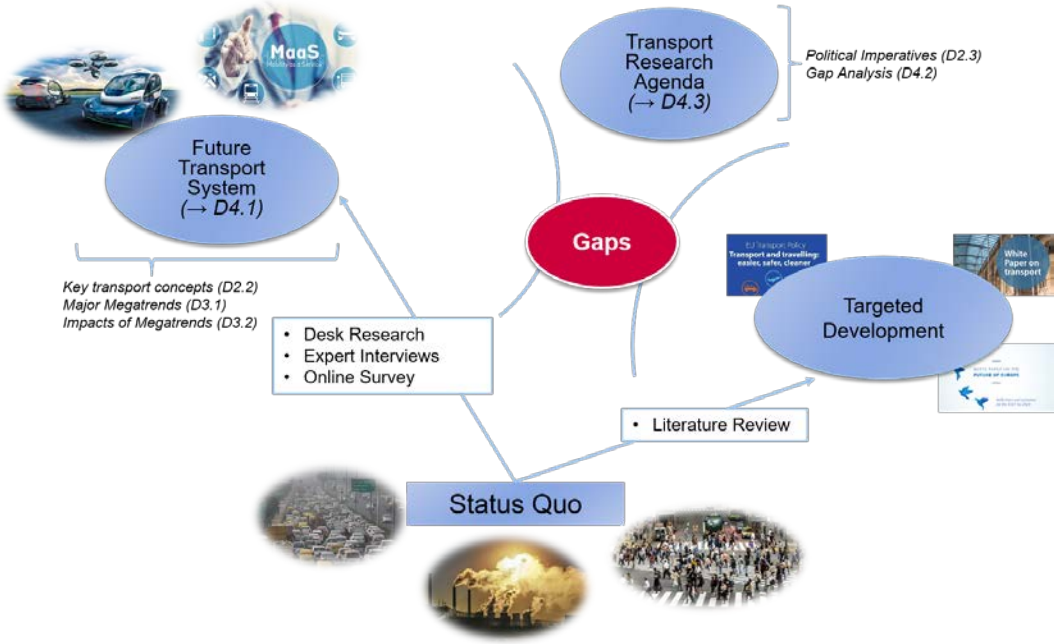

Figure 2: Synthesis approach in T4.3 (Source: ZHAW)

The **Status Quo** describes the situation, if nothing else is being done and we continue to live as before. As a result, e.g., climate targets will not be achieved, the growth paradigm will prevail and the negative consequences of this development will probably be felt fairly soon in various areas of life. This "present" state was derived from the characterization of the model of a transport system with its various constituting elements in *D4.1 Sketch of the future transport system*.

In order to prevent the development as outlined before, the European Union sets various goals, policies and strategies to ensure e.g. innovation and long-term competitiveness in the different sectors of the European Union. Based on the initial literature analysis in T4.3, key policies, visions and strategies were included into the analysis at this level of the synthesis process, resulting in a picture of the **Targeted Development** of the European Union.

The **Future Transport System** represents our visionary system state of the future, including in particular the key results from D4.1. Based on the literature review in T4.1, it delineates the major trends currently emerging within the different elements of the transport system. Furthermore, it includes the major transport concepts as elaborated in D2.2 and key megatrends and their impact on the transport system as elaborated in D3.1 and D3.2.

The future transport system as well as the strategies, policies and visions of the European Union, are being confronted with various barriers/challenges, weak signals and opportunities, which delineate the visionary system state from the current state of the art. Depending on the nature of the latter, trends that we see emerging today may be able to establish themselves within the system, remain in niche existence or disappear completely from the surface. The final step of the analysis was therefore to identify **Gaps and Blind Spots** in transportation research, tackling the challenges and opportunities mentioned before to become trends and developments reality in the future, including results from *D4.2 Gap Analysis* and *D2.3 Political Imperatives*, resulting in the present ***D4.3 Transport Research Agenda***.

2.1 Definition of target values

As a starting point for the synthesis of the results coming from the different WPs and the previous tasks in WP4, target values were defined to allow a comparison of challenges and potential fields of research in mobility and transport elaborated in the different WP's with the aspired development of the transport sector by the European Union. For this purpose, a short desk research on key visions, goals and strategies was carried out, focussing on the latest published policy papers of the European Union with a specific focus on sustainability in mobility and transport. It has to be noted though that this desk research was very concentrated and non-extensive since this step was merely about defining a maximum of three target variables, which were integrated into a conflict matrix in order to subsequently identify gaps in transportation research by comparing the target variables with challenges and potential fields of research in mobility and transport. The following sources were examined in more detail to derive target variables for the conflict matrix:

- European Commission, 2011. White Paper on Transport. Roadmap to a single European Transport Area – towards a competitive and resource-efficient Transport System.
- European Commission, 2013. General Union Environment Action Programme to 2020. Living well, within the limits of our planet.
- European Commission, 2016. A European Strategy for Low-Emission Mobility. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions.
- European Commission, 2017. White Paper on the Future of Europe. Reflections and scenarios for the EU27 by 2025.

The literature analysis has shown that the most relevant source, particularly with regard to EU sustainability objectives in mobility and transport, is the most recent White Paper on Transport. The following three target variables with corresponding sub goals were derived from the 2011 White Paper on Transport for further analysis:

Target variable 1: Development of new and sustainable fuels and propulsion systems

- Break the oil-dependence
- Clean urban transport
- CO_2-free city logistics
- Low-carbon sustainable fuels
- CO_2 reduction in the maritime industry

Target variable 2: Optimising the performance of multimodal logistic chains, including greater use of energy-efficient transport modes

- Shift from road freight to rail or waterborne transportation
- Efficient and green freight corridors
- Complete European high-speed rail network
- Medium-distance passenger transport mostly by rail
- EU-wide multimodal TEN-T 'core network'
- High-quality and capacity networks with corresponding information services
- Connected airports to (high-speed) rail networks
- Connected seaports to rail freight and inland waterway systems

Target variable 3: Increasing the efficiency of transport and of infrastructure use through information systems

- Modernised air traffic management infrastructure
- Equivalent land and waterborne transport management systems
- European global navigation satellite system (Galileo)
- European multimodal transport information, management and payment system
- Zero fatalities in road transport
- Safety and security in all modes of transport
- Application of 'user pays' and 'polluter pays' principles

2.2 Gaps and blind spots in transportation research

In order to simplify the further descriptions and to prevent misunderstandings, the terminology of gaps and blind spots in transportation research must first be clarified:

The term "gaps" refers to the need for research resulting from the new character of the future transport system - which research has to be done in order to achieve/enable it, including the political goals. These gaps can be derived from recent developments within the transport system plus impact factors and trends; but they are so to say rooted in the given system inheriting a certain path-dependency.

"Blind spots" goes beyond this, trying to identify new fields of research making use of the challenges and opportunities coming up with the transformation of the transport system. In this we tried to include a perspective of thinking out of the box, and liberating thinking for research from historically driven transport research. This perspective is meant to identify research fields beyond scientific communities and society's mainstream, which are open for disruptive innovation, research in other fields than transport but with potential use for it, bottom-up research agendas etc.

To identify gaps and blind spots in transport research, a conflict matrix was created, containing the most relevant strategies of the European Union for future transport (see the previous chapter) in the columns and identified challenges and potential fields of research within the rows. The formal structure of the identified gaps and research topics within the conflict matrix was adapted to the thematic structure from the trend research in *D4.1 – Sketch of the future transport system*, which was derived from an existing systemic model for mobility and transport.

With this grid as a basis, underrepresented research topics resulting from the desk research in D4.1 as well as from the expert's assessment in the qualitative Interviews and the online survey in D4.1 were assigned to the corresponding thematic field. In addition, results from D*4.2 Gap Analysis* were included in this step. D4.2 analysed advantages of each of the transport concepts of the future elaborated in *D2.2 Report on key transport concepts of the future* as well as the obstacles that appear on their path of realization. By cross-checking the breakthroughs and the obstacles of the transport concepts of the future, existing gaps were identified and areas for future priority transport research programs defined. Altogether, this resulted in an extensive list of potential future research topics in mobility and transport, providing the basis for a new holistic research agenda in transportation that contains potential key research and innovation pathways for the future.

In addition, a problem-oriented interpretative approach was used to identify blind spots in transport research that aimed to identify additional and previously neglected needs in R&D. Those blind spots may be crucial to overcome possible barriers/challenges that inhibit currently the implementation of emerging trends as well as to strengthen existing opportunities in order to enable a faster implementation of emerging trends within the system.

Results from this work step were further discussed in a workshop in Brussels with representatives of the European Commission and at the final conference in Belgrade (ICTTE Belgrade 2018) in a separate session with mobility experts from Europe.

2.3 Research agenda for future transport research

Based on the identification of gaps and blind spots in transportation research, including key outcomes from D4.2 Gap Analysis, future research needs & priorities were defined in a final work step, resulting in a blueprint of a transport research agenda, consisting of key research and innovation pathways for the future. These are expected to have a major potential for supporting a system transformation and re-organization of the mobility system in a holistic way towards sustainability and have therefore been prioritized according to the urgency of actions needed. In addition, key political imperatives (D2.3) and technological advances were taken into account in the development of the future priority research fields, considering as well key megatrends and their impacts on transportation research.

3 Research topics in mobility and transport

In this chapter, all underrepresented research topics resulting from the desk research in T4.1 as well as from the expert's assessment in the qualitative Interviews and the online survey in T4.1 are briefly described. These also include the most important gaps from *D4.2 Gap Analysis*[1] and the blind spots in transportation research derived from the analysis. This provides the basis for a new holistic research agenda in transportation that contains potential key research and innovation pathways for the future. The formal structure of the identified gaps and research topics (see Figure 3) is based on the structure of the trend research in *D4.1 – Sketch of the future transport system*, which was derived from an existing systemic model for mobility and transport.

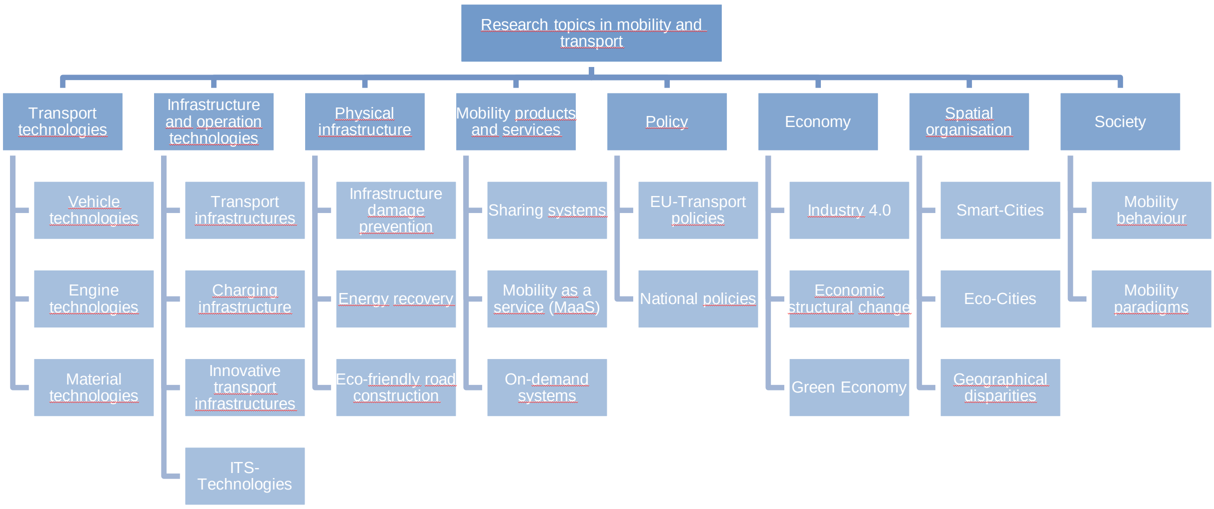

Figure 3: Formal structure of the identified gaps and research topics (Source: ZHAW)

3.1 Transport technologies

Innovations in transport technologies play a key role in the current transformation process of the mobility system. Whether it is about the reduction of CO_2 emissions through optimized engine efficiencies, the electrification of propulsion systems, autonomous driving systems or the development of new and more efficient battery technologies, various trends and innovations are currently emerging, having a major potential to support a shift of the mobility system towards sustainability. However, these developments are still fraught with numerous uncertainties and open questions that need to be addressed in future research and development activities in order to unleash the full potential of these emerging technologies. In this chapter, potential research topics in the areas of vehicle, engine and material technologies are identified and briefly explained. The topics below include all modes of transport and relate to both passengers and freight applications.

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[1] For more information, see Maraš and Pjevčević (2018).

3.1.1 Autonomous vehicle systems:

1) *Ethics and behaviour algorithms in unpredictable traffic situations*

In the ongoing development of autonomous vehicles towards full autonomy, it remains unclear, how the system will react in challenging and unpredictable traffic situations. Which algorithms decide, for example, in the case of an unavoidable crash? Who may decide in such situations about life and death of fellow human beings? Thus, central ethical questions arise in the ongoing development of autonomous vehicles that need to be addressed in future R&D activities, in order to enhance the EU's strategic goals towards zero fatalities in road transport and more safety and security in all modes of transport.

2) *Rebound effects*

In the past, technological innovations leading to gains in efficiency have been (partly) overcompensated by rebound effects, resulting in a much worse situation compared to the initial state. Autonomous vehicle systems offer a huge potential to make traffic flows more efficient and thus reduce congestion on the overcrowded roads. On the other hand, people could switch from slow traffic (walking and cycling) to this new mobility solution, depending for example on design, comfort and price models of the corresponding mobility services. This could in turn result in an increase instead of the aspired decrease of vehicles on the road. Future R&D activities therefore need to become aware of rebound effects, triggered by technological innovations respectively the potential behavioural change induced by these innovations.

3) *Co-existence in mixed traffic situations*

In the transition phase from conventional to fully autonomous vehicles, various conflicts are likely to occur in the initial co-existence, particularly due to different driving behaviours of humans compared to the (probably) rather defensively programmed driving styles of autonomous vehicles. In this respect, future R&D activities need to focus increasingly on behavioural aspects, in order to ensure the EU's strategic goals towards zero fatalities in road transport and more safety and security in all modes of transport. This also includes the development of new liability and insurance models, which are adapted to the new conditions.

4) *Regulatory framework conditions*

In the course of the ongoing development of autonomous driving systems towards complete autonomy, regulatory framework conditions are still not adapted - especially for field tests. This entails risks for the European automotive industry, which could fall behind the global competition, with considerable effects on the attractiveness and innovative capacity of Europe. Future R&D activities therefore need to focus more on appropriately adapted regulatory framework conditions in order to remain competitive in global competition. In addition, a wide variety of laws must be adapted to the new conditions (e.g. rules of the International Maritime Organization IMO that require a minimum number of crewmembers on a ship).

5) *Cross-border coordination and harmonization*

Even in the case of a complete implementation of autonomous vehicles within national transport systems, people will still desire to travel abroad. This will require a trans-European harmonisation and standardisation for autonomous vehicle systems in order to make cross-border traffic with autonomous vehicles possible. In addition, the logistics system will also have to adapt to these changing conditions in order to sustain transnational logistics services. In the course of the development of autonomous vehicle systems, future R&D activities therefore need to address increasingly questions of transnational system harmonization in order to enhance the EU's strategic goal towards a European multimodal transport information, management and payment system.

6) Social justice and equity

Autonomous vehicles have a great potential to simplify the transport from A to B and to make it more pleasant for the consumer. However, there is a risk that autonomous vehicles could develop into an exclusive commodity, benefitting the rich and create a higher burden for low-income people. Future R&D activities therefore need to address questions of social inclusion with regard to autonomous vehicles and new mobility products and services in order not to exclude anyone from this newly emerging mobility opportunity.

7) Beneficial impacts of autonomous vehicles

Even before a fully autonomous vehicle is in operation, these are attributed with various advantages such as greater safety, reduced emissions and increased road capacities through optimized traffic flows. However, there are more and more critical voices that see the advantages of this new technology only in connection with, for example, new business models, shared mobility or the development of high-capacity transport infrastructures. Future R&D activities therefore need to assess, under what conditions we benefit the most from autonomous vehicles, especially with regard to a transformation towards a sustainable transport system.

8) Revenues for cities

By connecting autonomous vehicles with ITS-technologies to the road infrastructure, traffic sins are expected to rapidly decrease (probably to zero if there will be just autonomous vehicles on the roads). This, however, will affect the budget of cities or local authorities, where traffic fines constitute a significant percentage of the budget. In the course of the further technological progress towards complete automation of road vehicles, budgets must be adjusted accordingly and new or alternative financing options must be found, in order not to have to make savings in other areas due to this newly emerging technology.

9) Consumer confidence

One of the biggest fears in the development of autonomous driving systems, especially on the part of consumers, is the complete loss of control over the vehicle and the exclusive trust in the computer. Especially in air traffic, the pilot still represents a person of trust and many people consider it difficult to board an aircraft without a pilot. Future R&D activities therefore need to address increasingly the consumer's fears and feelings in the development of new technologies and corresponding offers in order to fully benefit from these new opportunities.

10) Safety and security issues

With advancing digitization in the automotive industry, various safety and security issues are currently arising. Autonomous vehicles for example could be misused for terrorist attacks or be hacked for other malicious purposes. Aspects of cyber security must therefore increasingly be addressed in future R&D activities in order to enhance the EU's strategic goals towards zero fatalities in road transport and safety and security in all modes of transport. This also means that vehicle manufacturers and providers of mobility services must be able to prove that they handle data securely. In addition, it must be clarified whether driving data and personal data must be stored separately, or whether they may also be linked and further processed.

3.1.2 Drones for passenger and freight transportation:

1) *Legal framework conditions for commercial operations*

The current legal basis in most countries stipulates that drones must be in the line of sight during operation and always be controlled live by the operator. Against the background of the great potential of drones (both in passenger as well as in freight transportation), a circumstance that will severely limit the technology's development. Future R&D activities therefore need to focus increasingly on appropriately adapted regulatory frameworks, to enable commercial operations of drones in the future and thus to enhance the EU's strategic goals towards clean urban transport and CO_2-free city logistics.

2) *Infrastructure & Services*

For large scale commercial operations (especially in freight transportation), drones will need designated spots for package delivery and unloading, which, apart from flying, will be the real challenge in the future. This will require a completely new network of infrastructure services that needs to be planned in the existing infrastructure networks that are already working to capacity (particularly in airspace). Future R&D activities therefore need to focus increasingly on the planning and arrangement of drone infrastructure and services, in particular to lay the foundation for clean urban transportation.

3) *Standardised training and certification programmes*

If the drone technology will be able to establish on a large scale, people who control, service and fix drones will be in high demand in the future. In connection with the new infrastructure that this newly emerging technology will require, completely new training and education structures for drone pilots and maintenance workers will be needed. Future R&D activities therefore need to focus increasingly on transnationally standardized and harmonized training and educational requirements that arise in connection with the progressive development of the drone technology.

4) *Safety and security issues*

Similar to the previously described autonomous vehicle systems there arise various safety and security issues in the course of the technological advancement of drones as they could be misused or hacked for terrorist attacks, parcel theft or other malicious purposes. On the demand side, there is still a lack of confidence in the technology among drones, especially in passenger transportation. Aspects of cyber security and confidence-building measures must therefore increasingly be addressed in future R&D activities in order to enhance the EU's strategic goals towards safety and security in all modes of transport. In addition, new liability and insurance models need to be developed and deployed (in particular against parcel theft), which are adapted to those new conditions.

3.1.3 Innovative vehicle technology concepts (e.g. Hyperloop One):

1) *System integration & cross-modal coordination*

Although they are currently receiving a lot of media attention, revolutionary transport concepts such as the *Hyperloop One* or the underground logistics concept *Cargo Sous Terrain* are still in the initial testing phase. However, such concepts could make a significant contribution to traffic reduction on overcrowded roads by providing new transport capacity on a separate (partly underground) transport infrastructure. In order to benefit from these new capacities, they need to be integrated into the existing system and coordinated with the conventional means of transportation. Future R&D activities therefore need to focus increasingly on requirements and adjustments in cross-modal coordination for efficient systemic integration of such new transport concepts in order to enhance the EU's strategic goals towards optimized performance of multimodal logistic chains.

2) *Economic efficiency*

One of the biggest obstacles in large-scale implementation of revolutionary transport concepts are their overall costs. In the specific case of the *Hyperloop One*, it is particularly the magnetic levitation technology and the (additional) infrastructure needed, which represent the largest cost items. In addition, it is not yet possible to fully estimate, what additional costs would be expected from repair and maintenance work if the technology were to be implemented on a large scale. Before the public sector, in particular, invests in these new technology concepts, they must be examined in detail for their economic viability.

3) *Spatial impact*

A major requirement for large-scale implementation of revolutionary transport concepts such as the *Hyperloop One* would include land acquisition and building resp. tunnelling rights, resulting in a high danger of abuse of power, gentrification and spatial respectively property conflicts for example through land expropriation. Future R&D activities therefore need to pay greater attention to the impact of such large-scale technology projects, in particular for space and population, by defining the legal framework at an early stage or by identifying suitable areas.

4) *Safety and security issues*

Especially in rural areas, the freestanding tubes could - in the specific case of the *Hyperloop One* - provide a simple target for terrorist attacks. Given the revolutionary nature of these new technologies, terrorists would receive a great deal of media attention. Future R&D activities therefore need to develop solutions as to how such large-scale infrastructure projects can be adequately protected and what security measures need to be taken, in order to enhance the EU's strategic goals towards safety and security in all modes of transport.

3.1.4 Electric propulsion systems

1) *Consumer anxieties*

One of the major obstacles currently hindering a widespread diffusion of electric vehicles are consumer fears about too little range, insufficient charging possibilities and higher purchasing costs compared to conventional vehicles. Future R&D activities therefore need to find ways to make this new and (potentially) more sustainable drive solution more attractive to the masses in order to enhance the EU's strategic goals to break the oil-dependence in transportation and to promote sustainable propulsion technologies. In this context, intensified science-public cooperation could be a solution to give people the opportunity to test the technology on a model and overcome existing fears on the consumer side.

2) LCA of electric vehicles & supply of resources

Although electric propulsion could be in principle a clean alternative to the classic combustion engine, the overall eco-balance still shows very poor values at present, mainly due to the energy-intensive battery production and propulsion by electricity from non-renewable sources. With regard to sustainability, it is also uncertain what impact the predicted boom in electric mobility will have on the mining areas for cobalt and lithium, most of which are located in politically unstable regions (e.g. human trafficking, resource exploitation, etc.). Future R&D activities must therefore take a more holistic perspective on the life cycle assessment of electric vehicles. Political measures should be taken to replace coal-fired power plants with renewable energy sources. In addition, research into the efficiency of lithium-ion technology and into alternative energy storage systems must be promoted and Plan-B scenarios for resource self-sufficiency need to be developed in the case of deteriorating political relations with the mining countries.

3) Hydrogen production

Fuel cell technology is not yet a considerable alternative to electric mobility due to the industrial production of hydrogen that requires a high primary energy demand. In addition, there is no large scale infrastructure to transport the hydrogen from its production site to the filling stations what still requires transportation with trucks (with corresponding CO_2 emissions). However, with regard to the previously described issues in electro mobility (e.g. resources shortage and mining of lithium and cobalt in political unstable regions), fuel cell technology could become a valuable alternative to lithium-ion technology in the future and support the EU's strategic goals for sustainable fuels and propulsion systems. R&D activities therefore need to focus increasingly on enabling the production of hydrogen with less primary energy demand. In addition, sustainable solutions must be found for hydrogen transportation.

4) Hybrid drivetrains

Especially for air traffic and the shipping industry, hybrid drives are a suitable way of achieving significant emission savings during the transition phase to CO_2-neutral mobility. Future R&D activities must therefore increasingly offer opportunities for auxiliary power supply such as for example rotor sails for ships. In addition, the potential of variable energy solutions for different areas of application must be exploited to a greater extent. Especially in shipping, most ships today are equipped with standard engines, although these could be designed differently depending on the application (e.g. short vs. long distance). For this reason, different engine outputs are required for individual purposes in order to enable a more efficient use of energy.

5) Alternative fuels

In order to challenge conventional drivetrains, sustainable propulsion systems with alternative fuels are needed in the transition phase towards complete electrification. Future R&D activities should therefore focus on advanced bio- and synthetic fuels, relevant for the decarbonisation of the existing road transport fleet and for sectors that could remain at least partially dependent on liquid fuels, such as aviation or trucks in the medium distance segment (up to a distance of 300 kilometres). In addition, the potential and possibilities of solar fuel must be further investigated. These measures can make a significant contribution to reach the EU's strategic goals for low-carbon sustainable fuels.

3.1.5 Improved battery storage systems:

1) *Eco-balance of batteries & recycling*

With regard to the overall eco-balance of batteries, the production of batteries in particular is very energy-intensive and has a proven negative impact. In addition, there are hardly any or no concepts as to what will happen to the batteries at the end of life. These challenges will continue to intensify in the future, especially with regard to the forecasted boom in electric mobility. Future R&D activities therefore need to focus increasingly on optimized and less energy intensive battery production processes. Furthermore, it has to be examined, to what extent raw materials within batteries can be reused in second life as well as what happens to the non-reusable components. Circular economy approaches are particularly appropriate within this context.

2) *Competitive alternative energy storage systems*

Energy density of lithium-ion batteries is still not sufficiently advanced to equip for example aircrafts for long-distance flights. Future R&D activities therefore need to focus increasingly on alternatives to the lithium-ion technology, which can store energy more efficiently and which make it possible to drive long-distance means of transportation with electrical energy. In this context, the potential and feasibility of nanotechnology needs to be examined and exploited more intensively in the future. These research foci will make a significant contribution to the achievement of the EU's strategic goals to break the oil-dependence in transportation.

3.1.6 Additive manufacturing:

1) *Cost & time expenditure*

Additive manufacturing can lead to a more cost-efficient production, as storage costs can be saved through printing on-demand. In addition, additive manufacturing can also be expected to have a positive effect on the sustainability of the transport system, as it could result in fewer transport journeys in logistics. However, speed and productions costs are currently the limiting factors of this technology for a widespread diffusion within the industries. Future R&D activities therefore need to further develop the technology, particularly in terms of production speed and cost efficiency.

3.2 Infrastructure and operation technologies

High-performing infrastructure and operation networks may be crucial for a large-scale implementation of newly emerging transport technologies. In addition, high-performance infrastructure networks offer a great potential to improve the efficiency of transport processes and can therefore have a positive effect on the overall sustainability of the transport system. However, many ambiguities are currently still under discussion which will have to be overcome in the coming years in order to fully exploit the potential of the newly emerging technologies in mobility and transport. In this chapter, potential research topics in the areas of transport infrastructures, charging infrastructure and intelligent transport systems are identified and briefly explained. The topics below include all modes of transport and relate to both passengers and freight applications.

3.2.1 Transport infrastructures

1) *Transnational standardisation and harmonisation*

Despite major efforts already being made to harmonise infrastructure systems across Europe, gaps can still be identified, especially with regard to the EU enlargement countries where different standards, regulations and procedures prevent impeccable cross-border transport operations. It is therefore important to take greater account of this circumstance, particularly in view of the rapid pace of technological developments and innovations. Future R&D activities must therefore constantly reassess the alignment of transnational systems and, if necessary, initiate appropriate measures to prevent certain countries from being not able to keep pace with the rapid technological development. These are important measures to avoid further fragmentation within Europe as well as to enhance the EU's strategic goals towards an EU-wide multimodal TEN-T 'core network' and high quality and capacity networks with corresponding information services.

3.2.2 Charging infrastructure

1) *Large-scale expansion of the charging infrastructure*

A large-scale expansion of electric charging stations can be seen as a necessity to promote electro mobility for long distance travelling and to transform the transport system towards sustainability in the future. Future R&D activities therefore need to increasingly focus on the determination of suitable locations in order to enable an area-wide charging network. In addition, uniform and generally accessible information channels must be developed through which users of electric vehicles can be informed about charging options. Finally, it is also necessary to define the political incentive systems needed to reinforce the EU's strategic objectives in developing new and sustainable fuels and propulsion systems and to overcome oil dependency in European transport.

2) *Charging time*

In addition to the prevailing fear of range in electric vehicles, the charging time is also a basic obstacle for many drivers when deciding to buy an electric vehicle. Future R&D activities must therefore further develop the charging infrastructure in such a way that the vehicles can be charged in a reasonable amount of time and the consumer does not lose too much time as a result. In this context, the standardisation of charging systems between various vehicle suppliers must be further improved.

3) *Cross-border coordination and harmonization*

In order to further promote electro mobility and to enable long-distance travel, transnational coordination and harmonisation of the charging infrastructure is a necessity for the future. Future R&D activities must therefore assess how the different country systems could best be coordinated and harmonised with each other. This includes in particular a uniform information system on charging infrastructure, uniform charging connections and a uniform billing system with fixed prices per charging process. This results in a reduction in consumer stress and reduces further fear of range. In addition, the strategic goals of the EU towards a European multimodal transport information, management and payment system will be further enhanced.

4) Grid adaptation

In the current debate towards a transition to electro mobility is still not clear, whether the electricity grids have enough capacity for the predicted EV-Boom and if the required energy can be provided mainly from sustainable and renewable energy sources, in order to operate electric mobility sustainably. Future R&D activities therefore need to assess the extent to which electricity grids will be additionally burdened by electric vehicles and appropriate adaptation measures are necessary to be planned. In addition, further capacities must be created to generate electricity from sustainable production. In order to compensate for daily fluctuations in the grid, approaches to feeding energy back into the grid must also be examined. Flexible charging processes such as Vehicle-to-grid (V2G) technologies or intelligent charging systems that charge electric vehicles during off times have therefore a great potential in the future and need to be considered increasingly.

5) Inductive charging technology

While stationary and semi-dynamic inductive charging systems are generally expected to be implemented on a large scale in the future, there are still some major concerns regarding fully dynamic inductive charging (e.g. on motorways), especially with regard to the technical implementation and the overall economic efficiency of the system. Future R&D activities therefore need to assess, to what extent inductive charging technologies can also be used over large areas, for example on motorways. In this context, it is also important to examine whether only individual sections or individual lanes can be equipped with this new technology and whether it can thus be operated more cost-efficiently.

3.2.3 ITS-technologies (V2I/I2V)

1) Data security issues

With advancing digitization in the transport industry, various safety and security issues are currently arising by using data of paired devices such as autonomous vehicles for malicious purposes. In addition, the storage and further processing of personal data by individual providers represents a danger with regard to changing power relations. Aspects of cyber security and misuse of data must therefore increasingly be addressed in future R&D activities in order to enhance the EU’s strategic goals towards zero fatalities in road transport and safety and security in all modes of transport.

2) Blockchain technology

Against the background of the potential data security issues described above, blockchain technology could be a valuable solution, for example for integrated and automated secure payments in the vehicle. Future R&D activities must therefore intensively explore the potential and possible applications of blockchain technology in the transport sector in order to support the EU's strategic goals for safety and security in all modes of transport and for developing a European multimodal transport information, management and payment system.

3) *Artificial intelligence*

Through artificial intelligence (AI), a computer-based system learns to perceive the environment, evaluate it and derive meaningful actions in real time (Jeschke, 2018). As a cross-sectional technology, this offers enormous opportunities for mobility and transport in terms of operation, coordination and optimization of the transport system. As systems based on artificial intelligence are less or not controlled by humans, they come along with open questions and potential risks. Future R&D activities therefore need to assess not only options provided by artificial intelligence for improving the transport system, but also potential negative effects and the way and degree, to which a technological system should be empowered to decide and act autonomously. This could also include to determine the extent to which security and higher-level control will be necessary with regard to potential misjudgements and undesired actions of the system.

3.2.4 Truck platooning

1) *Legal framework conditions*

Truck Platoons can lead to increased efficiency and safety on the roads due to the constant driving style and the improved reaction time compared to a human driver. However, the legal framework conditions for autonomous driving as well as for integrating truck platoons into the transport system is still lacking. Future R&D activities must therefore increasingly work out what the legal situation looks like, for example in the case of accidents with truck platoons, and determine these accordingly. In addition, further research is needed into how autonomous truck platoons can be integrated into mixed traffic with vehicles driven by humans and how they must be coordinated and communicate together. This will further support the EU's strategic goals for efficient and green freight corridors.

2) *Practical application*

Initial practical tests have shown that various questions still need to be clarified before truck platoons can be implemented on a large scale and applied in practice. For example, there is still no uniform coupling between different vehicle manufacturers available. In addition, a payment model for convoys consisting of different forwarders is missing, as fuel costs and driver time can only be saved by the autonomously following trucks. Future R&D activities must therefore focus increasingly on the practical implementation of the technology. It is necessary to develop appropriate coupling and billing models between different providers in order to be able to use the technology efficiently and prevent monopoly situations.

3.3 Physical infrastructure

Due to climate change and its forecasted changes in the weather patterns, the transport sector and in particular its traffic infrastructures are expected to be increasingly challenged through more frequent extreme weather events (e.g. storms, flood events or extreme heat and cold weather conditions). This requires appropriate adaptation measures to ensure the functioning of the infrastructure facilities even under changing conditions. In addition, the transport infrastructure has increased considerably over the past decades and has taken up large areas of the country. In the course of the sustainability transformation of the transport sector, future research activities need to examine, how these areas could be converted or used for alternative purposes. In this chapter, potential research topics in the areas of infrastructure damage prevention, energy recovery and eco-friendly road construction are identified and briefly explained.

3.3.1 Infrastructure damage prevention

1) *Preventive measures against the effects of climate change*

As a result of climate change, transport infrastructures will be increasingly exposed to extreme weather events in the future, which can lead from failures to partially breakdowns within the transport system and the corresponding negative consequences for economy and society. Future R&D activities therefore need to focus increasingly on prevention measures to make the infrastructure more robust against the predicted external influencing factors. In addition, alternative approaches for maintenance and repair works need to be developed in order to cope more efficiently with the expected increase in the total amount of interventions. These measures will make a significant contribution to achieving the EU's strategic goals towards high-quality road networks and safety and security in all modes of transport.

2) *Self-healing roads*

With regard to the predicted increase in heat and cold waves through climate change, roads can suffer more damage. For this reason, various approaches are currently being developed to directly re-close cracks in the road through incorporation of magnetic particles or micro bacteria into the coating. However, it is not yet entirely clear what ecological side effects could potentially occur by applying such methods. In addition, cost efficiency is still largely unclear, because it is not yet possible to fully predict, which road sections should be given most likely priority for such measures. Future R&D activities therefore needs to focus increasingly on the potential negative ecological side effects of self-healing roads. In addition, it is necessary to identify, which road sections could be most affected by damage due to the predicted climatic changes in order to be able to proactively respond to the changing conditions.

3.3.2 Energy recovery

1) *Solar roads*

As sustainability transformation progresses, more and more efforts are being made to use traffic areas for the recovery of energy, for example by solar roads. To date, however, construction of such roads is very cost-intensive. In addition, various problems arise, in particular with contamination of the solar collectors. Future R&D activities therefore need to focus increasingly on the cost-effectiveness of solar road construction. In addition, further research must be carried out into the angle at which roads can produce energy most efficiently, and corresponding potential areas must be identified at an early stage. Finally, measures must be developed to ensure that solar roads can be maintained efficiently and cost-effectively in the event of pollution or snow in order to generate as few energy production losses as possible.

3.3.3 Eco-friendly road construction

1) *Recycled materials for road construction*

Similar to the previously described solar roads that pursue using road infrastructure for sustainability purposes, there are also efforts being made using recycled materials as asphalt admixtures to improve road quality, lower material costs and reduce landfill waste. However, such concepts have not yet been economically viable. Future R&D activities therefore need to examine, to what extent the use of recycled materials in road construction could be made more cost-effective.

3.4 New mobility products and services

In the course of the megatrend digitization, several new mobility products and services have emerged in recent years. Whether it is about sharing systems, mobility as a service (MaaS) or mobility on-demand, all these newly emerging offers create a new layer on the existing mobility structures resulting in a self-controlling system of real-time traffic planning, on-demand availability and smooth transitions from one mode of transport to another. However, these new mobility products also raise a number of uncertainties and unresolved issues that need to be addressed in future R&D activities, particularly with regard to their sustainability, which should be their real strength. In this chapter, potential research topics in the areas of sharing systems and mobility as a service are identified and briefly explained. Since they are similar in their nature and cover the same research areas, topics described in the section mobility as a service also apply to on-demand services (dealt with separately in D4.1).

3.4.1 Sharing systems

1) *Socio-economic response to sharing systems*

The development of a sharing economy is expected to have a positive effect on the sustainability - also in the transport sector. Although sharing systems have already been able to establish themselves, especially in slow traffic, a strong reluctance can still be observed, especially in the automotive sector. Future R&D activities must therefore increasingly investigate the conditions under which people are willing to share the car with other occupants or to renounce owning their own car. In particular, incentive systems need to be researched and questions of individual safety through sharing with strangers need to be addressed. This will serve the EU's strategic goals towards clean urban transportation and high-quality and capacity networks with corresponding information services, to enhance a European multimodal transport information management and payment system.

3.4.2 Mobility as a service (MaaS)

1) *Rebound effects*

MaaS offers are predicted to have an overall positive impact on the sustainability of the transport system through more efficient traffic processes and a significant reduction in the number of cars on the roads. However, there is as well a great danger that people could switch from slow traffic (walking and cycling) to MaaS services, depending for example on price and comfort of these new mobility offers (similar to autonomous vehicles). Future R&D activities therefore need to become aware of rebound effects, triggered by technological innovations respectively the potential behavioural change induced by these innovations. This also includes research into incentive systems for a more sufficient behaviour in mobility consumption or the strict application of 'user pays' and 'polluter pays' principles also for newly emerging mobility offers.

2) *Integration of applications*

In order to optimally exploit the advantages of MaaS (e.g. efficient travel processing using different means of transportation from different providers), newly developed MaaS applications need to be able to be integrated into an already existing and established system environment from existing mobility providers. Future R&D activities must therefore increasingly focus on the system conformity of new mobility applications in order to be able to integrate new providers in the fast growing and changing transport market, including incentives for traditional mobility providers to connect their platforms with MaaS. In this context, it should also be examined to what extent a uniform transport management and information system could further optimize or simplify MaaS, in order to enhance the EU's strategic goals towards a European multimodal transport information, management and payment system.

3) *New business models*

The development of mobility as a service creates opportunities for new business models with new players entering the mobility market. Future R&D activities therefore need to focus increasingly on emerging value creation opportunities for other industry branches such as for example the insurance, energy or media.

4) *Policy frameworks*

Implementation of MaaS can face financial challenges for new service providers, especially in cities where public transport services are subsidized. Only when governments identify MaaS as a type of sustainable transport system with the same state subsidy policy or tax cuts, MaaS can be applied in a city where subsidies and taxes are offered for those travelling by public transport. Future R&D activities therefore need to focus increasingly on the design of policy frameworks for implementation of MaaS, which handle these services similar to public transportation, in order not to run the risk of providing a service without users due to a lack of financial incentives.

5) *Ethics and data security issues*

With advancing digitization in the automotive industry, various safety and security issues are currently arising, especially with regard to autonomous mobility services, as these vehicles could be misused for malicious purposes. Aspects of cyber security must therefore increasingly be addressed in future R&D activities in order to enhance the EU's strategic goals towards safety and security in all modes of transport. In addition, mechanisms that prevent data misuse and guarantee the protection of personal rights (despite complete data transparency) need to be developed. This further includes that mobility providers must be able to adhere to data protection guidelines, with corresponding systemic adjustments. In addition, provisions must be made at an early stage regarding the handling and proceeding of driving data and personal data.

3.5 Transport related policies

Research needs arise on one side from policies itself, as decisions for steering and/or changing certain developments need innovation to reach the goals set in political programmes. On the other side, policies cause dilemmas, e.g. if policies from different fields are contradictory to each other or to real world issues. Potential research topics in transport related policies arise from several of such identified gaps. One of the main tenets of the European Union's transport policy is striving for a single, optimised European transport system contributing to competitiveness with high-quality transport infrastructure providing high accessibility for citizens (European Commission, 2011) – at the same time providing efficient, safe, secure and sustainable transport (European Commission, 2018). This includes in detail political goals of reducing congestion, oil dependency and greenhouse gas emissions as well as providing equal accessibility across the EU. While some targets imply an extension of the mobility system and quantitative improvement with growth, going along with increasing mobility demand, goals of reducing negative consequences and side effects of transport contradict this.

Political strategies are embedded in a history of past and in the mainstream of current decisions [2] - which were identified and analysed by Moraglio et al. (2018) as *political imperatives* from two different perspectives: I. *demands* as imperatives formulated **to** the political sphere, and II. *intentions* as imperatives formulated **by** the political sphere itself. Contrasting the demands to the political sphere with the intentions formulated by the political sphere reveals gaps between what stakeholders (from industry, NGOs, supranational and intergovernmental organizations, science and governments) consider as issues to be politically addressed and what policies consider as relevant to be targeted (Figure 4).

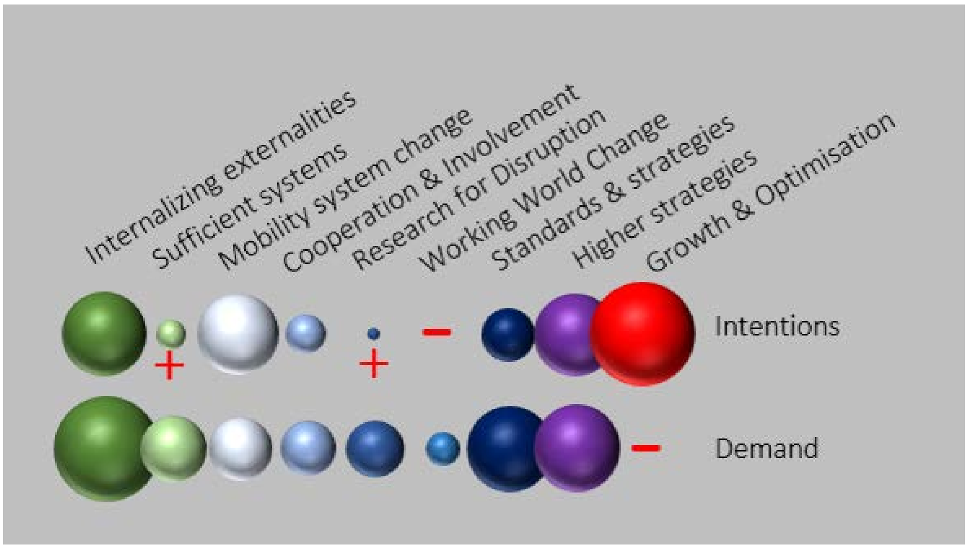

Figure 4: Gaps in transport related policies (Source: ZHAW)

Strategies for growth and optimisation of the system are strongly emphasized by policy, while they are almost a non-issue on the demand side. Common standards (e.g. technical or operational standards) appear a bit underestimated by policy compared to what demand side requires. Concerning research allowing for disruption in innovation this gap is much bigger, as political intentions only rarely include this demand side requirement - a fact supported by results of a stakeholder survey among >100 stakeholders of European transport, where almost 60% experts stated that policy is lagging behind when it comes to frame conditions for innovation (Hoppe and Trachsel, 2018). A similar gap appears in the field of sufficient transport

[2] "perspectives or theories that purport to advise governments on what policies they should adopt in this context as a matter of efficiency, fairness, justice, or some other conception of right and wrong" (Trebilcock 2014, p. 9)

systems. To summarize, the perspective of political intentions is partly still driven by traditional motif to extend the current system. However, systemic change is strongly mentioned including internalizing externalities. Thus, system transformation is a goal in policy, but ways to realizing political intentions differ from outside requirements. While stakeholders demand more radical policies, the latter appear rather traditional and locked-in in path dependency. The strong role of policy for system transformation was also emphasized in a survey, where around 70% mentioned that policy should intensify activities to internalise negative external effects (Hoppe and Trachsel, 2018).

From the described upcoming developments and identified gaps, the following research fields were derived:

3.5.1 Integration of transport and environmental policy

The gap analysis revealed conflicting policies in the transport sector, ranging from better accessibility and growth, and thus more emissions, to environmentally friendly transport, with the aim of reducing emissions from transport. Research could support bridging the gap by identifying best practice and ways for integrative political strategies and regulations. Effective incentives and optimal frame conditions are other relevant research fields as well as addressing the basic question of how to create regimes ensuring sustainable development, e.g. based on implementation of different funding regimes, internalizing external costs or enabling long-term political continuity for critical issues beyond election periods.

3.5.2 Qualitative development enabling transport for competitiveness

The political goal of strengthening competitiveness of Europe is still strongly linked with the paradigm of economic growth, which leads to a postulated need to extend the transport system, which will result in increasing traffic. This not only creates conflicts with environmental policies and such addressing health and quality of life in cities, but is also linked to the critical question of high investment costs in transport and external cost, making it necessary to develop a new perspective. So far, there is a lack of research on qualitative improvements to transport systems to avoid increasing mobility demand. This includes reorganization of the transport system and transport sector/industry, access management, flexible low-cost infrastructure solutions etc.

3.5.3 Role of and options for policy in system transformation

New political organization is necessary for systemic transformation, as an integration of different policy and planning fields and regional levels is necessary as well as the inclusion of new stakeholders within transport coming along with new mobility solutions. Research in this fields includes decision making processes, alliances and ways of cooperation on an international, regional and local level – with special focus on participatory processes with citizens and industries involvement.

3.5.4 Policies for redefining and redesigning mobility in the context of economic transformation

Economic structural changes related to technological developments like digitalization and innovation in production like industry 4.0, logistics and organization come with both challenges and opportunities for transportation. Policies are crucial when setting frame conditions, incentives or barriers in order to direct development consistent with overall economic, transport and environmental political goals for Europe, cities and regions. Supporting economic development in this context by appropriate, modern mobility solution or even better replacing mobility, setting respective political incentives for developing options or substituting need for physical mobility are research fields in this area.

3.5.5 Innovation policy for disruptive and break through innovation

As revealed by research and gap analysis there is a need for policies sufficient for driving innovation with system changing potential, beyond the mainstream. This research field is related and consistent to the previous described ones, as innovation policy would force systemic transformation. The focus should be on how political research management (including definition of topics, proposing procedures and assessment, eligible institutions, funding schemes etc.) could guarantee research with the highest innovation potential – going beyond mainstream and allowing for disruptive innovation supporting system transformation. This might include providing open innovation spaces, institutions and initiatives.

3.6 Economic and organisational structures

Disruptive technologies are changing the markets and increasingly challenging traditional sectors. Whether it is about renewable energies, alternative mobility services, autonomous vehicles, industrial and household robots or the Internet of Things, all these newly emerging trends and developments offer a huge potential for the development of new markets and the change of existing structures. On the other hand, they also raise a number of questions, in particular as regards the impact on the human labour force in different sectors and on the labour market in general. In this chapter, potential research topics in the areas of Industry 4.0, economic structural change and green/circular economy are identified and briefly explained.

3.6.1 Industry 4.0

1) *Effects on mobility and transport*

The ongoing trend of Industry 4.0 is severely affecting the logistics sector, forcing logistics providers to adopt new measures and technologies such as driverless delivery vans, delivery robots or drones to remain competitive in the future. Future R&D activities must therefore increasingly examine how those developments will affect mobility and transport, considering also behavioural aspects such as an increase in e-commerce and the corresponding impact on the traffic volume.

3.6.2 Economic structural change

1) *Changes in the labour market*

Technological progress and newly emerging business areas are leading to a fundamental reorganization of the industry. The automotive industry in particular is expected to face significant changes, for example due to new production opportunities such as 3D printing. In addition, the elimination of traditional occupations such as bus or taxi drivers due to autonomous vehicles can have significant impacts on the labour market in the future. Future R&D activities must therefore investigate how the automotive industry and related sectors will change in the future and what effects this will have on the employment structure. This includes in particular assessing, to what extent job losses can be compensated in other sectors with corresponding retraining programs.

2) New job opportunities

As described above, technological developments can lead to job losses. On the other hand, they also offer opportunities for new competitors and industries. Electric vehicles, for example, are less complex and therefore easier to build than cars with a combustion engine, what could make it considerably easier for competitors from outside the industry to enter the automotive sector. In addition, the control and maintenance of autonomous vehicle fleets will open up completely new training opportunities. Future R&D activities must therefore examine what new value creation opportunities could be created in the course of the advancing technological developments and assess the corresponding impacts on the labour market.

3.6.3 Green and circular economy

1) Recycling and upcycling

In the automotive sector in particular, the predicted increase in the number of electric vehicles and the raw materials required for battery production can lead to further exploitation and overuse of natural resources. It is therefore important to take care of these critical raw materials and find ways in future R&D activities, to reuse raw materials within means of transportation in second life. In addition, further procedures need to be developed to ensure the sustainable disposal of non-recyclable materials. Circular economy approaches must therefore be increasingly applied in the transport industry, what requires for example development of incentives for producers and sensitising them for a sustainable use of the scarce resources. Usage of end of life batteries from EVs in applications for stationary energy storage will need to become more widespread while carbon fibre shortage will require recycling solutions to be investigated for such materials.

2) Renewable energy solutions

In order to ensure the necessary transition from fossil to renewable energy sources, new large-scale solutions for energy production from renewable sources will have to be found in the future. Future R&D activities therefore need to increasingly develop strategies and incentive systems for the production, storage and consumption of electricity from renewables and make appropriate adjustments, for example to grid capacity. In addition, efforts must be made to increase energy efficiency within means of transportation (e.g. energy density in batteries from electric vehicles), which can be achieved on the one hand through technological advances, but also through modified construction methods and new and more efficient materials (e.g. aerodynamic optimizations and lightweight construction).

3) Critical raw materials

Due to the increasing pressure on natural resources in mining countries (particularly due to technological progress in industrialized countries and the corresponding demand in natural resources), a more careful handling of the latter must be striven for in the future. Future R&D activities must therefore increasingly examine the processes of resource extraction in the mining countries and formulate strategies and measures for improvement in order to fulfil their social, economic and environmental responsibility in these countries. This includes, in particular, improving factors such as social justice, fair working conditions and environmental compatibility.

3.7 Spatial organisation and structures

The ongoing megatrend urbanization will confront cities and their transport systems with increasing challenges in the future. On the other hand, there arise as well various opportunities, especially for mobility service providers. However, in order to benefit fully from this potential, various hurdles must be overcome, both from a technological and a regulatory point of view. In this chapter, potential research topics in the areas of smart-cities, eco-cities and geographical disparities are identified and briefly explained.

3.7.1 Smart-Cities

1) Technological requirements

Smart cities are characterized by complete digital networking between things. With regard to traffic, this can in particular make traffic flows more efficient and thus pave the way for fully autonomous driving. However, this requires comprehensive coverage with the next generation of mobile communication network (5G), which is not yet available. Future R&D activities must therefore increasingly focus on the development and nationwide implementation of the next generation of mobile communications, in order to enhance the EU’s strategic goals towards European multimodal transport information, management and payment systems.

2) Data security & liberty rights

In the context of the full digital interconnection of things, there are various concerns arising about data security and people's personal rights. Full data acquisition of technology providers may for example lead to abuse of power and data. In this respect, future R&D activities need to focus increasingly on the development of mechanisms that prevent data misuse and guarantee the protection of personal rights despite complete data transparency.

3) Planning barriers

Some practical examples have shown that obstacles have been encountered in the development towards smart cities because planning instruments were not sufficiently adapted to the new needs. Future R&D activities therefore need to examine, to what extent planning instruments of city authorities need to be adapted to meet the requirements in particular in connection with digitisation and networking of things.

4) Societal impacts

As a result of increasing digitalisation and the development towards smart cities, technocratic ideal cities are arising, which prioritize technology instead of social aspects with hitherto unknown effects on societies and traditional cityscapes. In the course of further digitisation and digital networking between man and infrastructure, future R&D activities must therefore take into consideration social aspects when planning and developing smart cities. In particular, it is important to identify at an early stage what negative effects could arise on social communities in order to counteract potential conflicts and social hotspots within cities at an early stage.

3.7.2 Geographical disparities

1) Decentralisation

Autonomous vehicles offer a great potential to radically change the transport system in the future. By eliminating the need to steer the vehicle, the occupants can take care of other things during the journey and thus make good use of the travel time. However, there is a danger that people will move further into the periphery, since commuting in an autonomous vehicle is suddenly seen as a favour rather than a burden, with corresponding consequences for spatial development. Future R&D activities must therefore increasingly take into account the influence of autonomous vehicles on spatial development. In particular, the extent to which autonomous vehicles reinforce decentralised spatial development and what effects this would have on the landscape, land prices and potential segregatory movements should be further examined.

2) *Coordination between city and countryside*

The development of new technologies such as autonomous vehicles and corresponding mobility services (e.g. MaaS, on-demand mobility, car sharing, etc.) carries the risk that these will be implemented primarily in urban areas and that rural areas will experience a disadvantage in terms of transport services. Future R&D activities therefore need to assess, how highly developed urban transport systems can be coordinated and harmonized best with (potentially) less developed rural transport systems in order to enhance the EU's strategic goals towards high-quality and capacity networks with corresponding information services. This includes for example modelling of mobility demand in peripheral regions based on activities, lifestyles or responses to work and travel behaviour, in order to capture the decision-making process and to provide corresponding required offers in peripheral regions.

3.8 Societal and behavioural issues

Since the (negative) effects of climate change are increasingly affecting our everyday life, a shift in the behavioural patterns to more sustainable actions in large parts of the society is a necessity in the future. In this respect, newly emerging technologies and mobility services (e.g. autonomous vehicles in combination with MaaS) offer a great potential for a shift in personal behaviour patterns towards sustainability. However, it cannot yet be predicted, whether the mobility users will be willing to adopt these new opportunities and what potential rebound effects this could have. In this chapter, potential research topics within the areas of mobility behaviour and mobility paradigms are identified and briefly explained.

3.8.1 Mobility behaviour

1) *Impact of new mobility products and services*

Technological innovations striving for more efficiency have been (partly) overcompensated in the past by rebound effects. This risk also emanates from autonomous vehicles in combination with new mobility services such as MaaS or mobility on-demand by people switching from slow traffic (walking and cycling) to this new mobility options. In addition, such services also offer the opportunity to provide new user groups with individual motorised mobility, in particular pensioners, children or physically disabled people. Future R&D activities therefore need to assess, what impact new mobility products and services could have on the individual behavioural patterns of these different user groups in order to make conclusions about how future mobility options must be designed, to not worsen the impact on the mobility system in the future.

2) *Future leisure and travel behaviour*

Digitization, new technologies and societal trends are increasingly affecting our leisure behaviour. It is partly already assumed that people will work less in the future due to increasing automation and therefore have more spare time at disposal for individual needs, with (potentially) considerable impacts on the overall mobility demand. Future R&D activities therefore need to assess, how leisure time is organised in the future and what effects this could have on individual mobility and travel behaviour. In particular, it is necessary to examine which new forms of leisure could emerge and what role individual mobility will play within those new forms. In addition, it is necessary to examine the potential of virtual worlds of experience and the extent to which they could compensate for long-distance travelling.

3) *Change of mobility habits*

Even if new technologies come around with new opportunities for reducing or even replacing the need for physical mobility it is not for sure the development will go this direction. Besides the fact that movement itself is part of human life and nature technological innovation as autonomous driving have the potential of allowing the time during trips to be multifunctional; reading, electronic entertainment or working might not only be possible while being transported but the time spent might no longer be considered as travel time lost for other activities. Thus, supporting mobility behaviour change and establishing new, more sustainable mobility habits, not only in commuting but especially in leisure mobility is a relevant topic for research.

3.8.2 Mobility paradigms

1) *Individual car ownership*

Although a potential willingness for a shift towards multimodal travel options is currently visible, various studies and surveys indicate that a complete renunciation of owning a vehicle is not yet an option for the majority of people today. This in particular, because there is still a distorted picture of the value definition of a car, with ownership still being given more weight than to its use. Future R&D activities must therefore increasingly focus on how prevailing paradigms can be overcome. In particular, ways must be found to enable people to rethink their value definition of a car as well as to find ways to create incentives to increase vehicle sharing and reduce low occupancy. This will be from particular interest with regard to the further development of autonomous vehicles in combination with new mobility products and services.

2) *Growth vs. sufficiency*

As the gap analysis revealed, there are various policies in transportation contradicting each other through addressing increased accessibility and growth on the one side and such aiming for green and sustainable mobility on the other side. However, this is not limited to transport policies alone, but can also be projected onto our everyday lives. Research should therefore increasingly address questions of how to overcome paradigms of growth. In particular, this could include finding ways and incentives to encourage people to think more about sufficiency and limiting their needs to what is necessary in order to get away from the current thinking that success and prosperity can only be achieved through growth.

3.8.3 Changing lifestyles, opportunities and risks for sustainable mobility

1) *Change of lifestyles and mobility*

Mobility behaviour is related to how people work and live, including preferred activities, ways of social life, structure of households and family life etc. These fields are under constant change with some developments are linked to technological innovation. Increasing interest in personal health and life optimisation, in leisure activities and social life as related to digitalisation and virtualisation affect mobility needs and behaviour. Thus, understanding the links between these lifestyle changes and mobility behaviour as well as using trends of changing lifestyles to increase attraction of active mobility modes, multimodal mobility and individualized public transport via Mobility as a Service are some relevant research fields of the future.

2) *Ageing population*

Improved health together with increased wealth, travelling options and language skills support a more active lifestyle. In particular, for older generations, the total demand for mobility is therefore expected to grow further in the coming decades. However, it remains unclear how this age group will react to the newly emerging mobility solutions and technology options in the transition phase of the mobility system, especially in individual transportation. Future R&D activities must therefore increasingly examine the mobility behaviour of older generations. On the one hand, in order to be able to take suitable measures at an early stage to meet any increase in transport demand with the corresponding offers, on the other hand, however, also in order to adapt newly emerging offers to the needs of these generations and to further develop them accordingly.

3) *Dealing with disparities*

Even if mobility demand is increasing related to lifestyle trends, demographic ageing and importance of leisure activities in general, this does not account for all. Within Europe, countries, regions and societies disparities of income, access to mobility services as well as abilities to use modern technologies exist and might increase with further differentiation of technological, economic and educational development. Thus, ensuring inclusive mobility based on an even more sophisticated – and expensive – transport system is a challenge. Research should focus on how to provide inclusive mobility considering the dimension of technologies, price and individual abilities related to the upcoming innovations in transport and the transformation of the transport system.

3.9 Blind Spots in transportation research

From a system theories perspective, organisations can be considered as existing based on decisions, referring to previous and future decisions and thus are following an organisational logic of interdependent decisions – rather than rational problem solving (Luhmann, 1981). These organisations and other social systems are included in the overall system of society leading to the consequence that perception of problems as well as decision on solutions and activities are depending on previous ones. As all actors – including scientists, experts and politicians – are part of the system, identifying blind spots and thinking out of the box is difficult, if not almost impossible. Thus, for this work, we chose the approach of underlying a radical problem oriented perspective. While part of future research is driven by previous and recent technological development, e.g. autonomous driving requiring certain infrastructure, sensor and safety technologies, other needs for R&D arise when considering global and European problems as well as such of city regions and rural areas. The identification of blind spots is based on systematically analysing and identifying additional research fields and topics needed in order to solve these problems. The starting point is the perspective of a necessary transformation of the transport sector addressing problems such as increasing emissions related to climate change and health issues, overloaded transport infrastructure, safety and social inclusion in new mobility services, rising costs for transport, scarcity of resources including energy as well as increasing demand for and scarcity of land in city regions.

Based on this problem perspective, the results from previous deliverables (in particular D4.1 and D4.2), 13 blind spots in transportation research have been identified that are crucial for systemic transformation of the transport system towards sustainability but which at present still receive too little attention from the research community. The blind spots have been derived in an iterative process from the previously characterized research fields and were further classified into four fields of action: (1) Economy and Business Models, (2) Society and Culture, (3) Policy and Institutions and (4) Science and Technology R&D.

3.9.1 Economy and Business Models

Mobility and transport are closely linked with the economy via supply and demand; the transport system itself is an economic sector working under the rules of markets. Thus, economic aspects of transport are of main importance to be addressed in research.

Striving for a circular economy

The material cycle on earth has gone off course. Reports such as the increasing plastic parts in our oceans confirm this fact on a daily basis. It is therefore important to find new ways of recycling or upcycling in the future in order to bring the material cycles on earth back into equilibrium. This includes change from the short-term to the long-term perspective, especially when it comes to life cycle of products, investment in infrastructures or use of natural resources.

R&D for sufficiency

Almost all areas of life today are influenced by the prevailing growth paradigm. Especially in the case of natural resources, it becomes more and more obvious that this growth spiral will sooner or later overload the system. A growth-critical thinking about the prevailing system order is therefore needed. Future R&D will have to find ways to develop sufficient business models and in general a sufficient business mentality, resulting in a new business world, which does not only focus on profit maximization.

Dematerializing the world

As digitalisation progresses, more and more areas of life are regulated by (immaterial) data instead of physical objects. This trend is also increasingly noticeable in parts of the population where sharing of things or use of (virtual) services instead of products becomes “en vogue” before individual possession. In addition, this has a lasting effect on the overall consumption of resources. Future R&D therefore needs to find ways to get back from our short-term driven mind set to a long-term thinking. We need again durable products of quality. Therefore, we need to find ways in establishing new values of production as well as consumption in the consumer goods industry.

3.9.2 Society and Culture

The future of the transport can be considered as socio-technical development, with new technologies and mobility concepts together with political frame conditions affect social development and are in turn influenced by user needs and acceptance.

Promoting Science-Public Cooperation

Due to fears and ambiguities, there is a certain reticence towards innovative and sustainable new mobility products and services. Particularly in the field of electric mobility, the fear of low range still prevails, although the majority of today's car owners would actually be more than adequately served with the current range of electric vehicles. People therefore must be offered more opportunities to test and convince themselves of those new technologies. In addition, it is also important that science increasingly prepares its work in a way that is appropriate for the addressees, and that the broad mass of the population is able to participate in the discussion. Thus, public communication supporting socio-technical transformation is one of the key issues.

Establishing new forms of work and leisure

A large part of today's traffic volume could be reduced if more employers would be willing to offer their collaborators new working models. In addition, there is a huge potential for reducing CO_2 emissions from travel. Future R&D activities therefore need to take into account, what possibilities could emerge for example from virtual (leisure) worlds. A new leisure and travel behaviour is needed, until sustainable propulsion solutions have been established on a large scale in all means of transport (especially in the aviation industry).

Establishing sustainability as mainstream thinking

The success of sustainable mobility products requires acceptance of users. It is therefore a necessity to create a social movement towards sustainability. Future R&D therefore needs to find ways to force sustainable decision making and to establish it as mainstream thinking. A social movement needs to evolve in culture and effective ways for communicating sustainable values need to be developed (e.g. through marketing, advertising, influencing, incentivising, etc.).

3.9.3 Policy and Institutions

Related to the fundamental changes coming along with technological innovation and megatrends with their impact on mobility and transport political strategies would need to adapt. This includes different levels, such as policy for regions and cities, global policies and national ones.

Implementing an energy system transformation

In order to achieve the climate targets set, a conversion our energy system to sustainable energy sources is a necessity. Furthermore, this will form the basis for a sustainable transport system, since switching to electric mobility in particular can only achieve a sustainability effect if the energy for charging the batteries also comes from sustainable energy sources. Future R&D activities therefore need to focus more on strategies and incentive systems as well as different ways for promoting sustainable energy solutions, to find acceptance among the population as well.

Developing alternative and reliable energy solutions

Although electric mobility represents one of the biggest trends in the field of engine technologies, there are various doubts arising about this technology that need to be solved in order to make electric mobility a sustainable alternative to the conventional internal combustion engine. Looking at the life cycle of an electric vehicle for example, it still does not perform much better that a conventionally powered vehicle. In addition, there is a big question mark regarding the origin of resources for battery production (e.g. lithium and cobalt), which are exploited to a large extent in politically unstable regions – as well as concerning recycling of batteries. A critical reflection on electric mobility is therefore needed, which includes the policy as well as the research community within the ongoing research process. Ways to 100% substitute fossil through renewable energies need to be developed. The latter aspect is also reasonable in order to reduce the risk of dependence on energy imports from politically volatile regions.

Avoiding Rebound Effects in resource consumption

Gains in efficiency and innovation (e.g. through technological progress) most likely will be overcompensated by rebound effects – as happened in the past. In particular, in the case of autonomous driving systems, there is a risk that, contrary to the intended reduction of vehicles on the roads, there will be more vehicles on the road due to new user groups using this new mobility solution. Future R&D activities must increasingly be aware of potential (negative) rebound effects from (disruptive) innovations.

Decentralising the transport sector

The increasing centralisation in all areas of life means that especially in rural areas it is no longer possible to offer a sufficient range of services, resulting in increased traffic into the central hubs and a loss in the basic offers for large parts in our society. “Back to the local” could be a provocative approach to show people the advantages of less mobility and to re-encourage local solutions. Future R&D will therefore need to finding ways to strengthen the peripheral regions again.

Becoming a role model for the world

Europe has always held a leading position in research and development. Many innovations have been born here and carried out throughout the world. Accordingly, Europe serves as a model for large parts of the world, which can also be transferred to the transport sector. In the course of the forthcoming transformation of the transport system towards sustainability, Europe must become increasingly aware of this again and consciously assume a leading role in the field of sustainable transport. In addition, Europe must also take responsibility and, in particular, make this transformation possible for developing and emerging countries as well through mutual exchange.

3.9.4 Science and Technology R&D

Science and research play a key role when it comes to the future development of the transport system. While innovation and progress has taken place in Europe in the past, one has to be aware that even this field is dominated and limited by mainstream thinking of scientific communities, research investments and policy. In order to use full innovation potential and creativity for best solutions the horizon of research has to be broadened.

Enabling bottom up research

In order to enable the development of disruptive, unexpected, innovative solutions “risk capital” needs to be allocated for science and research. Bottom-up ideas on solutions, but also on the problems to be addressed would increase the potential of successful solutions – which today is limited by top-down strategies for research and the recent scientific system neglecting and excluding approaches beyond mainstream thinking.

Redesigning urban mobility

In the course of the megatrend “urbanisation”, large parts of our society will be living in cities in the coming decades. The mobility systems in particular will therefore be facing major challenges and congestion and pollution are expected to further increase. R&D activities therefore need to focus more on measures to improve air quality and to reduce the deadly health impact of pollution in the cities. For example, cities could increasingly promote active mobility by demonstrating its benefits (e.g. health aspects) and making it overall safer (e.g. through new infrastructure concepts or a decoupling of slow traffic from roads). In this context, the focus leading the redesigning of urban mobility should lay on quality of life.

Establishing public transport as new “comfort zone” for travelling

Individual car ownership is still regarded as a status symbol in large parts of our society. The constantly growing prosperity in our world will further accelerate the number of cars on our roads resulting sooner or later in a system collapse. In order to be able to persuade people to turn away from individual car ownership, public transport in particular must assume a stronger supremacy among the various modes of transport. In this respect, public transport must become a new oasis of well-being so that no one will miss having their own car in the future. This goes along with simple and uniform services (e.g. information, billing, etc.), Trans European standards and a flexible, secure, cheap and convenient mobility offer. R&D must therefore be realigned accordingly.

3.9.5 Overall concepts

Besides blind spots allocated to the fields of economy, policy, society and R&D there are a number of concepts comprising and affecting some or all of them. These overall concepts can be considered as tasks and strategies to be supported and implemented in the economy and society as well as related institutions and political regulations.

Establishing a new mobility paradigm beyond growth

Growth of population, economy, wealth and consumption lead to increasing demand for mobility with the consequence of driving the system towards scarcity of resources. In order to address related problems not only rethinking, but also re-designing and re-structuring the transportation system is necessary. The recent paradigm considering growth as precondition for economic competitiveness and social wealth needs to be replaced by new concepts. In this context, transportation is linked to many other fields like the economy, the energy sector or trade, to name only a few. Taking these interrelations into account, addressing the basic problem of the dominant growth paradigm needs research and development with an integrated focus on the mentioned fields, e.g. on innovative transport and economic models.

Cultural turn in mobility

A cultural turn in transport system development with a shift from quantity of mobility towards quality is necessary, as linked to previously mentioned aspects (e.g. circular economy, redesigning urban mobility with regard to quality of life in cities etc.). This includes also to realize the benefits of less mobility and slow mobility and to support the development of alternatives to the recent system towards this direction.

4 Research Agenda for future transport research

Integrating the identified gaps, research fields and blind spots in current research results in a holistic agenda for future transport research to support a system transformation and re-organization of the mobility system consistent with political goals of the European Union.

The research agenda pays regard to two main streams of trends, on which Europe not only needs to react, but which define main R&D needs in transport:

1. *Internal trends* of the transport system: revolutionary technological developments will lead to a fundamental change of the transport system affecting supply side, markets, mobility services and vehicles. Form and effects as well as related risks and opportunities of these trends are still unknown.
2. *External trends* affecting the transport system: the trends come along with pressure to redesign the system to address climate change, emission problems, high density in cities, health and safety issues. Those trends lead to risks and a need to react, also providing opportunities for Europe to shape and improve the transport system.

In this situation, shaping the transformation of the transport system to cope with the developments is the main issue. R&D plays a key role here, as it is crucial in analysing and understanding the problems, developing solutions as well as enabling transformation as *guided development of the transport system towards a desired direction*. Funding for R&D is **the** political instrument of directing innovation and development towards addressing both the mentioned internal and external issues.

The importance of R&D and need for active shaping does not account only for the transport system itself, but also for the energy system as well as for the development of cities and regions. Technological innovation and socio-technical trends come along with the chance to be picked-up and to be directed towards solving the problems related to external trends. For example, new technologies might be used for low emission mobility services run by alternative energies. Thus, directing R&D in transport aligned to other European strategies like environmental policy, policy for cities and regions as well as decreasing social disparities across Europe has the potential for supporting polyvalent solutions. Otherwise, innovations will develop under the conditions of current market mechanisms, which are based on limited fossil energy, external resource dependency, waste and overuse of resources. It is important to avoid any system change multiplying current problems and side effects of transport in order not to contradict political efforts for high quality of life, health and competitiveness.

Based on these considerations, research fields were prioritized according the urgency of actions and were put into temporal order between *short term* and *long-term actions* (see Figure 5). The temporal classification indicates the importance and urgency of **starting** actions and should not be misinterpreted as only taking place in the time span allocated. Many identified research fields are both important and urgent, to be addressed but need to be continued for years and decades. Due to the recent dynamic development in technologies, the pressure on policy to solve related problems and set respective frame conditions as well as the long-term effects of measures and investments in transport, many research fields appear as short-term actions. This means these research fields should be implemented as soon as possible and continue into the future.

Action fields allocated to the other end of the time scale as long-term actions are more visionary pointing to future scenarios for the European transport system.

The research fields identified by the gap analysis reflect inconsistencies between visions and strategies respectively conflicts between goals (e.g. growth-driven vs. sustainability policies) – as already inherent in strategies formulated by the European Commission: *Efficient transport is a precondition for maintaining the EU's prosperity — we need* ***less congestion****,* ***fewer emissions****, more employment and* ***more growth*** *(EC, 2011).* The goals *to develop and promote transport policies that are efficient, safe, secure and sustainable, to create the conditions for a competitive industry that generates jobs and prosperity* (https://europa.eu/european-union/topics/transport_en) are not necessarily leading into the same direction as growth lead to non-sustainable development in the past. Breaking this mechanisms is the key here.

The research agenda addresses **gaps of contradictory political goals** as mentioned in the fields of *avoiding rebound effects*, *developing consistent strategies*, *aligning R&D to sufficiency, realizing the circular economy* and *establishing sustainability as mainstream thinking* – with their related subtopics. Research in these fields is relevant for and related to many aspects of the transport system such as infrastructure, vehicle technologies, operations, investments, mobility demand etc.

Rebound effects of the past have led to an overall increase of fossil energy consumption and related emissions – not in spite of, but due to increasing energy efficiency in transport. Thus, technological developments and innovations aiming to optimize the transport system by increasing efficiency need to be accompanied by measures to avoid rebound effects. Less is known, about how to avoid rebound effects. Research in this field is necessary related to supply (e.g. especially but not exclusively autonomous vehicles) and demand side (e.g. mobility behaviour). As a basis to bridge these gaps, arising from different needs a fundamental shift of thinking, decision making and implementation is necessary. R&D is essential here, when it comes to analysing the problems and developing disruptive innovations in the fields of the *circular economy* and supporting *R&D for sufficiency* (e.g. for new mobility solutions as MaaS, policies in this context and new mobility paradigms). A crucial research question in this context is how to establish sustainability in mainstream thinking, not only in the economy and the transport sector, but in society and among mobility users. To put this in practice, the *development of consistent strategies* is crucial, which means to align transport and environmental policy to prevent conflicts and realize benefits for the European society and economy. This might require innovation in political and administrative organization, where research could contribute to by identifying best practice and developing models for cooperation and strategy development. Research should help to shift the focus from a quantitative growth-perspective towards a qualitative perspective (optimization) as a basis for that.

Some research fields cover research needs of recent technological innovation like *enabling emerging technologies* or *redesigning public transport as "comfort zone" for travelling*. *Emerging technologies* come with great opportunities to transform the transport system consistent with the political goals of the EU into one supporting future competitiveness and high quality of life. However, there are also risks of external and negative side effects, misinvestments and impairment of the quality of life. Research especially in the main dynamic fields such as transport infrastructure and ITS-systems is needed to further develop the technological basis as well as for more specific innovations like Hyperloop or platooning. In this context it is also important to innovate the way how *public transport is designed*. This group of research fields also includes disruptive innovation: the way how and which innovation is enabled, reflected in the topics of *promoting science-public cooperation*, *forcing bottom up research* or *ensuring resilience of the transport system.* In all of this fields continuous research needs will arise during the process of systemic change in transportation – with not all to be identified yet in detail. Increasing the potential for R&D leading to smart innovation it is necessary to broaden research perspectives and open them to the public while driving *science-public cooperation*, where best practice and forms of cooperation will need to be developed. This is especially relevant in technological innovation, e.g. electric propulsion or autonomous vehicles. Besides the common practice of defining research topics top down, changing the procedure towards *bottom up research* allows to gain unusual, out of the box approaches in research; the need for research on innovation policy is related to this. The increasing implementation of IT-solutions as a basis for the transport system as well as autonomous systems increases the complexity of the transport system. In order to handle this complexity and to back-up the transport system, R&D to *ensuring resilience of the system* is necessary – considering different dimensions as ITS-Systems itself, transport infrastructure, but also effects on and potential for the environment and cities.

Research needs in transport, are also closely related to other fields via supply and demand connections as reflected in the research fields of: *redesigning urban mobility*, *implementing an energy system transformation* as well as *establishing new forms of work and leisure*. Within these fields, research would need to provide knowledge about dynamics between transport, the economy, population and spatial development in order to *redesign urban mobility* with focus on quality of life. Understanding the effects on and potential for sustainable transport of *new forms of work and leisure* as related to structural change of the economy, industry 4.0 and linked mobility behaviour are main topics for research and development of new mobility solutions. Due to the high relevance of energy, also addressing *energy system transformation* in transport is part of this bundle of research fields – with research needs concerning electric propulsion, improved batteries, charging infrastructure, energy recovery and the circular economy.

Besides this, more visionary long-term goals require higher and overall strategies, to which research could contribute in the fields of: *decentralizing the transport sector*, *becoming a role model for the world* or *dematerializing the world.* Similar as in energy a *decentralized transport sector*, which is related to changes in industry and production (additive manufacturing) and the EU relevant topic of spatial disparities, requires research and development on new concepts, coordination modes and implementation respectively change of the given system. Related to this and the above-mentioned research topics with a strong focus on innovation for system transformation, Europe could become a role model for the world, which could strengthen competitiveness in the long-term. R&D contributing to solving global problems is a clear competitive advantage, closely related to policies. Thus, research can help to find out how political strategies could be most beneficial for this. At the end the vision of *dematerializing the world* as an ambitious research mission allows to go beyond classic R&D, driving disruptive innovation, which are not only related to the above mentioned technologies as enabler, but to the way how we move as dealt with in topics on sharing systems or new mobility paradigms.

All identified research fields are part of different dimensions, such as science, policy, society or the economy, but all of them are depending and affecting more than one dimension –

reflecting the complexity of the transport system and its future to be developed. The change in turn is fundamental. More than anything else the precondition for achieving a transformation of the transport system, an energy revolution and the implementation of resource thinking is a cultural turn towards sustainability in its original sense of enabling our future.

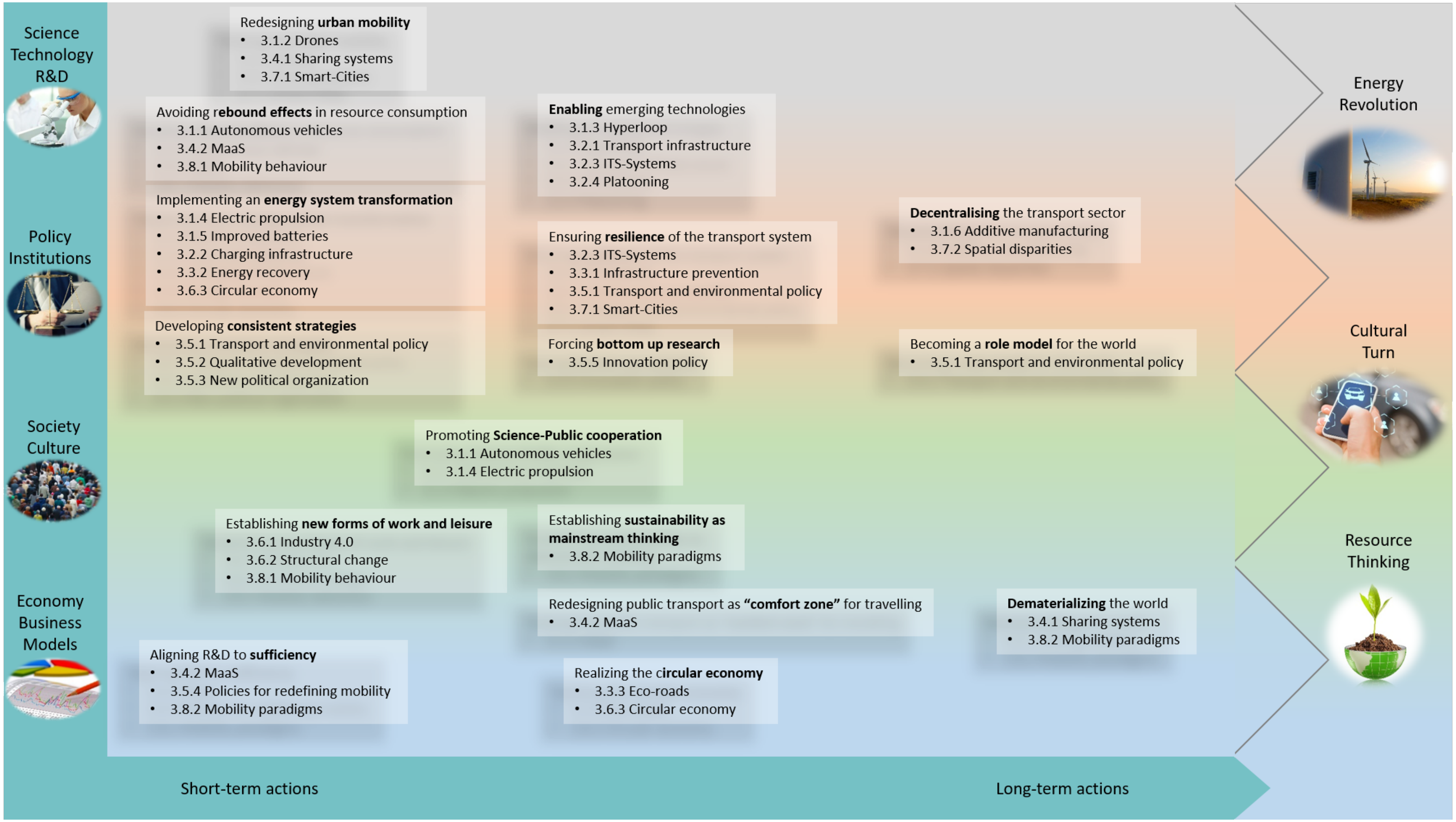

Figure 5: Agenda for a systemic transformation of the transport system (Source: ZHAW)

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