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D4.1 Sketch of the future transport system

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Abbreviations

AAT	Autonomous Aerial Taxi
ANP	Analytical Network Process
ART	Autonomous Rail Transit
BMW	Bayerische Motoren Werke
CEO	Chief Executive Officer
CES	Consumer Electronics Show
CO_2	Carbon Dioxide
CTI	Commission for Technology and Innovation
DB	Deutsche Bahn
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EC	European Commission
ESIF	European Structural and Investment Funds
EU	European Union
EV	Electric Vehicle
FCV	Fuel Cell Vehicles
GDP	Gross Domestic Product
ICE	Internal Combustion Engine
ICT	Information and Communication Technology
IEA	International Energy Agency
ISI	Frauenhofer Institute for Systems and Innovation Research
ITS	Intelligent Transport Systems
IVL	Swedish Environmental Research Institute
I2V	Infrastructure to Vehicle
LCA	Life Cycle Assessment
MaaS	Mobility as a Service
NEV	New Energy Vehicle
OPEC	Organization of the Petroleum Exporting Countries
OPTIMISM	Optimising Passenger Transport Information to Materialise Insights for Sustainable Mobility
QDA	Qualitative data analysis
R&D	Research and Development
RMIT	Royal Melbourne Institute of Technology

SAE	Society of Automotive Engineers
SCCER	Swiss Competence Center for Energy Research
SESAR	Single European Sky ATM Research
StAGN	Standing Committee on Geographical Names
TEN-T	Trans-European Network - Transport
TOSA	Trolleybus Optimisation Système Alimentation
TUB	Technische Universität Berlin
UAV	Unmanned Aerial Vehicle
UBS	Union Bank of Switzerland
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe
UNFCC	United Nations Framework Convention on Climate Change
UNWTO	World Tourism Organization
US	United States
V2I	Vehicle to Infrastructure
V2G	Vehicle to Grid
V2V	Vehicle to Vehicle

Executive summary

The mobility system is about to change due to various influencing factors such as political decisions, technological innovation or 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. The present deliverable provides therefore a sketch of the future transport system, focusing on differential aspects such as the changing role of mobility and new mobility paradigms, technological innovation and emerging new mobility solutions, new stakeholder networks in a changing competitor's landscape, etc. This will serve as a basis to derive in a further step blind spots in transport research as well as future research priorities for EU transport research.

The methodological approach pursued in the underlying research project involved in a first step a desk research on future trends in mobility and transport. Results indicate that many technological innovations are about to be developed and implemented that are expected to have a big potential to serve as future game changers. In particular autonomous driving enabling technologies can be expected to dominate the future transport system. Further fundamental changes can be expected in the field of engine technologies through the increasing electrification of conventional drivetrains. These developments might be accompanied by the supply of alternative energies of fuels running in parallel. In addition, IT-based mobility solutions are expected to provide more intermodality, enabling shared mobility and MaaS services to emerge on a large-scale.

According to the initial trend overview, qualitative interviews with experts from the transport sector were conducted in order to close any gaps within the trend research as well as to formulate hypotheses on the evolutionary development of the transport system. The formulated hypotheses were subsequently verified in a large-scale online survey with transport-related experts from industry, policy and academia. Results show that autonomous vehicle systems are expected to have rather positive than negative impacts on the transport system. However, large-scale implementations of autonomous driving systems are expected to be implemented first in cargo/freight than in passenger transportation and probably also in urban rather than in rural settings. An implementation of drone technology is expected rather in cargo/freight transportation than in passenger transportation although rather as a niche technology. Furthermore, there is a significant tendency visible, that private car ownership will decrease in the future due to newly emerging mobility products and services. Shared mobility rides appear to have a high potential in the future whereas revolutionary transport concepts such as the *Hyperloop One* are not expected for being implemented on a large-scale. Regarding the impact of technological innovations, there is a strong tendency visible that the increasing electrification of drivetrains as well as lightweight construction could have both positive impacts on the sustainability of the transport system. Ultimately, survey results show that regulatory frameworks are currently not adapted with regard to newly emerging technologies and internalisation of negative external effects is seen as crucial, in order to achieve a sustainable transport system in the future.

This finally resulted in a sketch of the future transport system that - summarizing results of the trend analysis on future technologies in transport, relevant social and economic developments, policy strategies as well as the perspectives of experts on the future of mobility - will be fundamentally different from the current system state, resulting in the following key findings:

- On the level of impact factors for transport, related to megatrends of globalisation, urbanisation, demographic ageing and related scarcity of resources, the main tendency of future development is about growth, resulting in an increase in resource consumption and related emissions. Disparities on a social, income and economic level as well as the shift of population towards cities are therefore likely to be accentuated in the future.
- The ongoing structural change in the economy (related to digitization) can be considered to be as fundamental as the industrialisation, transforming production, industrial sectors and retail as well as organisation of the economy. These trends will be reflected in social developments, the labour market and lifestyles.
- Effects of various influencing factors on mobility demand and supply are still difficult to estimate – even if it is likely that an increase of transport will result due to growth. Thus, efforts in emission reduction and towards a circular economy from the political side will be crucial and serve as game changer, determining the effects of innovation.
- Besides demand and supply related effects on the transport system recently many technological innovations are about to be developed and implemented showing a high potential to serve as game changers. But even if those innovations will be part of the future mobility system and shape it in a different way compared to today, change is quite unclear as effects on mobility demand are depending on many other aspects. However, there is a strong technology driven mind set apparent, shaping the vision of the coming developments and the future transport system in terms of positive effects (e.g. emissions, resources).

From the synthesis of the results of the various work steps in D4.1, several questions arise and give a first idea about potential blind spots in today's perspective on what is relevant for the future mobility system as well as potential gaps in innovation and research. It will be crucial to investigate in a further work step those gaps and blind spots in current transportation research in order to make recommendations for future priorities in EU transport research. This will be the main objective in the following D4.3 – Transport research agenda, for which the present deliverable with its findings will form the main basis.

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 constitute a dynamic knowledge base repository on the major developments in the transport sector. This will provide a visualisation of the INTEND's main outcomes. The basis for the platform will be Transport Synopsis Tool which is already 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 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. Especially the field of system re-organisation will go along with 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)

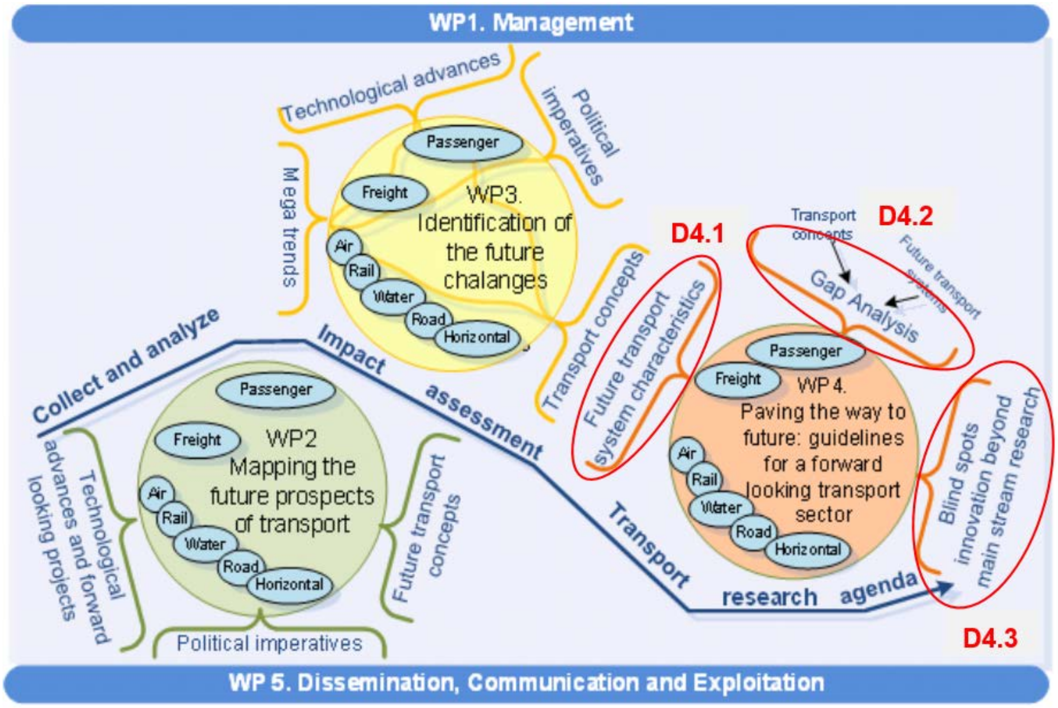

Figure 1: The INTEND workflow and relations of D4.1 with other work packages

1.2 D4.1 - Sketch of the future transport system

The mobility 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. To identify these research needs of a future transport system, the latter has to be characterized in a first step. Thus, in D4.1 the system aspects, borders and dynamics of the future transport system will be redefined with an outlook on the systemic change – including results of previous work packages, especially task 2.2 (Identification of key transport concepts of the future). This will provide a basis to illustrate and understand the research needs coming up with the transformation of the transport system as described in D4.3 - Transport research agenda, considering the major influencing (mega-) trends with their impacts from WP3 (Identification of future challenges).

D4.1 includes in specific a characterization of the future transport system with main focus on differential aspects, such as: the changing role of mobility itself and new mobility paradigms, technological innovation versus new mobility solutions on a conceptual basis, change of systemic borders, new stakeholder networks and changing competitors' landscape. The analysis of this task was carried out on a broad initial desk research on future trends in mobility and transport and on an online survey about the evolutionary development of the transport system that based on hypotheses that were formulated on the results of qualitative interviews with experts from the transport sector.

2 Research approach, methodologies and appliance in T4.1

Research needs related to the future transport system will differ from today depending on changes due to political decisions, technological innovation or new mobility concepts as well as global socioeconomic trends. T4.1 aims therefore to provide a comprehensive characterization and theoretical foundation of the current transport system, including all areas relevant to mobility that are expected to undergo major changes in the future. In addition, emerging trends and developments influencing the transport system will be identified, to predict possible transformation paths in the future. This will serve as a basis, to finally draw a sketch of the future transport system, with main focus on differential aspects such as: the changing role of mobility, new mobility paradigms, technological innovation, new mobility solutions and stakeholder networks and the changing competitors' landscape. The workflow as pursued in T4.1 is shown in the figure below.

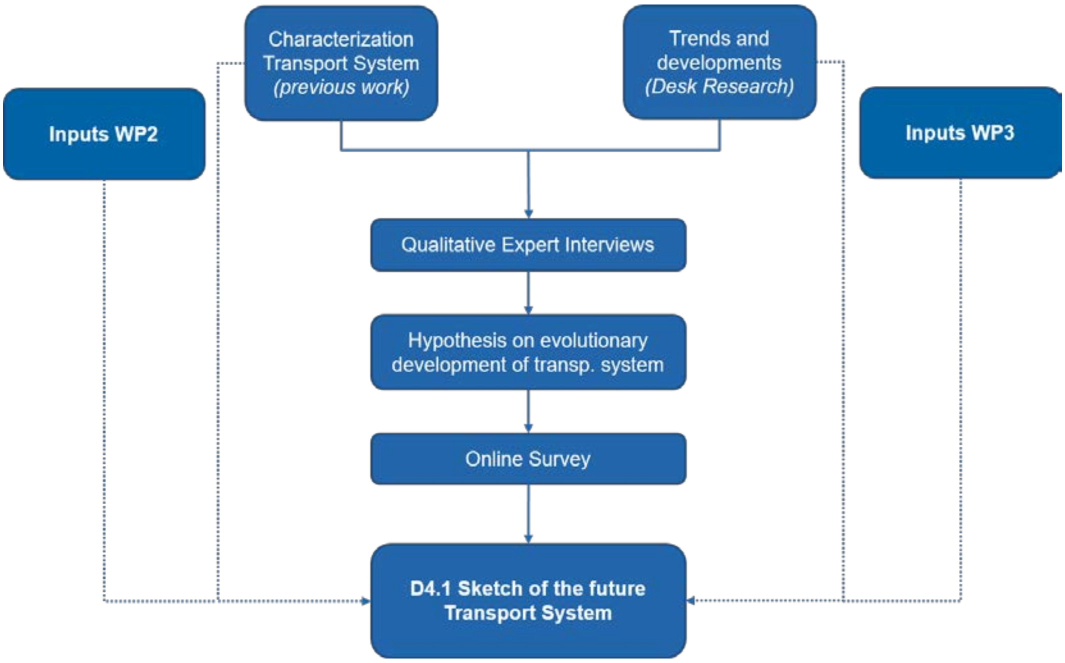

Figure 2: Research approach and methodologies in T4.1 (Source: ZHAW)

To approach the targets set in T4.1, the following research questions were conductive:

- *Which elements make up the transport system and how are they interacting with and influencing each other?*
- *What trends and developments are currently emerging that could lead to a transformation of the transport system in the future?*
- *What will the transport system look like in the future with regard to a potential transformation of the current system?*

To answer the first research question, an existing **model of a transport system** and in particular its constituting elements were characterized and adapted to the specific context and needs of the INTEND project. To answer the second research question, a **desk research** was carried out to detect current trends and developments in the transport sector. The desk research particularly aimed to identify potential "game changers", having the ability to support a paradigm shift towards a transformation of the transport system in the future. This formed

the basis to conduct in a third step the **expert interviews** with experts of the transport sector, to get more in depth findings on the future development of the transport system and to scientifically legitimize the results of the initial desk research. In a fourth step, the key findings of the expert interviews and results from previous work packages were combined to formulate **hypotheses** concerning the evolutionary development of the transport system as well as to derive the questions for the following **online survey**. This ultimately resulted in a **sketch of the future transport system**, providing a basis to illustrate and understand the research needs, priorities and opportunities coming up with the transformation of the transport system, as shown more in depth in *D4.3, Transport research agenda*.

2.1 A systemic model of transport

As a starting point for the initial desk research, a model of a transport system has been applied. The model was developed in the initial stage of the *Swiss Competence Center for Energy Research (SCCER) - Efficient Technologies and Systems for Mobility*[1] research project. As a theoretical foundation, the model draws on the Multi-level perspective (MLP) introduced by Geels (2002), a framework to explain systemic transformation processes. It is important to note that when you look at mobility from a systemic perspective, many different aspects and dimensions of 'transport' and 'mobility' with their interactions need to be considered. A too one-sided focus (e.g. only on technological development) must therefore be avoided in the research process.

The structure of the model was elaborated through questioning experts on their perception of the mobility system and its constituents, as a reflection of a system's draft that had been produced at an earlier stage based on literature review and the research experience of the project consortium. This resulted in a systemic delineation of mobility that addresses the mobility system through its holistic nature with mobility related aspects, drivers and transport-related fields. In addition, it provides a framework, to understand past and current developments in the different fields of the system, as well as to project possible pathways for a future transformation of the system. The model consists of the following six thematic fields:

1. Technology / R&D
2. Policy
3. Economy
4. Society
5. Transport sector
6. Spatial order

Each of the six thematic fields consist in addition of various components that interact with each other or have an interrelationship. This results in a total of 14 components, which further subdivide the main thematic fields of the systemic model (Hoppe and Michl, 2018).

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[1] The main objective of *SCCER* is to develop the knowledge and technologies essential for a transition from the current fossil fuel based transportation system to a sustainable one, including minimal CO_2 output, primary energy demand as well as virtually zero-pollutant emissions (SCCER Mobility, 2018).

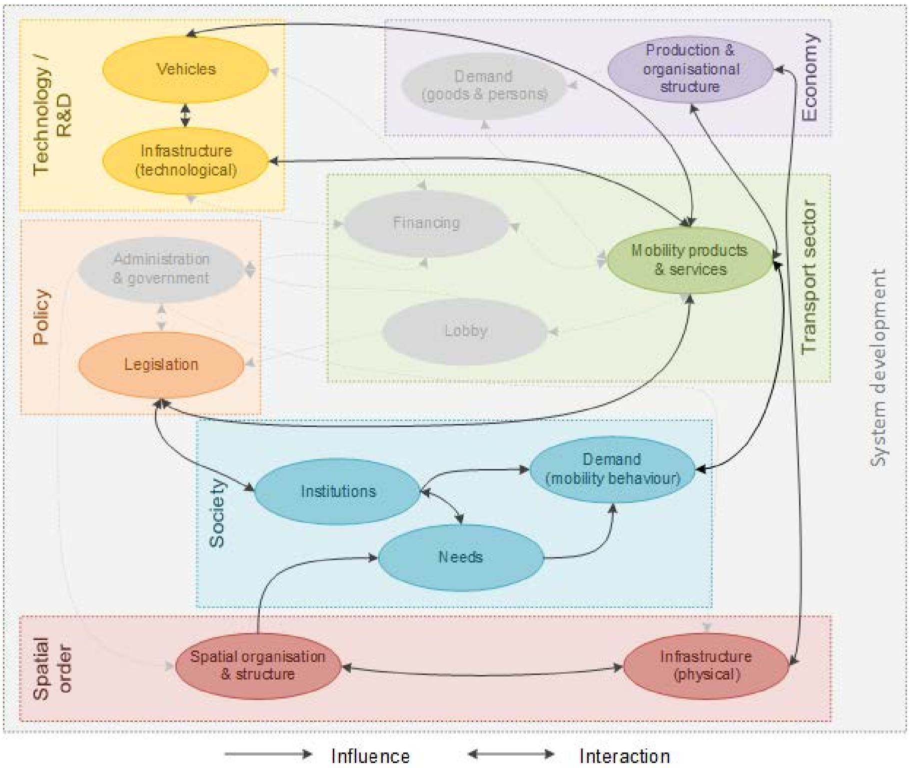

Figure 3: Model of a transport system (Source: Hoppe and Michl, 2018)

For the specific purpose of the INTEND project, the model of the transport system has been reduced to those system elements that will most likely play a major role in future transportation and that are reflecting promising research areas, especially with regard to systemic change. Starting from initially 14 components, we focused therefore in our further analysis on 10 components (not greyed out in Figure 3), which can be seen as crucial for future transportation research. The six thematic fields and their specific components are briefly described in the following subchapters, following their initial description according to Hoppe and Michl (2018).

2.1.1 Technology / R&D

Vehicle technology can range from simple inventions – such as the wheel thousands of years ago – to highly complex modern visions such as the *Hyperloop One*, a giant vacuum-tube transportation system for the future of freight and mass transit (Bradley, 2016). The dominant socio-technical regime, at least since the middle of the 20thcentury, is the individual car, powered by an internal combustion engine (Geels, 2005). Other relevant technologies, that have already been around for many decades but capture only a small percentage of total mobility – so called subaltern regimes – are trains, buses, trams and bikes (Geels, 2012).

For their practical operation, vehicles need a corresponding **infrastructure**: cars and buses need roads, trains and trams need rail networks, planes need airports and flight corridors, etc. The technological aspects of infrastructure include building materials and design, but also traffic management systems, ranging from simple traffic lights to complicated ICT infrastructure (e.g. for autonomous vehicles) as well as charging infrastructure for alternative fuels.

2.1.2 Policy

Political and administrational actors, their decisions, their strategies and their actions are essential steering variables for the transport system. Policy as a thematic field of the transport system includes two components, which complement each other:

Legislation sets the legal framework and incorporates the highest formal regulatory and steering function in the mobility system. Basic decisions are reached, e.g. about climate policy, but also specific mobility-related issues are decided (e.g. regulations for more safety in transports, allocation of subsidies for infrastructure projects, directives on road pricing, etc.).

The executive branch – **governments and administrations** – implements the legal framework and applies it to specific situations. This means for example controlling the abidance by the laws of other actors, developing specific tools and methods to reach the goals that were set, controlling of funding, and many other aspects.

2.1.3 Economy

The thematic field "Economy" describes all the activities of persons and companies in producing and selling goods and services and distributing them to their consumers. This generates a considerable share of transportation demand in two ways: 1) directly for transporting goods and services as well as business trips of working persons and 2) indirectly through the necessity for people to commute to their workplace. The mobility demand depends on how and where and which type of goods and services are produced (Production and organisational structure).

The general economic structure of a country is an important factor in the mobility system. Different economic sectors result in different **demands for transportation**. Furthermore, the **production and organisation structure** (e.g. value chains, just-in-time production, etc.) are also closely interrelated with spatial conditions. Especially the spatial aspects of infrastructure play an important role here (Rietveld, 1994). Additionally, work-related mobility is depending on who needs work when and where, which depends on the other hand on the requirements of the employers such as the degree of specialisation of the workforce (which influences the length of average commuting distances) or the need of a person to physically be at a certain place to fulfil their job. From the economy's side, there are different aspects of mobility demand. Generally, transportation of goods and transportation of people need to be distinguished. Transportation of people includes mainly work-related mobility such as business trips whilst demand for transportation of goods is independent from that of people (yet both are interrelated as they share the same infrastructure).

2.1.4 Society

People need and want to move between places, which is a key aspect of mobility. The choice of means of transport, selections of routes and travel times and decisions about whether to move or not is summed up as "mobility behaviour" of individuals and groups. This mobility behaviour is the result from individual needs and preferences, which are (at least partly) shaped through the interaction with others (institutions).

Every person has some basic **needs**. According to Maier et al. (1977) those basic needs consist of living, working, supplies, education, recreation and social interaction. The facilities required to fulfil these needs are usually not located all in one place and therefore transportation is necessary that people can meet all their needs.

How the previously described needs are put into practice is a matter of perceptions, interpretations, experiences and preferences, which all can be summed up as **institutions**. Institutions therefore are a framework of norms and values, which influence people's mobility behaviour.

Finally, **mobility behaviour** can be seen as the combination of needs and institutions, which is put into practice by buying and utilizing mobility products and services. Mobility behaviour can be (statistically) assessed through different variables or indicators such as distances travelled, travel time, modal choice, etc.

2.1.5 Transport sector

The thematic field "transport sector" includes all public and private companies and institutions as well as their activities to provide mobility services. It includes the components Financing, Lobby and Mobility products & services.

Financial aspects are essential for decisions about whether certain mobility offers are made or not. Furthermore, the transport sector constitutes nowadays as one of the major contributors to GDP in industrial countries and holds therefore a severe economic importance.

Regarding this economic importance, there are several stakeholders in the transport sector that have economic interests, which they want to protect and/or expand. Besides economic measures to increase market shares or develop new markets, it is also an option for them to try to influence ongoing political discussions. **Lobbying** attempts therefore to direct legal frameworks and administrative/governmental activities and decisions in a favourable way.

Finally, with **mobility products and services**, vehicles, maintenance and organisation as well as corresponding business models, the transport sector provides the basis for mobility. Examples for actors are vehicle-manufacturers, vehicle shops, public transport companies, service providers, infrastructure construction and maintenance companies, investors, public institutions providing infrastructure or services, etc.

2.1.6 Spatial order

Space is the "playing field" in which the actions and interactions of the previously characterised thematic fields take place. It acts in two ways: It 1) influences the actions of the actors in the mobility system through setting for example spatial limits and 2) can be influenced itself through the actions of the actors in it. Therefore, space needs to be seen as a dynamic construct that provides an essential factor influencing development but is also constantly transformed itself.

One of the key features of space that can be considered relevant for mobility is **spatial organisation**. The locations of facilities required to fulfil people's needs and desires are essential for the mobility demand. Spatial organisation and structure can therefore have a major influence on the volume of traffic and the future development and density of settlements.

The second spatial component of the mobility system is the **physical infrastructure**, which is complemented by the technological infrastructure. It provides the physical options and limitations for mobility. It determines further on, which transport modes can possibly be used to travel a certain path. The physical infrastructure does not always predefine its usage: roads can be used by motorised individual transport vehicles such as cars or motorbikes, as well as by public buses.

2.2 Desk research on future trends in mobility and transport

According to the previously described systemic model of transport, current trends and developments in the transport system were identified in a broad-based desk research. Information was collected from project reports, trend studies or journal articles as well as deliberately non-scientific sources such as transportation websites, future-oriented blogs or news reports, in order to capture the latest trends in the various fields of research. In addition, it proved to be very helpful to set up e-mail alerts, in order to keep up with all the ongoing trends and developments in mobility and transport.

Each identified trend was in a next step assigned to the corresponding system element within the underlying systemic model. This resulted in a detailed description and overview of emerging trends and developments in mobility and transport. To ensure consistency of content and for better readability, the chapter structure in D4.1 was slightly adapted in comparison to the given structure of the systemic model through merging of various sub-components. This resulted in a first draft of a thematic chapter structure of D4.1 as shown in Figure 4 below.

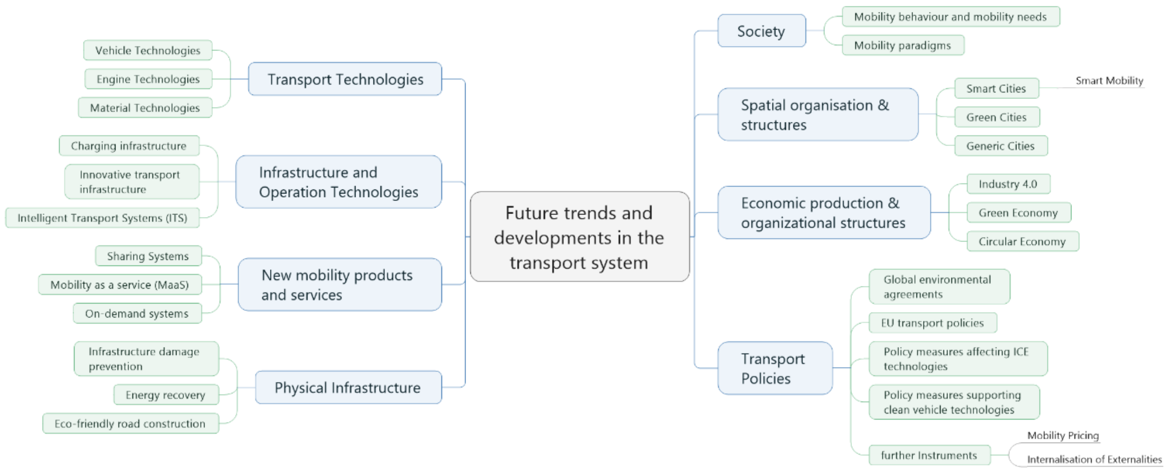

Figure 4: Main categories and the thematic sub clusters resulting from the initial desk research on future trends in mobility and transport (Source: ZHAW)

In a further step, a short summary of the main directions in which research and development in each sub cluster is heading to, has been made. The chapters concluded with an outlook on the future development within each thematic category, with a specific focus on potential challenges and opportunities. This served as a basis for preparing in a next step the expert interviews with various experts from the transport sector.

2.3 Qualitative expert interviews

The qualitative part in T4.1 included expert interviews with various experts from the transport sector. According to Bogner et al. (2005), the expert interview is a special application form of the guideline interview and can be characterized by the interviewer's specific interest in knowledge and the interviewee's specialist knowledge of a specific issue. The interview is conducted very similarly to a natural everyday conversation and allows the interviewee to permanently adjust the course of the conversation. Central advantages of expert interviews are that a lot of information can be obtained in a relatively short time and ambiguities or issues that need to be clarified can be dealt with directly. A major disadvantage, especially with

sensitive questions, can be that respondents can hide their true personal opinion behind the "socially desired" one in their answers (Bogner et al., 2005).

The expert interviews in WP4 were intended to provide additional insights and perspectives on the future transport system in order to close possible gaps resulting from our initial desk research and to scientifically legitimize the latter. Furthermore, results from the expert interviews formed the basis, to formulate in a next step hypotheses on the evolutionary development of the transport system, which, in a final step, have been verified by an online survey.

2.3.1 Interview guide

At the origin of the qualitative research process was the development of the interview guideline. In this respect, the main topics of the interviews had to be defined and delimited in a first step. The main topics derived on the one hand from the objectives of the underlying research project and on the other hand from the thematic main categories and sub clusters as they resulted from the initial desk research (see Figure 4). In a last step, the compilation of thematic fields has been revised, rearranged and integrated into the interview guideline, which consisted finally of nine open questions. The draft version of the interview guide was subsequently revised in a circular process, in particular after the first two interview sessions.

2.3.2 Expert selection

In a next step, potential experts for the interview sessions have been selected and contacted with a unified cover letter. The provisional selection was determined on the one hand from the own professional network and on the other hand from contacts of the partners within the INTEND consortium. The following criteria were of particular importance in the selection of the experts:

- Equal relationship between experts from industry, policy and academia
- Integration of all modes of transport and expertise from the passenger and logistics sector
- Regional diversity among experts

Due to cancellations or unavailability of the desired experts, the initially targeted distribution of experts and the predefined criteria could not be fully complied with. Finally, 17 experts working in organisations with headquarters in nine different countries agreed for an interview. From those 17 experts, seven can be assigned to the group of industry related experts, five to academia and another five to politics. A detailed overview of the experts, their countries of origin and their industry affiliation is shown in Table 1 below.

Table 1: Metadata of the interviewed experts

Expert	Organisation	Country	Expert group
1	Ernst Basler und Partner	Switzerland	Industry
3	Free University of Brussels	Belgium	Academic
4	Cantonal administration of Zurich	Switzerland	Policy Maker
2	Tel Aviv University	Israel	Academic
5	Hochschule für Technik Berlin	Germany	Academic
6	AVIAREPS AG	Germany	Industry
7	MSC Mediterranean Shipping Company	Switzerland	Industry
8	Duale Hochschule Baden-Württemberg	Germany	Academic
9	Road and Bridge Research Institute	Poland	Academic
10	Ministry of Infrastructure and Environment	Netherlands	Policy Maker
11	VTM global	Portugal	Industry
12	VDI/VDE Innovation + Technik GmbH	Germany	Industry
13	EURIST (European Institute for Sustainable Transport)	Germany	Policy Maker
14	EURNEX (European Rail Research Network of Excellence)	Germany	Policy Maker
15	Continental Intelligent Transportation Systems	United States	Industry
16	Global Policy Institute	United Kingdom	Industry
17	ALICE (Alliance for Logistics Innovation through Collaboration in Europe)	Belgium	Policy Maker

2.3.3 Interview phase

In a next step, the interviews were conducted during March and April 2018. Due to the large spatial distances between interviewer and the interviewees, the interviews were conducted by telephone or via Skype either in German or in English language. Direct personal contact with the experts was therefore not possible in the scheduled interview setting. At the beginning of the interviews, the aim of the work and the planned topics of discussion were communicated to the experts. In addition, the consent of all respondents was obtained to record the calls electronically, which considerably facilitated the subsequent evaluation work. During the interviews, the respective expertise of the interviewees was taken into account and the thematic focus of the interview was directed accordingly. After the first two interviews, it became apparent that the interview guide in its original version needed some adjustments in order to improve practicability for the remaining interviews. At the end of each interview, the respondents were given the opportunity to address further topics that they considered important and that have not yet been addressed during the conversation.

2.3.4 Transcription of the interviews

The next step was the transcription and evaluation of the interviews with Qualitative Data Analysis (QDA) Software. However, transcription of the interviews started already during the interview phase, which had the advantage that the interview situations were still relatively present, what ultimately made the transcription and evaluation work considerably easier. If possible, the interviews were literally transcribed. According to Kuckartz (2016), however, simple transcription systems with corresponding transcriptions are more than sufficient for most research projects because transcribing the wording as accurately as possible can often make the text difficult to read and thus hinder rather than promote the following data analysis. For the transcription of the interviews, the software MAXQDA 12 was used, which in addition provides extensive options for coding and visualization of the collected data.

2.3.5 Data analysis with QDA-Software

After completion of the transcription process, the transcripts and in particular the information contained therein were further analysed. The analysis was limited to the material relevant to the underlying research project. As a theoretical framework within this work step, the qualitative content analysis - as introduced by Mayring (2010) and adapted by Kuckartz (2016) - was used for structuring the content (see Figure 5). According to Mayring (2010), the core of a content analysis is the category system that aims for breaking down and reassembling the data. This reduces the amount of data for a better understanding and simplification of the interpretation. According to Kuckartz (2016), the formation of categories in a content structuring qualitative content analysis takes place in a multi-stage procedure both inductively (on the material) and deductively (independently of the empirical material). In doing so, the data material is relatively rough coded (deductively) along the main thematic chapters in the Deliverable resulting from the initial desk research. In a next step, the categories of the material itself are further developed and differentiated (inductively). Finally, all data material is re-encoded in a second run with the categories now defined and evaluated on a category basis. The following figure schematically shows the course of a content structuring qualitative content analysis, as it was also applied for the data analysis of the present work.

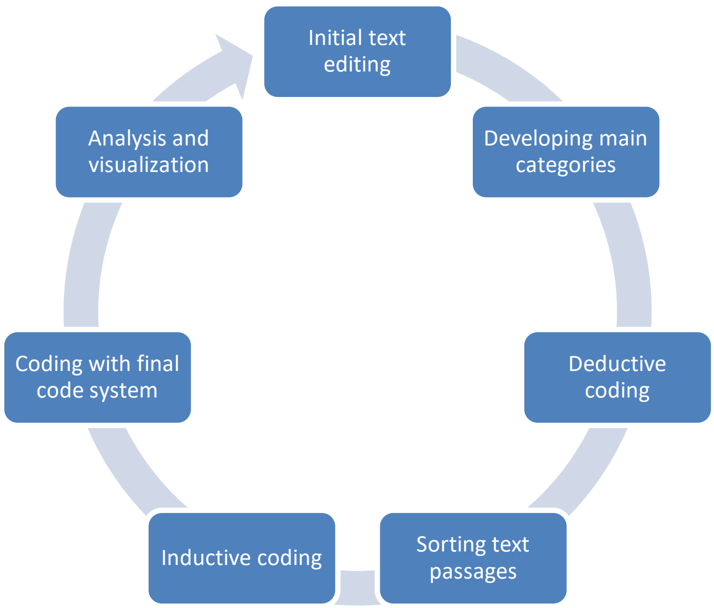

Figure 5: Procedure of a structuring content analysis (according to Kuckartz, 2016)

According to Figure 5, the first step in a structuring content analysis is the initiating text work. All transcripts are carefully read and particularly relevant text passages are highlighted. In addition, spontaneous ideas and initial thoughts for the subsequent coding process can be recorded directly in the form of memos within the transcripts.

In a second step, the main thematic categories are defined. According to Kuckartz (2016), these can often be derived more or less from the research questions, since these were already conductive during the collection of the data. According to Kuckartz (2016), the more material one has worked through, the clearer gets the distinction between purely singular topics and those that would be of particular significance for the analysis of the research questions. Furthermore, a first test run with a subset of the empirical material is highly recommended in order to check the applicability of the defined thematic categories.

After defining the thematic main categories, the next step includes going through the entire empirical material and coding it line by line with the corresponding thematic category (deductive coding). In this way, only the text passages relevant for further work are coded and everything unimportant remains uncoded. Within the underlying research project, the first coding process occurred among the thematic main categories resulting from the initial desk research (see Figure 4) with the following codes:

- Transport Technologies
- Infrastructure and Operation Technologies
- New mobility products & services
- Physical Infrastructure
- Society
- Spatial organisation & structures
- Economic production & organizational structures
- Transport policies

Following the coding with the main categories, all text passages are compiled with the same category. This step can be done relatively easily using QDA software. Subcategories are then created for all main categories on the basis of a subset of the empirical material (inductive coding). These can first be compiled as an unordered list, which is then ordered and systematized in a further revision step. According to Kuckartz (2016), it is also advisable to formulate a definition for each subcategory and to provide exemplary evidence of this using a quotation from the empirical material. This clearly defines what conditions must be met in order for a text section to be assigned to the corresponding subcategory.

Finally, a second coding process takes place, in which the text passages coded with the main categories are revised with the differentiated category system. This step represents a rather labour-intensive work phase in the evaluation process of the qualitative data, which stands and falls with the quality of the previously characterized work steps. If, for example, the subcategories were formed on a too low proportion of material, it is essential to specify and expand the subcategories, which requires a new run through of the whole material, with considerable additional time expenditure (Kuckartz, 2016).

After completion of the second coding process, the analysis of the processed data material takes place. In the underlying research project, a category-based evaluation was carried out along the previously described eight main categories.

2.4 Online Survey

The quantitative part in T4.1 included an online survey with transport related representatives from the academia, industry and policy sector. Main objective of the online survey was to verify hypotheses on the evolutionary development of the transport system, which were formulated based on the results and findings of the expert interviews.

According to Zerback et al. (2009), the specific advantage of online surveys is that multimedia elements can be integrated within the survey. In addition, the online survey allows (potential) respondents to be contacted easily, quickly and - provided it is done via e-mail – without any shipping costs. This possibility is particularly important because the strategy of contacting potential participants several times apart and in different forms (via e-mail, social media channels, etc.) has proven to be helpful in increasing their willingness to participate. However, Zerback et al. (2009) refer also to the considerable methodological problems of online surveys. The focus is on difficulties in recruiting respondents and the resulting limitations in the meaningfulness of the information obtained. Scientific work should therefore deal with these problems in an appropriate way.

2.4.1 Formulating hypotheses

At the beginning of the work for the quantitative part in T4.1, hypotheses on the evolutionary development of the transport system were formulated, based on the previously conducted interviews with experts from the transport sector. In this respect, all text passages from the interviews with the same coding have been summarized thematically in a first step. Subsequently it was examined, what topics were rather often mentioned from the experts, to segregate them from the other statements. From this reduced selection of expert's assessments, the most relevant ones - with regard to the future development of the transport system - were selected for the further work. In a final step, hypotheses and corresponding counter-hypotheses on the future development of the transport system were formulated based on this selection of future oriented statements. This completed all the basic work required to create in a next step the online survey.

2.4.2 Survey creation with 'Questback' (Unipark)

The online survey was set up with the software-package 'questback' (Unipark) and contained altogether 14 pages (excluding welcome page, disclaimer and ending page) with one question per page. The survey took about 5-10 minutes to complete, was only available in English language and completely anonymous. In order to participate in the survey, participants had to confirm a mandatory disclaimer at the beginning of the survey that informed about the purpose of the survey and the handling of personal data. At the end of the survey, participants had to indicate their origin and industry activity, in order for the survey to be successfully completed. A total of three different types of question were used within the survey:

1. **Single selection:** Due to the questionnaire structure with one hypothesis and one counter-hypothesis per question, an ordinal scale with five different answer options was applied to answer the questions in most cases. The survey participants were able to indicate how strongly they agree with one of the respective hypotheses or whether they are indifferent to this question. Since these questions were not defined as mandatory questions in the system, it was also possible that the survey participants could abstain from a personal assessment. This has the advantage that people are more likely to continue with the survey than if they are not given this opportunity.

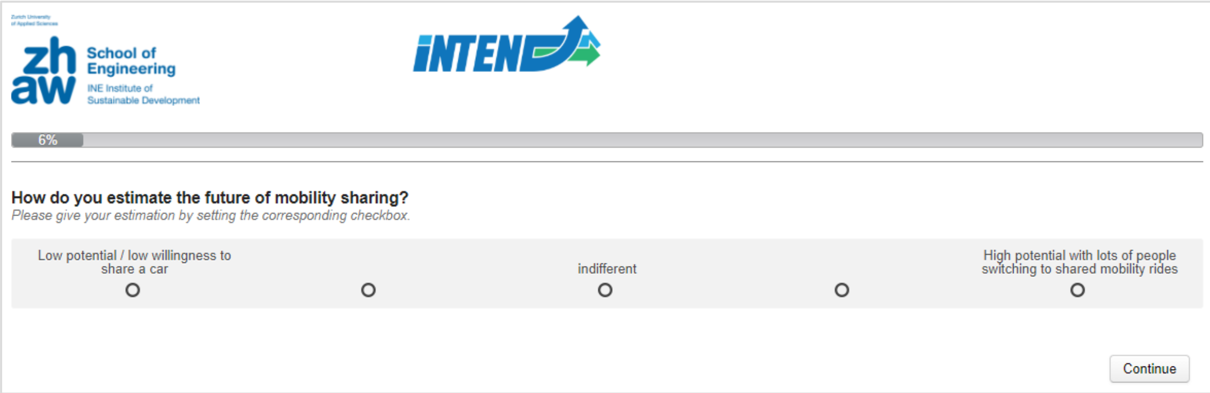

Figure 6: Example of a question from the online survey of type single selection side by side

2. **Slider:** In two cases, a slider was selected for answering the questions. In this case, the question was not formulated as a hypothesis vs. counter-hypothesis, but contained the specification of a scenario, which the survey participants had to assess according to its probability of occurrence. In the selection of answers, the gradations from very unlikely to indifferent to very likely with the respective intermediate steps (rather unlikely or rather likely) were available for selection.

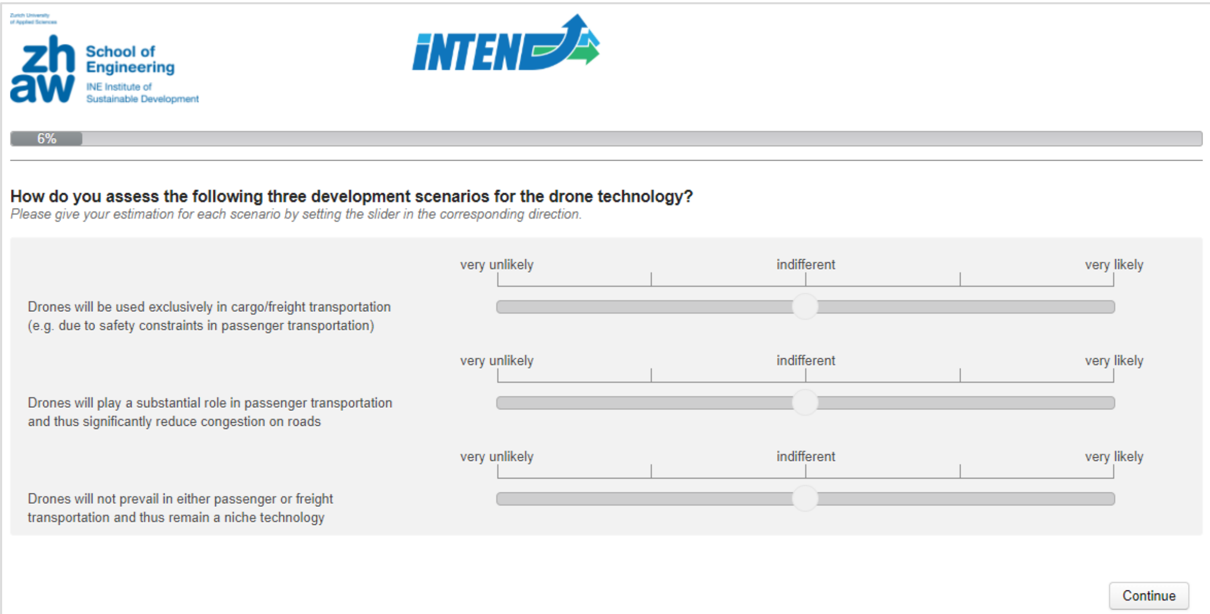

Figure 7: Example of a question from the online survey of type slider

3. **Open question:** In one case, an open question was asked about the participants' assessment of future EU transport research funding. For the evaluation of this question, the software MaxQDA was used – similar to the evaluations of the expert interviews. This enabled the various inputs of the survey participants for future research funding within the EU to be categorized thematically and coded into various sub-categories for further processing and analysis.

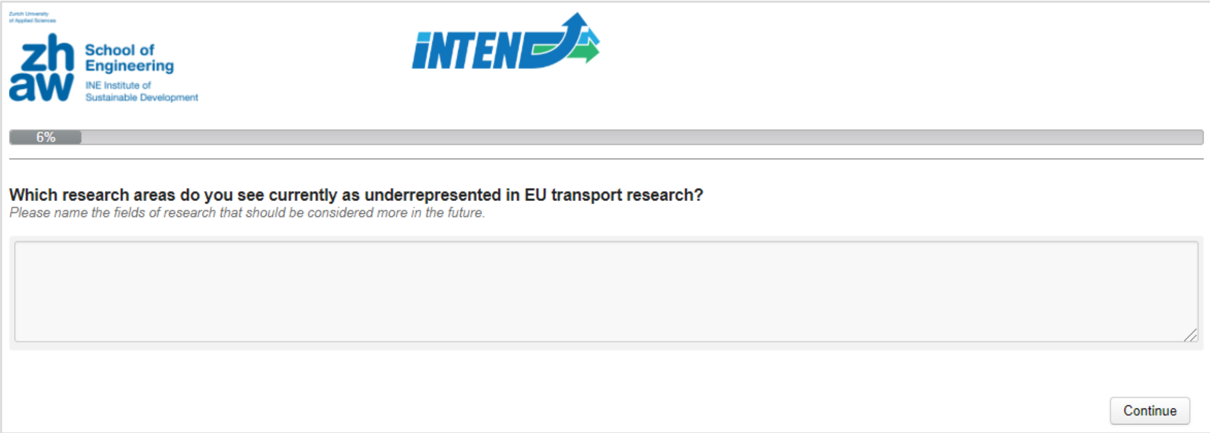

Figure 8: Example of a question from the online survey of type open question

After creating a first draft of the survey, an internal pre-test was carried out in order to check the questions on their consistency, comprehensibility and relevance for the research topic. Following this review phase, the survey was ready to enter the survey phase.

2.4.3 Survey phase

The online survey was conducted in the first two weeks of July 2018. The start was deliberately set for Tuesday, as experience has shown that people are more willing to take part in surveys in the beginning of the week. Besides our own professional network, the survey link was shared with the partners in the INTEND project consortium in order to send it to their contacts within the transport sector. In addition to the distribution of the link via e-mail, various opportunities offered by social media were also exploited to gain even greater attention and participation. The survey link was regularly shared via the following channels:

- INTEND project website (news section) & Facebook page (228 subscribers)
- Twitter (216 followers on different channels)
- LinkedIn, Xing, Research Gate, etc. (more than 800 professional contacts in total)
- MobINE Blog → https://blog.zhaw.ch/mobine/ (average daily visitors: 10)

After the first week, it was evaluated how many survey participants took part and what their respective origin or industry affiliation was. It became apparent that 56 of the targeted 100 participants had already been reached. However, due to a certain overload of participants from science coming mostly from the partner countries, it was decided to contact in the second week primarily international experts from the industry and politics.

2.4.4 Evaluation and preparation of the results

After a total of 2 weeks and after reaching the target number of 100 completed questionnaires, the survey was closed. Altogether, we reached 106 completed questionnaires with a sample size of 284 participants. This results in a completion rate of around 37% (see Table 2).

Table 2: Sample size, completed datasets and completion rate of the online survey (Data: ZHAW)

Survey	Sample size	Completed datasets	Completion rate
INTEND Online Survey WP4	284	106	37.32%

Based on our sample size of 284 participants, we had a total of 178 cancellations of the survey to report. Most of the cancellations were recorded on the welcome page with a total of 156. This may be due to the fact that a large number of people was reached through our advertising activities on social media, that clicked on the link out of curiosity, but were not prepared/willing to take part in the survey at all. A further 14 abortions were recorded on the disclaimer page. As an explanation, certain people may have been bothered by the fact that they had to give their consent in order to continue with the survey. Within the survey, another five cancellations were recorded in the thematic area “Economy” and one each in the thematic areas “Drones”, “implementation of autonomous systems” and “spatial planning”. A detailed overview of the number of cancellations during the survey is shown in Table 3 below.

Table 3: Detailed overview of the survey cancellations (Data: ZHAW)

Page	Cancellations	Advanced to page
Welcome Page	156 (54.93%)	284 (100.00%)
Consent Form	14 (4.93%)	128 (45.07%)
Economy	5 (1.76%)	114 (40.14%)
New Mobility Products & Services	0 (0.00%)	109 (38.38%)
Engine Technologies	0 (0.00%)	109 (38.38%)
Material Technologies	0 (0.00%)	109 (38.38%)
Innovative Transport Infrastructures	0 (0.00%)	109 (38.38%)
Drones	1 (0.35%)	109 (38.38%)
Autonomous Systems: Implementation	1 (0.35%)	108 (38.03%)
Society	0 (0.00%)	107 (37.68%)
Autonomous Systems: Impact on Transport	0 (0.00%)	107 (37.68%)
Spatial Planning	1 (0.35%)	107 (37.68%)
Policies: Awareness of Development	0 (0.00%)	106 (37.32%)
Policies: Sustainability	0 (0.00%)	106 (37.32%)
EU Transport Research	0 (0.00%)	106 (37.32%)
Participants Information	0 (0.00%)	106 (37.32%)
Ending Page	0 (0.00%)	106 (37.32%)

In a final work step, the data from the online survey was evaluated and processed using tables and graphics for further work steps, in particular as input for the sketch of the future transport system.

3 Future trends in mobility and transport

A trend characterizes a change or transformation process over time. This can be a surface phenomenon (e.g. product trend) as well as deep, lasting changes, so called megatrends such as globalisation or digitization (Zukunftsinstitut, 2016). Pillkahn (2017) defines a trend as something that is currently “in” or rather a direction, in which something is heading to in the future. A trend therefore describes the time-measurable course of a development into a certain direction. Generating an overview of trends and developments according to a predefined systemic framework model can be considered as an appropriate method for detecting potential “Game Changers” within a system, having the ability to support a paradigm shift towards a transformation of the current system state in the future.

3.1 Transport Technologies

The mobility sector is continuously changing through various technological developments and innovations. Some of these trend technologies have newly emerged while other technologies exist for several years already, not able to exceed their state as a niche technology yet. Aside from their current state of diffusion, the majority of today’s trend studies assigns new technological innovations a key role in the 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 or the development of new battery technologies, all those trends and developments may have a major potential to change the mobility system towards sustainability in the future. According to the EU funded research project OPTIMISM [2], trends and developments in the transport sector can be structured into the four technological fields 1) vehicle technologies, 2) engine technologies, 3) material technologies and 4) infrastructure / operating technologies (see Figure 9).

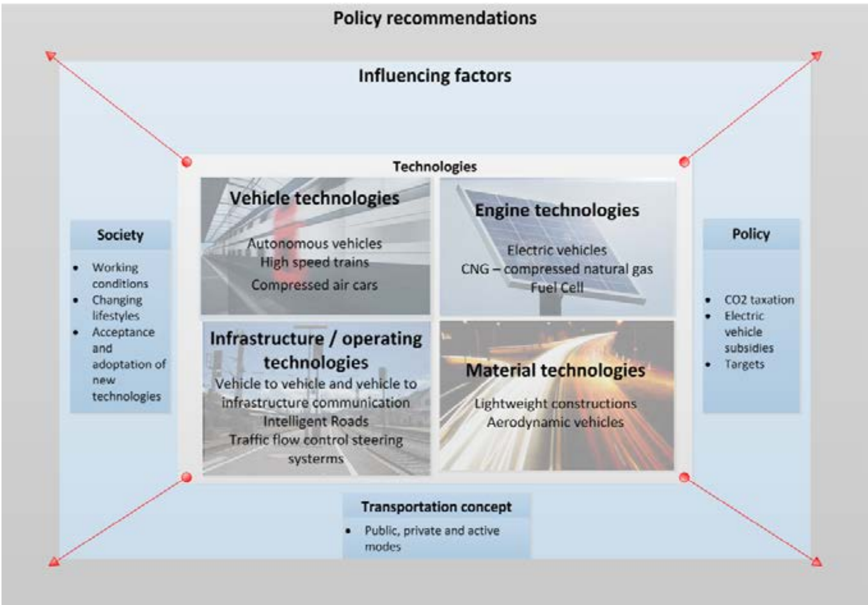

Figure 9: Technology assessment grid from the OPTIMISM project (Delle Site et al., 2012)

[2] The aim of the OPTIMISM project (Optimising Passenger Transport Information to Materialise Insights for Sustainable Mobility) was to develop strategies and methods for optimising passenger transportation, with a special focus on new ICT solutions.

3.1.1 Vehicle technologies

In the field of vehicle technologies, one major trend that can be observed is the development of **autonomous vehicle systems**. Over the past years, cars have been equipped with all kinds of driving assistance systems like cruise control, intelligent cruise control, collision warning and avoidance, lane-keeping support and all kind of navigation systems (Giannopoulos, 2004). At the moment it is already technologically possible to let vehicles drive autonomously (without any intervention of a car driver). However, due to non-technical issues (e.g. consumer confidence and legal aspects) as well as difficulties involved in controlling a vehicle in unpredictable and challenging traffic conditions (especially in urban areas), the introduction of autonomous driving will take, in practice, years (Delle Site et al., 2012). According to a study of Wadud et al. (2016), a complete integration of autonomous vehicles into the transport system (SAE level 5 - Full Automation) does not seem realistic before 2030. Several other studies even speak of a timeframe from 2050 until autonomous vehicles will be able to fully replace conventional vehicles on our streets (Tauber, 2016). Nevertheless, technological developments have put a lot of pressure on governments to make regulatory changes permitting on-road testing of autonomous vehicles (Schreurs and Steuwer, 2016).

Figure 10: Vision of future driving in an autonomous vehicle (Source: volvo.com)

In the context of autonomous driving, the Canadian company *X-Matik* recently presented an innovative system, which is supposed to be able to convert conventional vehicles into autonomous ones. The core elements of this new system are front-facing cameras, a central processor and a control unit, which are integrated into the existing vehicle technology. Thus enables the system to steer, accelerate and brake independently and further on to recognize road markings as well as other vehicles and pedestrians. Although there are still some weaknesses in the system and no information on the price have been provided yet, the Canadian company plans to enter the market in 2019 (Krishnan, 2017).

The trend of vehicle automation not only takes place in the automotive industry but also in the other transport modes. In the ship industry for example, Northern European countries in particular take a pioneering role in the transformation process towards autonomous shipping. The technology already exists in countries like Germany, Denmark or Norway. The latter for

example plans to put into service the first autonomous cargo ship on coastal routes by 2019. Another project in Japan of different shipbuilders and technology companies aims to launch 250 container ships for intercontinental routes without any human crew member and controlled remotely by 2025 (Birger, 2017).

In the aeronautical sector, the two major global players *Boeing* and *Airbus* are both conducting tests with autonomous systems. While *Boeing* is pursuing concrete plans for autonomous aircrafts, its competitor *Airbus* is focusing on a concept of a self-driving vehicle that can be transformed into a drone. While the concept of *Airbus* is still in its early days, *Boeing* intends to undertake its first test flights in reality as early as in summer 2018 (Futurezone, 2017). In the area of airfreight transport, the *Institute of Engineering Thermophysics of China* and the Chinese aircraft manufacturer *Longxing UAV Systems* performed in October 2017 (after two years of development) the maiden flight of China's heaviest cargo unmanned aerial vehicle, the *AT200*. The aircraft features a $10m^3$ cargo compartment, which can accommodate about 1.5 tons of freight. According to the developers, the aircraft operates in both, autonomous and remote pilot modes and is particularly suitable - due to its design - for freight flights to hard-to-reach and remote places such as mountain areas (Aerospace Technology, 2017).

Ultimately, autonomous systems are also increasingly being tested in the railway industry. While there are a few prototype systems for passenger transportation, the main focus of the railway industry lies currently on autonomous systems for shunting and cargo operations. The mining company *Rio Tinto* for example was testing a train in autonomous mode since the beginning of 2017 in Australia (Leary, 2017). In July 2018, they conducted the first delivery of iron ore by an autonomous train that was monitored remotely in an Operations Centre in Perth more than 1'500 kilometres away (Rio Tinto, 2018). In this context, it is worth mentioning another newly introduced and innovative system from China, which is a hybrid of a bus and a train. This vehicle, called *Autonomous Rail Transit (ART)*, looks like a regular tramway with the difference, that it moves on rubber wheels and there are no rails needed for operation. The vehicle is powered by a lithium-ion battery with a range of about 25 kilometres (10 minutes charging time) and follows in its operation a pre-set route laid out by white dots on the road. The world's first ART system will be launched in 2018 in the Chinese city Zhuzhou on a 6.5 kilometre long track (Jie, 2017). The developers expect this system to be a cost-effective alternative to expensive subway systems, which small and medium-sized cities in particular often cannot afford (Caughill, 2017).

Another innovation in vehicle technologies that has developed rapidly over the past few years are **drones**. While drones were formerly mainly used in the military sector, they are now increasingly being used in private and commercial applications. According to a study of a leading global insurance company, 600'000 drones are currently in commercial use in the United States and about 1.9 million in private ownership. These numbers are expected to triple by 2020 (Dobie et al., 2016). In addition, numerous logistics companies are currently planning to use drones for the distribution of goods. *Amazon* for example supplied its first customer by drone in December 2016. However, the legal framework conditions for regular commercial operations are still insufficiently worked out (Amazon, 2017).

An innovative concept for drone technology has been tested in 2017 in Sweden in rescue services with defibrillator-carrying drones. The idea behind it is that medical technologies can be faster in remote areas using drone technology compared to conventional emergency services. First tests have revealed that drones were about 16 minutes faster on-site than the

emergency services, what could significantly increase survival chances for people suffering a cardiac arrest. However, commercial use of this technology is not yet foreseeable, as the laws in Sweden currently require that drones must be operated on sight (Siddique, 2017).

First concepts based on drones also exist for passenger transportation. In 2016, the Chinese drone manufacturer *Ehang* presented its *Ehang 184*, a single-seater aircraft that should be able to carry its passengers autonomously over a distance of up to 32 kilometres. According to the company, this would be the world's first aircraft having the ability to transport passengers autonomously (Cavanagh, 2017). First successful tests of this autonomous aerial taxi (AAT) have been carried out in Dubai in 2017 (Schmid, 2017).

Figure 11: The Chinese passenger drone *Enhang 184* (Source: enhang.com)

Besides innovative concepts of air transport services, several logistics companies are currently carrying out initial case studies for the delivery of smaller goods over short distances by using **delivery robots**. The Estonian company *Starship Technologies* has developed a small, six-wheeled robot that is driven to a central starting point in an electric van (which also serves as a base station for the robots). From there, the robots drive their goods automatically to the customer on the sidewalk. According to the manufacturer, the range of the robots shall be up to 6 kilometres (Pluta, 2017). One major constraint that remains and that could further delay a complete implementation of the technology are conflicts with pedestrians on the sidewalks which could lead to a fundamental need of rethinking the whole concept of sidewalks and its initial functions (Wong, 2017).

A further technology, which has already been adapted in cities like Amsterdam, Venice or New York but only on a combustion engine basis, are **water taxis**. However, there exist some new concepts, which, in comparison to many other solutions already implemented, are operated without the classic combustion engine and could therefore be a valuable alternative towards a more sustainable transport system. The French start-up company *SeaBubbles* for example has introduced an interesting concept in 2016. Their water taxi concept consists of small electrically powered hydrofoil boats, which can carry up to five passengers on a group taxi basis from specific landing stages. Particularly in large cities with extensive waterways - such as Paris or London - the system could contribute to relieving the roads in the future (Mawad and Boksenbaum-Granier, 2016; Pluta, 2016a).

Besides the previously described developments in vehicle technologies on a large scale, some **revolutionary transport concepts** are currently being developed, however still in a niche stage. They belong to the group of track-guided vehicles and in addition have a strong linkage to new infrastructure technologies as well as new power supply approaches (see also chapter 3.1.2, Engine technologies and 3.2.2, Innovative transport infrastructures). One of the most prominent examples in this category nowadays is the *Hyperloop One*, which has first been presented to the public in 2013. The *Hyperloop One* consists of an air-evacuated tube, in which transportation capsules transport freight or passengers at high speed from A to B by magnetic levitation technology (Stewart, 2016). First successful tests were carried out in 2017 on a 500-metre test track in Nevada (USA). The ambitious goal of the company are three functioning *Hyperloop* systems in service by 2021 (Field, 2017).

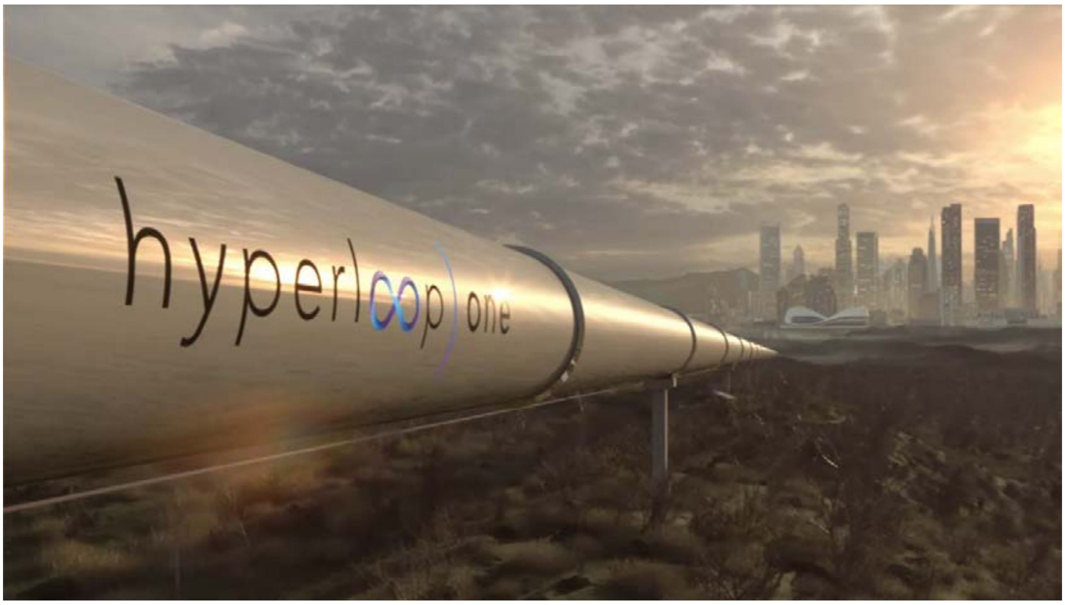

Figure 12: Vision of the *Hyperloop One* connecting cities at high speed (Source: hyperloop-one.com)

Similar to the *Hyperloop One*, the Swiss cargo transport concept *Cargo Sous Terrain* relies on autonomous capsules that run in an approximately six meter wide underground tunnel. Compared to the previously characterized system, the tube of the *Cargo Sous Terrain* is not under vacuum and the maximum speeds attained are with approximately 30 kilometres per hour much lower. The concept envisages for goods to be loaded and unloaded automatically in external hubs and then being distributed to multimodal City logistic systems in periurban areas. From there, the freight is transported further on with environmental friendly vehicles, whereby emissions of freight transport can be significantly reduced – especially for distribution in urban areas. A first test track is in planning (Cargo Sous Terrain, 2016).

Ultimately, a Chinese technology company presented in 2010 their prototype of a vehicle of approximately eight meters width and five meters height, which is fixed on rails next to the road and runs over the regular road traffic. This vehicle called *Trans Elevated Bus 1* would therefore never being stuck in a traffic jam, but rather pass over it (Pluta, 2016b). However, since the company has been targeted with charges of fraud, the project never went beyond test operation (Wilkens, 2017).

In the field of vehicle technologies, the focus of current research and development activities lies primarily on the further technical development of autonomous operation systems towards complete automation and their integration into the transport system. On the other hand, fundamental reflections about the impacts of autonomous systems on the transport system (increase or reduction of the overall traffic volume) are being discussed rather secondary. Furthermore, a widespread diffusion of unmanned aircrafts (especially in the logistics sector) seems possible, if legal framework conditions are further adapted. However, research is still lagging behind in this aspect. Ultimately, some innovative vehicle technology concepts are increasingly gaining popularity with regard to investment activities in the mobility sector (in particular the Hyperloop One).

3.1.2 Engine technologies

In the field of engine technologies, one of the major developments that is currently influencing the industry is the **electrification of conventional drivetrains**. This technology is becoming more and more important in terms of sustainability transformation and a lot has changed in the last few years: While the early generations of electric vehicles reached ranges of only a few kilometres, today even affordable middle class electric cars reach 300 kilometres and more with a single battery charge (Cobb, 2016). However, there remain several constraints concerning this technology: According to a study of the *UBS Group*, the global production of cobalt and lithium would have to increase between twenty and thirty times to ensure a complete switch to electric cars. In addition, it remains questionable, whether the current electricity grids are adapted enough to cover the predicted increase in electricity demand with sustainable energy sources (DWN, 2017). Finally, the big question mark remains the overall eco-balance of electric vehicles (LCA). Depending on the source, the latter can turn out positive, if the energy for the operation of electric vehicles comes from renewable energy sources (de Haan et al., 2013). According to several other studies, the production of batteries in particular is extremely damaging to the environment and has a severe impact on the overall environmental balance of electric vehicles. Romare and Dahllöf (2017) estimate in their latest study an emission of 150 to 200 kilograms CO_2 per kWh battery capacity. The production of one single *Tesla* battery would therefore cause about 17.5 tons of CO_2. Despite all these concerns and ambiguities, market shares of electric vehicles are currently constantly growing. Considering these developments, the share of electric vehicles could account for 25 to 40 percent of new vehicle registrations worldwide until 2030 (Arzt, 2017).

Although the discussion about the electrification of engines currently dominates in the automotive industry, there are also several examples in other transport modes to find. In the maritime industry for example, the world's second electric ferry went into operation in Finland in June 2017, connecting the cities Nauvo and Parainen on a distance of 1.6 kilometres. Scandinavian countries are currently playing a pioneering role in switching to electric ferry operations as orders for new electric ferries have been placed in all Scandinavian countries (Feusi, 2017).

In the aviation industry, a growing number of companies are nowadays exploring the potential of hybrid-electric propulsion technologies. *Airbus*, *Rolls-Royce* and *Siemens* have announced plans to collaborate on a hybrid-electric aircraft, whose maiden flight is scheduled for 2020. The consortium aims, to have a commercially viable hybrid regional passenger jet flying by 2030. According to the consulting firm *Roland Berger*, around 70 electrical propulsion aircraft programmes have been launched globally, about half of them by start-ups (Hollinger, 2017).

Finally, it is important to state that contrary to the general assumption that electrification is no longer relevant in rail transportation, this is still an important issue regarding sustainable future rail transportation. Diesel-powered locomotives are still widely used in global rail transportation, even in Europe, whose states have a comparatively high proportion of electrified railroads. In Germany for example, about 59% of all railroads are electrified. However, about 90% of total railway traffic is being handled on these lines. This means that diesel-powered locomotives are nowadays in particular on low-traffic and peripheral railroads in operation. In the course of the ongoing climate debate, research is therefore also being carried out in alternative and clean fuels for railways. However, none of these clean fuels has been able to establish so far, mainly due to high implementation costs of an additional supply infrastructure as well as the conversion of the existing drive technologies (BMVI, 2017). Nevertheless, in 2017 the Swiss railway manufacturer *Stadler Rail* announced the delivery of 18 trains - powered with vegetable oil - to the Dutch branch of *Arriva*. From 2020 onwards, these emission-free trains will be used primarily on secondary railway lines in the Netherlands and will replace the conventional diesel-driven trains that are still in use today (Stadler Rail, 2017).

A second important engine technology - especially regarding a sustainability transformation of the current transportation system - are **Hydrogen fuel cells**. Fuel cells can be used to convert hydrogen into electricity, which in turn drives an electric engine. Water is the only local emission resulting from this process. Although the vehicle-side efficiency of the hydrogen propulsion is estimated to be around 45% (depending on the source), the latter does not apply for the production of hydrogen, which is in comparison a lot more energy-intensive. According to Arena et al. (2017) increase of sales of fuel cell vehicles (FCV) are expected to be significant in the future but only in the long term. Until then, there are still several constraints such as the missing infrastructure network or a lack in efficient solutions for hydrogen production to overcome. Nevertheless, the *International Energy Agency (IEA)* estimates an FCV market share of about 17% by 2050 with 35 million annual unit sales (Arena et al., 2017). Further trend studies project, that by 2050, hydrogen fuel cell vehicles will become the fastest growing segment of the automotive market (Jaffery, 2016). This estimation coincides with *KPMG's* Global Automotive Executive Survey 2017, in which 78 percent of 1'000 interviewed senior automotive executives stated, that fuel cell electric vehicles will probably be the real breakthrough for electric mobility in the future (LeSage, 2017).

Besides the described developments in engine technologies, which may lead someday to significant improvements according the sustainability of the transport sector, there are some other engine technology concepts, which are nowadays still at a niche stage. One of these technologies are **linear motors**, as they are used in magnetic levitation systems (e.g. *JR-Maglev* or *Hyperloop One*). This drive technology does not require any moving parts, as traction is achieved through magnetic interaction of the track with the vehicles (Teraoka, 1989). Up to now, magnetic levitation technology has only received a very limited response from the market, in particular due to its relatively poor economic efficiency (Bartsch, 2013). Nevertheless, this technology can experience a renaissance in the future, especially in the course of a potentially successful further development of the revolutionary *Hyperloop One*. Currently the world's only commercially operated magnetic levitation train connects the city of Shanghai with its airport and generates an annual loss of between 70 and 80 million euros (Bartsch, 2013).

Another trend in the engine technologies, which can be observed in particular in public bus transportation, is the **combination of various drive and energy systems**, depending on the respective energy supply situation. A well-known example is the hybrid drive, which consists of a battery that is used as a temporary energy storage device. The battery is charged by the internal combustion engine or by recovering braking energy. External charging however is not possible in the system. More recent examples have only one type of drivetrain, which however can be fed from different energy sources. The city of Zurich for example has recently introduced the *SwissTrolley plus*[3], which can travel up to 30 kilometres without any external power supply, using both, electricity from an overhead line as well as battery-powered systems. An intelligent control software saves additionally data about the route profile and thus optimises overall energy consumption of the bus in subsequent journeys (Hotz, 2017).

A similar innovation - called *TOSA* - was introduced in the city of Geneva in December 2017. The core of this new technology (the world's first of its kind) is a hydraulic connection on the top of the bus, which connects to an overhead charging rail at selected bus stations for charging the battery during the holding period of the bus. Overhead lines for operation are therefore no longer necessary. According to the bus operator, this system saves up to 1'000 tons of CO_2 annually compared to buses with conventional diesel drivetrains (Watson, 2017).

Figure 13: Intelligent fast charging technology at a bus stop (Source: abb.com)

A final, rather secondary technology are **flywheels**. Flywheel storage is a method of mechanical energy storage in which a flywheel respectively a rotor is accelerated to high speeds. The energy is stored as rotational energy and can be recovered inductively by coupling the rotor to an electric generator and thereby braking it. Although this technology has been around for several decades already, it is nowadays almost exclusively used in motorsports as an additional drivetrain to the conventional one (Kuther, 2013).

[3] The *SwissTrolley plus* is a trolley bus, that combines traditional contact line technology with latest battery technology (high-performance traction battery and regenerative braking systems). First field tests were carried out in summer 2017 on different bus lines in the city of Zurich.

In the field of engine technologies, the research priorities nowadays focus on the electrification of conventional combustion engines, including improvements in weight and range of lithium-ion batteries. With regard to the various modes of transport, the focus lies primarily on the automotive industry whilst improved propulsion systems in the aircraft industry (as one of the main drivers of CO_2 emissions in the transport sector) are being discussed rather secondary. However, there is an increasing tendency to see in public transport companies that are converting their bus fleets from conventional diesel drivetrains to electric resp. hybrid drivetrains.

3.1.3 Material Technologies

In the field of material technologies, one technology that is becoming increasingly popular is the **additive manufacturing** process, better known as **3D printing**. Today, 3D printing is no longer only used for the production of prototypes, but is increasingly being used for mass production as well (Richter and Wischmann, 2016). In the automotive industry, manufacturing companies - whether car manufacturers themselves or manufacturers of automotive accessories and suppliers - are using 3D printing for the production of individual components (Schroeder, 2015). In 2018, an Italian-Chinese consortium presented its concept of an electric city car produced in series with 3D printing and with only wheels, windows, seats, drivetrain and chassis being produced in the conventional way. This has led to a drastic reduction in the number of components used (from more than 2'000 to only 57) and the production time. Production costs have thus fallen by more than 70% compared to a conventional produced car (Kempkens, 2018).

In the aerospace industry as well, 3D printing is becoming more and more popular. *GE Aviation* for example - the world's leading manufacturer of aircraft engines - uses already today more than 300 3D printers in its factories and aims to manufacture by 2020 about 100'000 additive parts every year (GE Reports Staff, 2017). In the European railway industry, the *Deutsche Bahn (DB)* - the largest railway operator in Europe - has already made about 1'000 spare parts using 3D printers. That number is expected to double by the end of 2017 and in 2018, a total production of about 15'000 components is planned (Global Rail News, 2017). Similar developments are also taking place in the maritime industry. *Britain's royal navy* for example plans to use 3D printed unmanned ships by 2030 (Hedstrom, 2015).

Besides the transport sector, 3D printing is increasingly being used in other (mobility related) areas, for example the construction industry. In October 2017, Dutch researchers from the *Eindhoven University of Technology* presented a 3D printed cycling bridge, which is, according to the researchers, the first ever reported civil infrastructure project built in an additive manufacturing process. Besides time savings in the manufacturing process, better manoeuvrability (allowing a broader range of shapes) and the lower environmental impact compared to traditional manufacturing processes (mainly due to the production process of cement) represent the key advantages of this new production method (Katz, 2017). According to Wood (2016), 3D printing technology could substantially disrupt conventional building practices by offering modular construction alternatives, onsite manufacturing of building materials, and the ability to create parts, tools and even complete machines on-demand.

Another technology that is increasingly being combined with 3D printing in production processes is **lightweight construction**. The main objective of lightweight construction is to save raw materials and energy due to lower vehicle weights. A systematic use of lightweight construction in the transport sector has been observed for the first time in aircraft construction

with the widespread processing of aluminium (IAI, 2016). Later on, the use of lightweight construction also spread into the automotive and railway industry, mainly due to rising energy costs, higher safety demands and more competition with other transport modes. In December 2017, the Swedish start-up *Uniti* presented a lightweight electric vehicle (about half a ton), which is specially designed for commuting in urban areas (Schäfer, 2017b). Another innovative concept has been presented in 2016 from the English car manufacturer *Riversimple*. Their fuel cell vehicle called *Rasa* weighs only about 580 kg, which is achieved through a carbon fibre chassis, made from very lightweight and extremely stiff carbon fibre composites. The chassis itself only weighs about 40 kg (Riversimple, 2017).

Similar goals to those of lightweight construction - especially with regard to energy optimization - are pursued with **aerodynamic optimization**. The aim is to design the form of vehicles and infrastructures (e.g. tunnels) in such a way that air resistance and consequently the energy required for locomotion is being reduced. The *German Aerospace Center (DLR)*, for example, is investigating this field of research on the basis of the *Next-Generation-Train*[4] (DLR, 2013). Other examples of aerodynamic improvements are to be found in the Japanese high-speed train *Shinkansen* (Railway Technology, 2017) or the already mentioned *Hyperloop One*, in which a transport capsule moves in an air-evacuated tube with considerably lower air resistance than conventional trains (Bradley, 2016).

Figure 14: Vision of the *Next-Generation-Train* (Source: dlr.de)

One of the major challenges within electro-mobility is the provision of sufficient electrical energy required for operation (see also section 3.1.2, Engine technologies). Intensive research is therefore being carried out in **improved battery storage systems**. With new solid-state batteries for example, the energy density (amount of stored energy per kilogram of battery

[4] The *Next-Generation-Train* is a research project of the *German Aerospace Center* dealing with questions like how fast, safe and environmentally friendly future high-speed trains need to be. Core elements of the research are lightweight construction and aerodynamic optimisation, integrating latest findings of the aerospace industry.

mass) can be increased up to three times compared to a conventional lithium-ion battery, what has a significant effect on the range of an electric vehicle (Bergert, 2017). The vehicle manufacturer *Fisker* for example announced in 2017 a new type of solid-state batteries, which should be able to reach a range of over 800 km and a charging time of less than one minute (Donath, 2017). In addition, the safety standards are supposed to significantly increase compared to a conventional lithium-ion battery, as those new battery types should not be able to explode (according to manufacturer's specifications). A series production is planned for 2023 (Glasmachers, 2017).

A final example in the area of efficient battery technologies that is controversial discussed since several years is nanotechnology. Nanotechnology can increase the size and surface of batteries electrodes so that they can absorb more energy during charging and ultimately increase the effective energy storage capacity of a battery pack (Janicek, 2016). Despite the promising potential that many experts see in this technology, a commercial application of Nano-batteries in the mobility sector is currently not foreseeable.

A major trend in the field of material technologies is the adaptation of additive manufacturing technologies in traditional industry branches. With the associated new possibilities (e.g. on-demand production), the focus lies currently in particular on the change of internal workflows, which could ultimately lead to a radical reorganisation of various manufacturing industries in the future. The resulting impact on the labour market however is in current discussions rather neglected. According to the limited ranges of electric vehicles, a lot of research is being carried out in improved battery storage systems (e.g. graphene, solid-state or flow cell batteries). On the other hand, the negative impacts on the overall eco-balance resulting from the battery production and battery disposal are rather neglected and the electric vehicle is widespread being seen as a panacea in the course of a sustainability transformation of the mobility system.

3.1.4 Outlook

In the **field of vehicle technologies**, our desk research revealed that there are some groundbreaking developments going on in autonomous driving. The big opportunity for autonomous cars in particular lies in the fact that they will be able to fulfil social functions as third places in the future. This means that autonomous cars are expected to become a sort of a second home between the workplace and the place of residence, where the commuter can spend his time meaningful during his journey (e.g. preparation for work). Autonomous systems therefore have a great potential to radically change people's initial way of thinking about the function of cars in our future everyday life (Rauch, 2017). In addition, it can be expected that autonomous systems provide greater safety, reduce emissions and increase road capacity through optimized traffic flows (Davies, 2016). However, for a comprehensive implementation there remain some critical issues in ethics and behaviour guidelines for autonomous vehicles (e.g. reacting principles when suddenly a pedestrian walks onto the street) as well as various obstacles regarding the regulatory frameworks and the user acceptance. Furthermore, it is likely that the beneficial impacts as mentioned above will only be fully captured, if autonomous vehicles are integrated in new business models (e.g. shared mobility), complemented by the construction of high-capacity transportation infrastructures (Franckx, 2015). Nevertheless, autonomous vehicles could have a strong disruptive effect on the transportation system and the current behaviour patterns and lead to a substantial rethinking of established business and ownership models. Yet it remains to be seen, how quickly this will be the case for individual passenger transportation. Currently there are many indications that autonomous systems first

will be able to establish themselves in the freight and logistics sector (e.g. autonomous cargo ships and trains), since company premises in particular are ideal test fields for autonomous driving (Ptock, 2018).

Furthermore, our desk research has pointed out that the development of unmanned aircrafts such as drones is progressing rapidly. In addition to its aspired use in the logistics sector (e.g. delivery of goods), initial tests in passenger transportation are being carried out in innovative and technology-oriented countries such as China or the Emirates, where legal boundary conditions are adapted easily on technological progress. In this context, Europe is still lagging behind, as the practical example of the defibrillator-drones in Sweden has shown. Nevertheless, once the legal framework conditions should become adapted accordingly, drones could have a strong disruptive effect on the transport system – although probably again first in the freight and logistics sector. A similar development is likely to be expected in the other presented (less popular) vehicle technologies, the delivery robots and the water taxis. Even if the legal framework conditions for these technologies could probably be adapted more easily, conflicts of use with exiting uses (e.g. pedestrians on sidewalks) are very likely to arise.

Finally, a big question mark remains for the innovative vehicle technologies presented, such as the *Hyperloop One*. This project is currently attracting a great deal of attention, particularly because of its new partnership with the *Virgin Group*. Nevertheless, these types of technologies are very capital-intensive and the financing and further development of them will probably strongly depend on fluctuations in the global financial market. In addition to the capital-intensive nature of these projects, they are also characterised by a high degree of spatial intensity. In the course of the projected extensive further development, spatial and property conflicts are likely to arise, which may delay or even block these projects in the future.

In the **field of engine technologies**, future discussions will mainly focus on the question, whether electric or fuel cell vehicles will take the lead in a possible sustainability transformation of the motorised private transport. Given a power grid that is based on renewable energy sources[5], electric vehicles have a great potential for reducing CO_2 emissions locally during their operation. In the sustainability debate however, people often ignore the impact of electric vehicles on the overall eco-balance, which is - in this specific context - highly negative influenced by the production process of the lithium-ion batteries. A recent study of the Swedish Environmental Research Institute (IVL) for example criticizes, that a vehicle with a conventional internal combustion engine can be driven for eight years before it has become as polluted as the production of one single battery for a Tesla Model S (Romare and Dahllöf, 2017). Furthermore, several experts predict already today massive resources shortage (especially lithium and cobalt metals) given the ambitious production strategies of several electric vehicle manufacturers.

Given these predictions, many people see the fuel cell vehicle as the ideal solution in terms of a sustainability transformation of our current transportation system, as hydrogen is more suitable as a storage medium (regarding energy density) in comparison to a lithium-ion battery. But also with this technology, there arise serious doubts concerning the overall eco-balance, as hydrogen has to be produced industrially and therefore has a high primary energy demand. In addition, a lot of energy is being required to transport the hydrogen from its production site

[5] In Germany for example, renewable energy sources account for just one third of total energy production. Around two thirds of the energy needed for electric vehicle operation would therefore come from nuclear, coal or gas power plants (Welt, 2017).

to the filling stations (Bay, 2017). Moreover, those filling stations are currently the crux of the matter, since huge investments in the infrastructure would become necessary in the future. According to a study of *McKinsey*, global demand for fuel cell infrastructure investments has been estimated at around 280 billion US dollars up to the year 2030. For a major breakthrough, fuel cell technology would have to become in particular more attractive in terms of price (Welt, 2017).

Nevertheless, regarding the ongoing political debates about climate protection and reduction targets, both of these technologies are expected to have a strong disruptive potential for the future within the automotive industry. However, a fundamental anxiety of too little range, inadequate charging infrastructure and high purchase costs are currently the three main reasons that prevent a widespread adoption of these (clean) vehicles on the car market. Furthermore, it will be interesting to observe, how engine technologies will develop in the other modes of transport. While electric propulsion technologies became increasingly commonplace in the automotive sector, the adoption in the aeronautical sector in particular is lagging heavily behind (mainly due to weight issues and insufficient energy densities of batteries). However, this might change soon regarding the transformational developments in the automotive industry (Hollinger, 2017). In any case, there will be a huge pressure for cleaner propulsion technologies on the aviation industry in the near future, as the industry nowadays accounts for approximately 2% of global CO_2 emissions. In addition, this value is expected to triple by 2050, as demand for air travel will further grow in the future (Hollinger, 2017).

In the field of **material technologies**, future developments will probably mainly focus on additive manufacturing methods and lightweight construction. As pointed out, 3D printing is increasingly being used in various transport related industries. Because 3D printing enables engineers to design individual parts with more intricate geometries (compared to traditional manufacturing methods), weight of the individual parts can be reduced significantly, what could further on have a positive effect on the overall energy consumption of the vehicles. In addition, 3D printing can lead to a more cost-efficient production, as storage costs can be saved through printing just the one item currently needed - eventually even on site. Nevertheless, speed and costs will probably be the limiting factors whether additive manufacturing methods are able to assert themselves in the transport industry or not (Kerns, 2016). Furthermore, it is still unclear, what impacts traditional manufacturing industries will be facing to, given these ongoing developments. As a matter of fact, whole industry branches and their supply chains and logistics services will have to reorganise themselves in the course of the transformation to Industry 4.0 and 3D printing (as an integral component of this development) will probably also contribute its part to this transformation process.

Furthermore, our desk research has pointed out that a lot of research is currently being carried out in the area of improved battery storage systems. Although there were recently several announcements of - as an example - new solid-state batteries with improved energy densities, none of these innovations have been able to establish themselves until serial production so far. Most car manufacturers will therefore most likely continue to rely on the proven lithium-ion technology, for which no major developments are expected in the near future (Welt, 2017). Furthermore, the question remains on how the developments in electro mobility - as pointed out in this chapter - will reconcile with the industrial production capacities of batteries and the supply of raw materials. According to a recent study of the *Frauenhofer Institute for Systems and Innovation Research ISI*, demand for batteries will increase dramatically in the coming

decade. As a result, current cell production capacities in Europe and Asia will most likely not be able to keep the pace with the predicted growth, what requires urgently an adaptation of all actors involved in the service and supply chains of the battery industry (Jung, 2017). For Europe, another aggravating factor is that around 90% of global battery cell production takes place in Asia (Elektroauto-News, 2018a). Besides that, the predicted one-side dependence on the lithium-ion technology will most likely lead to a raw material bottleneck of global lithium and cobalt supply, as in addition a large part of these raw materials are mined in politically unstable regions (Welt, 2017).

3.2 Infrastructure and Operation Technologies

According to the fast proceeding trends and developments in transport technologies, high-performing infrastructure and operation networks may be crucial for a large-scale implementation of these newly emerging technological innovations in the future. In addition, high-performance infrastructure networks improve the efficiency of transport processes and can therefore have a positive effect on the sustainability of the transport system.

3.2.1 Charging infrastructure for electric vehicles

With regard to the growing number of electric vehicles on the roads, the establishment of a well-connected and **seamless charging infrastructure network** is a major trend in the field of infrastructure and operation technologies. *Tesla* for example plans to build in Norway Europe's largest Supercharging station with 42 charging points (Lambert, 2017). The world's (currently) largest Supercharging station in operation is located in Shanghai and counts 50 charging points (Trends der Zukunft, 2017). In addition to these company-specific investments in charging infrastructure, several big car manufacturers built in 2017 a joint venture called *IONITY* that aims to build up a comprehensive charging infrastructure network for electric vehicles throughout Europe. In detail, the concept foresees the construction of 400 fast loading stations along the main traffic axes in Europe by 2020. Such an example of car manufacturers, joining forces to implement a large-scale charging infrastructure network, can be seen as an important milestone for making electro-mobility more suitable for long-distance travel in Europe (Holler-Bruckner, 2017). Furthermore, there are increasingly clear signals from certain national governments to expand the charging infrastructure for electric vehicles in their countries. China for example underscores its leading position in the field of electro mobility, as it plans to invest 16 billion euros in the expansion of its charging network over the next few years in order to achieve the ambitious goal of 4.8 million charging possibilities for electric cars by 2020 (Eckl-Dorna, 2017).

A technology that may have the potential to tackle the problem of seamless charging and that many experts predict has great disruptive potential in the future is **inductive charging technology**. At the core of this charging technology, a coil in the ground transmits electric power to the moving vehicle by a magnetic field (Vogel, 2017). An Israeli start-up has already carried out first successful tests of this technology and in a next step, an entire bus route in Tel Aviv is planned to be equipped with inductive charging technology (Fagan, 2017). Inductive charging however is not limited to road use only, but is also becoming increasingly interesting for domestic use. Several major car manufacturers have recently announced to launch initial solutions from 2018 onwards. In addition to stationary systems, some research is also being carried out for semi-dynamic inductive charging solutions (e.g. in taxi waiting areas or at bus stops).

The biggest drawbacks of our today's electricity grids are the storage of energy and unbalanced energy demands during the day. It would therefore be beneficial, if modern energy networks could provide fast-reacting storage facilities that provide the necessary amount of energy needed within a few minutes, such as grid-connected electric vehicles for example (Rubel, 2017). Current research in the field of charging infrastructure is therefore increasingly focussing on **bidirectional or Vehicle-to-Grid (V2G) charging technologies** (Schäfer, 2017a). Nevertheless, a large-scale market solution for bidirectional charging technology is currently not yet foreseeable.

Besides these trends on a large-scale, there are many other **innovative technologies with (probably) rather small-scale effects on the transport system**, such as the recently presented charging solution of the German mobility-start-up *Ubitricity* for charging electric vehicles on street lanterns. Core of this new technology is a mobile electricity meter that is integrated in an intelligent charging cable with an integrated mobile communication device. The cable automatically activates charging processes, records the amount of energy consumption for each vehicle and sends the data to a platform for billing (Stüber, 2017). This charging solution could be of particular interest to users of electric vehicles that have no charging possibility at home or simply for temporary charging processes during the day (e.g. during shopping).

Another innovative approach are exchange stations for electric batteries. The Swedish start-up *Powerswap* introduced its concept in November 2017 that aims to induce a general rethinking on charging electric vehicles in the future. Instead of utilizing a charging cable, the whole battery will be replaced from the vehicle in less than three minutes (according to the company). The empty battery then will be sent automatically to a charging storage where it is charged for reuse. Although a declaration of cooperation with a Swedish taxi company already exists, there remain severe doubts whether this concept will prevail in the future or not. In earlier years already, the electric car pioneer *Tesla* and the Israeli start up *Better Place* presented similar concepts. However, those concepts were ultimately not pursued further (Ecomento, 2017a).

A final innovative system for charging electric vehicles is the direct energy supply via overhead contact line. Such a system is currently being tested in Sweden on a two kilometre long motorway-section (Schatzmann, 2016). The technology includes two pantographs on the roof of the truck, which are connected with the overhead contact line and thus supply the vehicle with electricity (Ayre, 2016). The Swedish truck manufacturer *Scania* initiated the test track in order to minimise CO_2 emissions from the dense long-distance truck traffic from three industrial centres to the seaport in the city of Gävle (Schatzmann, 2016).

Figure 15: Electric truck, charged via overhead contact lines (Source: scania.com)

In the field of charging infrastructure, the focus of current research and development activities lies primarily on the implementation of large-scale charging infrastructure networks for promoting long-distance travelling with electric vehicles. In this context, several start-up companies are currently trying to enter the market with a corresponding niche product resp. business-model. On the other hand, it is still being discussed rather secondary, whether the global electricity grids are prepared adequately to provide sufficient and, above all, clean electricity in the course of the ongoing electrical transformation. In this context, innovative and efficient charging solutions (e.g. Vehicle-to-Grid technologies) have not yet been able to establish themselves on a large-scale in order to mitigate the predicted energy shortage in the future.

3.2.2 Innovative transport infrastructures

Based on the previously described trends in vehicle technologies, some innovative and forward-looking concepts for new transportation infrastructures have been introduced to the public recently. While some of them will be able to integrate into the existing infrastructure networks and thus have rather little impacts on the transportation system, others (due to their disruptive nature) will lead to a completely new way of thinking about transportation and probably revolutionize the latter.

As already mentioned in chapter 3.1.1, the Swiss cargo transport concept *Cargo Sous Terrain* represents another innovative transport infrastructure concept, designed especially for freight transportation in periurban areas. The concept consists of electric freight capsules, which operate on an underground track and therefore reduce significantly congestion and CO_2 emissions above ground (Cargo Sous Terrain, 2016). A first test track is expected to be opened in 2030, connecting a logistics cluster in the periurban region of the city of Zurich with the town centre (Schneeberger, 2018).

One of the most popular concepts nowadays is the *Hyperloop One* that has been presented by the innovator and *Tesla* founder Elon Musk in 2013 to the public (see also chapter 3.1.1). The infrastructure of the *Hyperloop One* consists of an air-evacuated tube that is installed above ground, similar to a pipeline (Stewart, 2016). In May 2016, *Hyperloop One* launched the *Hyperloop One Global Challenge*, inviting teams around the world to submit suggestions for possible routes (Lambert, 2016). According to this challenge, the company named in 2014 ten routes that are to be built first in the coming years. These are located in the United States, Canada, Mexico, the United Kingdom and India. Three out of these ten preselected routes are to be implemented already by 2021 (Hyperloop One, 2016).

Similar to the *Hyperloop One,* the German car manufacturer *BMW* presented recently an elevated road concept for E-bikes in urban metropolitan areas, named *BMW Vision E3 Way*. The *E3* stands for elevated, electric and efficient, the concepts three basic principles. By using elevated roads over existing roads, the concept foresees to create additional traffic capacity and make a significant contribution for sustainable mobility in urban areas. Initial feasibility studies have shown that a concept such as the *BMW Vision E3 Way* can reduce congestion, emissions, travel time and the risk of accidents significantly. Nevertheless, this is still a visionary concept and a practical implementation of this innovative concept is not yet foreseeable (FOCUS Online, 2017; Electric Cars Report, 2017).

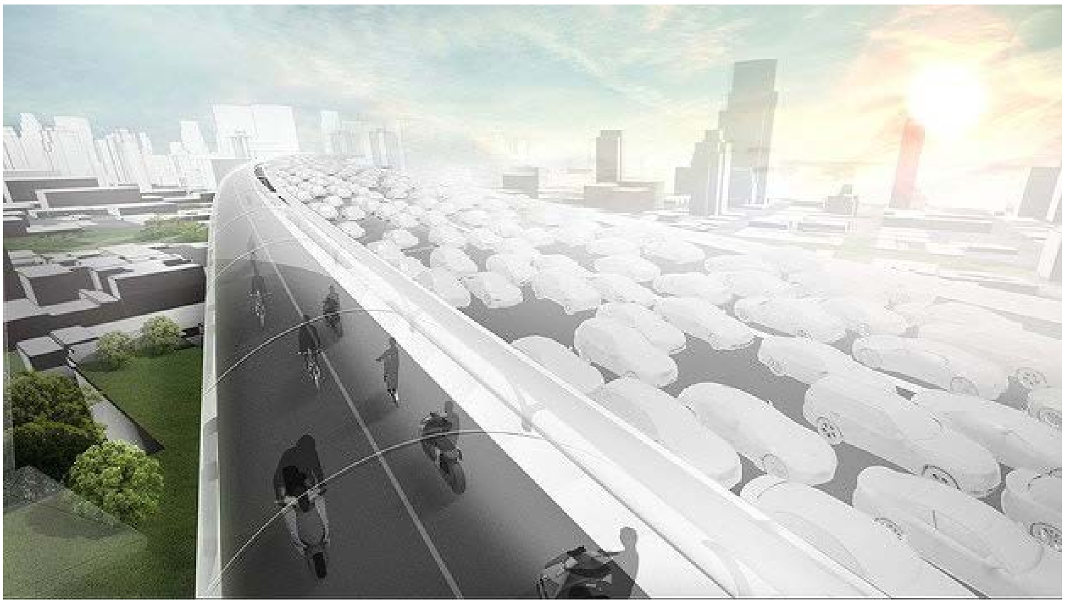

Figure 16: The *BMW Vision E3 Way* (Source: focus.de)

Another innovative concept for passenger and freight transportation in urban areas are the flying solar pods of the company *TransitX*. This concept intends to forego roads entirely, raising transportation networks to the height while leaving the ground space free for pedestrians and bicycles. People and freight are transported in lightweight solar-powered pods in a widespread infrastructure system that reaches wherever streets currently do. The main argument of the developers for this new technology is a cost advantage in building a complete new transport infrastructure instead of huge investments into an extension and adaptation of the existing infrastructure. In addition, the lightweight nature of the pods and solar powering are expected to significantly reduce operating costs compared to conventional means of transport. *TransitX* is currently building its first pilot in the city of Boston (Carpenter, 2018).

In the field of innovative transport infrastructures, some visionary concepts are currently emerging. Since these concepts are of a very capital-intensive nature, the focus lies currently on the acquisition of investors and concrete implementation activities are rather limited to the construction of prototypes and initial test tracks. However, little research is being carried out how these revolutionary concepts should be integrated into the existing transport system and what effects their high spatial requirement will have on the landscape and property rights of landowners (e.g. land expropriation).

3.2.3 Intelligent transport systems (ITS-technologies)

In the course of digitization and the advancing Smart City movement, Intelligent Transport Systems (ITS) are rapidly emerging. ITS-technologies optimize traffic flows and the use of infrastructure by intelligently managing and directing the different traffic components. Kantowitz and Le-Blanc (2006) distinguish three types of communication within ITS-technologies: Vehicle-to-Infrastructure (V2I), Infrastructure-to-Vehicle (I2V) and Vehicle-to-Vehicle (V2V).

Practical applications for V2I and I2V technologies can be found in car park management, traffic management, usage-based cost accounting or navigation applications (Ruchatz, 2017). V2V communication technologies (e.g. adaptive cruise control, lane departure assistance or

active brake assistance) have become widespread standard in the automotive industry due to the further evolution towards (partly) autonomous driving. At its core, the technology comprises a wireless network where vehicles exchange real-time data with each other about their actions. This data contains for example speed, location and direction of travel, which can be further processed - using complex algorithms - to alert drivers about hazardous situations ahead (Howard, 2014).

One of the major trends in V2V technology is **Truck Platooning**, where trucks are connected with each other in such a way that they automatically move one after the other at a constant distance. This intends to relieve the drivers and save fuel by using slipstreams at reduced vehicle distances. Furthermore, Truck Platooning may induce significant road safety improvements: While a human driver has a reaction time of about 1 to 2 seconds, V2V communication can reduce the response time up to 0.2 seconds according to a study of the German vehicle manufacturer *Daimler* (Wilkens, 2017). After a successful test drive of six different truck models over several days through five European countries in 2016, Truck Platooning could be technically applicable in Europe as early as 2020 (Wilkens, 2016).

Figure 17: Truck Platoon (Source: volvo.com)

A final technology that needs to be mentioned in the context of V2V communication is **swarm / collective intelligence**, which includes by definition that specific actions of individuals can evoke intelligent behaviours in the community through communication and networking activities (Dambeck, 2011). An example of an application relevant to mobility is the concept of community-based parking, which has been introduced by the German *Bosch Group* in 2016. The concept intends that a large number of vehicles participate simultaneously in the search of free parking spaces scattered throughout a city, thus making it much easier for the community to locate a free space than if each car had to search on its own. Once a "transmitter vehicle" detects a free parking space, this data is transmitted to a cloud, where it is further aggregated and processed into a digital parking card. Based on this data, the "recipient vehicles" receive a precise indication, where free parking spaces are currently available (Greis, 2016).

In the field of ITS technologies, current research and development activities focus primarily on V2V communication technologies, as the automotive industry is continuously developing towards (semi-)autonomous driving. Field tests of Truck Platoons as well as the further development of the next mobile phone generation (5G) play currently a central role here. However, security issues due to misuse of data or changing power relations through concentration of data generation on individual providers are being discussed rather secondary.

3.2.4 Outlook

In the field of **charging infrastructure for EV's**, our desk research has pointed out that current research and development activities focus mainly on an area-wide expansion of electric charging stations to promote electro mobility for long distance travelling. This can be seen as an important component regarding a transformation of the transport system towards sustainability in the future. According to Lieven (2015), the installation of a broad charging network on freeways can be seen as a necessity to increase a further adoption of electric vehicles in the future and policymakers should therefore rather focus on investments in charging infrastructure than on cash grants for EVs in their incentive programs. Furthermore, inductive charging represents for many experts a promising technology for the future. Nevertheless, 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 (Vogel, 2017).

In any case, charging infrastructure will be one of the main topics in the future and reportings such as the one recently published from the city of Oslo, where charging infrastructure is no longer able to keep up with electric car sales, show that this topic needs to be tackled urgently by the public sector (Ecomento, 2017b). Furthermore, there are still many uncertainties, whether the electricity grids have enough capacity for the predicted EV-Boom and if the required energy will be provided mainly from sustainable and renewable energy sources or not. The German electricity grid, for example, currently only receives one third of its energy from renewable sources and has therefore a tremendous need for action with regard to the overall eco-balance of electro mobility in the future (Welt, 2017). The same applies to the grid capacity, which is currently not prepared to the predicted increase in electric vehicle sales. A recent study of the consulting firm *Oliver Wyman* estimates that under the current regulatory framework, electricity supply in German e-mobility hotspots could fail regularly within five to ten years, if the grid will not be extended appropriately. 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 (Köllner, 2018).

In the field of **innovative transport infrastructures**, our desk research has pointed out that there are some very future-oriented projects currently emerging. However, as already mentioned in the previous chapter, these kind of transport concepts are characterized by a high capital intensity and are therefore in their further development and final implementation strongly dependent on the developments on the capital market. In addition, they require a lot of space and entail in some cases severe interferences into the landscape. Spatial and property conflicts are therefore likely to arise, what may delay the projects significantly. Therefore, it may be appropriate that the policy adjusts the legal framework conditions with a superordinate planning, as the example from the *Cargo Sous Terrain* in Switzerland has shown. For further action, the Federal Council of Switzerland recently agreed to support a

special law in order to create a uniform legal framework for the project instead of different regional regulations in each of the project-affected sub-areas (Chassot, 2016).

In the field of **intelligent transport systems (ITS-technologies)**, future developments are expected to focus mainly on technical advancements in communication technologies, especially in V2V-communication due to the rapid developments in autonomous driving. The further development of the next mobile phone generation (5G) is attributed an essential role here, because a fully automated vehicle can generate up to one gigabyte of data every minute. The 5G network will enable bandwidths of up to 10 gigabits per second and creates the conditions for millions of cars to communicate with each other simultaneously (Soller, 2018). ITS systems could therefore significantly optimize the transport system and make it thus more efficient. According to a study by the *Prognos* research institute and automotive supplier *Bosch*, networked and automated vehicles could save about 480 million kilometres of driving distance only through networked parking technologies. These calculations however were limited on metropolitan areas in Germany, the USA and China (Hallmann, 2017). Another study estimates that the intelligent transportation systems market value will grow at a rate of 12.7% between 2015 and 2024, reaching around 57.44 billion Dollars (Intelligent Transport, 2018). However, there remain some severe security concerns due to the possible misuse of data generated from ITS systems. It remains to be seen to what extent the newly emerging Blockchain technology could be a solution here in the future (e.g. for integrated and automated secure payments in the vehicle). Besides that, legal framework conditions for autonomous driving are in many countries not yet adequately adjusted, what also prevents newly emerging transportation concepts such as truck platooning from a practical implementation on a large-scale. As an additional obstacle for truck platooning, 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 lorries (FOCUS Online, 2018).

3.3 Physical Infrastructure

Due to increased mobility demands over the past decades and the continuous expansion of road networks, road infrastructure today accounts for a considerable share of the usable landscape. As a result, there are several efforts ongoing to attribute a considerable benefit to these “unproductive” areas in the future. In addition, road infrastructure in particular will face increased challenges, particularly in the context of increasing impacts of climate change. This requires an early development of adaptation measures to ensure the continuous functioning of transport systems despite changing external conditions.

3.3.1 Infrastructure damage prevention

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 exposed to storms, heavy rainfall, flood events or extreme heat and cold weather conditions. The direct consequences of the predicted increase in extreme weather events will very likely result in growing prices of mobility and transport products due to disrupted or obstructed traffic flows, the expenditures for repairing the infrastructure, the costs to make the transportation networks sufficiently robust against extreme weather events and rising insurance premiums (Hunsicker et al., 2012).

Current research activities in the infrastructure sector are increasingly focussing on adaptive measures to face the challenges mentioned above. For example, the *German Federal Highway Research Institute*, which is investigating future-oriented road infrastructures on a 25’000 square meter test site. One of the research topics deals with **self-healing roads** by mixing magnetic particles into the road surface. The idea behind this concept is comparable with the principle of an induction hob for heating magnetic pots. Induction energy causes the magnetic particles in the asphalt to become suddenly warm. The bitumen around them expands, alters its toughness - and seals small cracks (Schmidt, 2017). A similar concept, introduced in 2015 by the *Delft University of Technology*, uses bacteria to seal cracks in roads. The aim is to create a concrete blend containing bacteria in microcapsules that will germinate if water runs into the crack. As a result, the bacteria will produce limestone while multiplying and seal the crack before water can cause any structural damage (DWN, 2015).

Another adaptation measure - although a rather unsuitable one - which has been designed especially for pedestrian routes in endangered floodplains are **stepping stones**. The concept foresees that regular square stones are arranged at walking distance on existing bridges in flood areas. In case of a flood event (when the existing bridge will be underwater), the stepping stones still protrude from the water and allow pedestrians to further cross the bridge. During normal water level on the other hand, the stepping stones enhance the recreational quality of the bridge. This concept was first applied in practice during the rearrangement-programme of the river Waal in Nijmegen, Netherlands (NEXT Architects, 2018).

In the field of infrastructure damage prevention, the focus of current research and development activities lies primarily on adaptation measures to climate change such as self-healing roads for example. However, the ecological consequences, especially the use of bacteria, as well as cost-effectiveness of such measures are currently rather neglected in research.

3.3.2 Energy recovery

Another innovative concept are roads that generate electricity. Asphalt heats up strongly in summer and this energy can be used through pipes in the upper layer of the road. A liquid - such as water or a coolant - is used to dissipate the energy and later convert it into electricity. As a side effect, the temperature in the road decreases what results furthermore in less damage through cracks (especially in summer months). In addition, the pipe registers could also be filled with warmer geothermal water in winter - and thus defrost the streets what would require less salt during frost periods (Schmidt, 2017).

A more revolutionary way for road infrastructures to generate energy are **solar roads**, which consist of photovoltaic modules under safety glass. In Tourouvre in Northern France for example, a road section was paved in 2016 with solar cells that are to produce electricity for the street lightning of the 5’000 inhabitants of the town. At the end of 2014, the world's first solar cycle path was opened in Zaanstad in the Netherlands, in the north of Amsterdam, supplying some households with electricity (AFP, 2016). Besides these rather small-scale examples from Europe, China is once again presenting itself to the world as a pioneer of this new technology: Since the beginning of 2018, the world’s first solar highway is being tested in the Chinese province of Shandong. So far, only one kilometre of the highway has been equipped with solar panels. This section of the road is made up of three layers: The upper layer consists of a transparent load-bearing material that allows sunlight to penetrate. Underneath this material are the solar modules made of silicone and an insulation layer at the very bottom. According to the constructors, the solar highway should be able to withstand ten times more pressure than normal asphalt and have a theoretical capacity of one million kilowatt hours per year for the production of solar energy. In addition, it should also be possible to charge electric vehicles in the near future. However, with 458 dollars per square meter, the costs are relatively high compared to conventional construction methods. The test track must therefore first prove its worth before it will be further expanded (Ayoub, 2018).

Figure 18: Solar road in China (Source: gettyimages.com)

In the field of energy recovery, the focus of current research and development activities lies primarily on solar roads, however stronger in Asia than in Europe (despite some test tracks on bike paths for example). Cost-effectiveness and suitability in case of dirt or snow are still too little researched.

3.3.3 Eco-friendly road construction

Using recycled materials as asphalt admixtures to improve quality, lowered material costs and reduced landfill waste is not a new phenomenon. Until today, recycled rubber - mainly from used car tires - has usually been used for this purpose. Recently, several innovative approaches with other materials can be observed, some of which have moreover a significant (positive) influence on the overall CO_2 balance in road construction (Stocking, 2017).

In the city of Rotterdam, a project is currently in its conceptual stage, which intends using plastic bottles as a greener alternative to asphalt in road construction. The initiators see several benefits to current construction methods both in road construction as well as in maintenance. In addition, the material is more durable and can withstand greater heat disparities (between -40°C and 80°C), which can be a major advantage with regard to the predicted increase in extreme weather conditions because of climate change (Darroch, 2015). Furthermore, this new method is also seen as a possibility for recycling plastic waste accumulated at sea. In a next stage, several tests will be carried out to ensure whether this new technology will be safe in wet and slippery conditions or not (Mohabuth, 2016). However, a market launch is currently not yet foreseeable.

Figure 19: Concept of a road with recycled plastic bottles as raw material (Source: zmescience.com)

Besides plastic and rubber, there are some other innovative approaches for mixing recycled materials into asphalt. Researchers at *RMIT University* in Melbourne, Australia, for example made several field tests with cigarette butts, showing that they can improve roadway quality while safely containing heavy metals (Stocking, 2017). In another practical application in Sydney, recycled printer toner is mixed into asphalt and used for road construction. It is the world's first commercial use of toner waste resulting in an eco-friendly asphalted road. This innovative asphalt mix is 40% more energy efficient than the manufacture of standard bitumen, with a relative saving of 270kg of CO_2 emissions per tonne. This measure is part of Sydney's target to reduce its greenhouse gas emissions by 70% until 2030 (Tan, 2015).

In the field of greener asphalt, our desk research revealed that different concepts are being researched with new asphalt mixtures or completely new materials to improve carbon footprint of road construction. So far, however, no product has proven to be economically viable and suitable for mass production.

3.3.4 Outlook

In the field of **infrastructure damage prevention**, our desk research revealed that there is currently a research focus in the field of self-healing roads, although in a rather limited number. Furthermore, ecological issues and economic viability of such adaptation concepts on the effects of climate change are rather neglected in current research and development activities. Because there are still no significant practical examples on a large-scale implemented, it is rather difficult to predict in which direction this field will develop in the future. However, it is likely that in the course of the increasing effects of climate change (e.g. longer heatwaves, dryness, etc.) such concepts for the maintenance of the transport system will receive more attention in the short term.

In the field of **energy recovery**, our desk research revealed that there is a strong focus in current research activities on solar roads. Especially in China, some first large-scale concepts have been implemented recently. However, there are some serious issues concerning the cost-effectiveness of such futuristic infrastructure concepts. With estimated costs between 458 and 746 dollars per square meter (depending on the source), around 56 trillion dollars would have to be invested to convert the entire US road network to solar roads, for example. For a large-scale implementation of this technology, the price per square meter would probably have to fall further. Alongside the costs, the practical suitability is another big question mark. Roads are not initially built in the right angle to the sun for generating maximum energy. In addition, heavy soiling or snow cover lead to massive losses in productivity (Hornigold, 2018). Nevertheless, the expected shift away from traditional gasoline drivetrains to electric engines could lead to more research into such (sustainable) road concepts in the future.

In the field of **eco-friendly road construction**, our desk research revealed that different concepts are being under development with new asphalt mixtures to improve sustainability of road construction. However, no product has proven to be economically viable and suitable for mass production yet. Nevertheless, examples like the one from Sydney, where greenhouse gas emissions have to be reduced by 70% until 2030 and new methods for road construction are an essential component in the reduction measures, are positive signs that even more research will be carried out within this area in the coming decades.

3.4 New mobility products & services

In the course of digitization, several new mobility products and services have emerged in recent years. According to Rauch (2017), digital networking does not only provide for more mobility offers. It creates rather a completely new layer on the mobility structures and the exchange of data between road users, vehicles and the surrounding infrastructure achieves the next level of mobility: a self-controlling system of real-time traffic planning, on-demand availability and smooth transitions from one mode of transport to another. According to a study of the global research and consulting organization *Frost & Sullivan*, more than 20 million vehicles could be removed on urban roads annually as a result of a further growth in new mobility services (ride-sharing, ride-on-demand models, etc.) as from 2025 (Briggs and Sundaram, 2016).

3.4.1 Sharing Systems

One of the main trends that can be observed in the field of new mobility products and services are sharing systems, which are based on a fundamental rethinking in the ownership of mobility products, turning from ownership of transport modes to the use of transport modes (Delle Site et al., 2012). Especially in mature economies societies, a shifting to shared economies – at least in some products and services – is currently going ahead. According to a study of the Swiss consulting firm *Deloitte* however, that tendency is more evident for young generations (*Generation Y*) and car ownership in general is highly affected by new attitudes and behaviours (Corwin et al., 2016). According to Hoppe et al. (2017a), sharing nowadays mostly concerns bicycles and cars and can be divided into the following three categories:

- In **peer-to-peer sharing**, private individuals provide their personal vehicle via information and communication technologies such as online platforms of the sharing community. Sharing providers only provide the booking platform; vehicles and responsibility for maintenance remain with private individuals.
- **Freefloating** vehicles belong to a central provider who is also responsible for the provision and maintenance of the vehicles. The vehicles are parked on public areas and can be re-parked at any location after use, taking into account certain requirements such as the type of parking space or geofencing.
- The organizational structure of **station-based sharing** is similar to the previously characterized freefloating: the vehicles belong to one single provider. However, they are parked at a defined station and have to be returned at such stations; in some cases even at one and the same station.

Another type of sharing systems is ride sharing. In ride sharing, taxi rides are either shared (e.g. *uberPOOL*) or individual seats are made available in private rides. However, since these concepts usually work on demand and do not have fixed schedules or routes, this type of sharing system will be discussed in more detail in chapter 3.4.3, On-demand systems.

In the field of Sharing Systems, the focus is currently on Bike-Sharing offers. Several suppliers, especially from Asia, are pushing into the European market. However, there is only little research being carried out in incentive systems to further promote sharing of the private vehicle.

3.4.2 Mobility as a service (MaaS)

A further trend that can be observed is a growing range of mobility as a service (MaaS) products. In its original understanding, MaaS organises the entire transport chain for the mobility users. This includes the planning, booking and accounting of the trip in a mostly smartphone based system, integrating all types of traffic such as slow traffic, public transportation or sharing systems (Hoppe et al., 2017a). More recently, the term MaaS is also being used for service offers that are not smartphone based and that include for example only one single mode of transport.

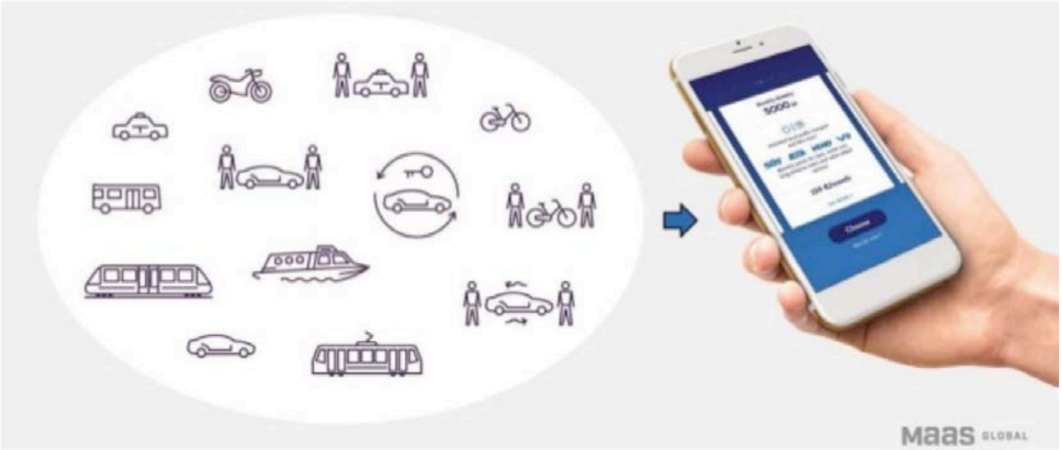

Figure 20: MaaS offers organise the entire transport chain for the mobility user (Source: maas.global)

Several MaaS projects are currently running in Europe, ranging from local initiatives to country-wide systems. Helsinki for example has announced its intention to eliminate the need for privately owned cars by 2020 through the implementation of MaaS (Franckx, 2015). In this context, a very popular example of an all-inclusive mobility service is the Smartphone Application *Whim*, introduced in 2016 by the Finnish company *Maas Global* in the city of Helsinki. The App integrates all modes of public and private transportation within the city. Users can either pre-pay for the service with a monthly subscription fee or pay as they go (Goodall et al., 2017). According to *Maas Global*, the aim of the app is to turn cities into car-free zones, offering the people a true alternative to car ownership because every mode of transportation is integrated in the app and easily available, what eliminates the need of city dwellers to buy a car. In 2018, the app will be launched in Singapore as the first Asian country with one of the most developed infrastructures in the world – the perfect place to enter the Asian market according to *Maas Global* (Othman, 2017).

Another innovative concept of a MaaS, which, in contrast to the previous example, is restricted to a single transport mode and is not based on a smartphone system, has been presented in 2016 from the English car manufacturer *Riversimple* with its lightweight vehicle *Rasa* (see also chapter 3.1.3, Material Technologies). Besides the ecological benefits that can be achieved with this car compared to conventional ones (mainly due to its lightweight construction), the business model behind the car is of particular interest: None of the vehicles are sold and the company remains the owner of the entire vehicle fleet. What they sell instead is mobility as a service. A simple pricing structure enables customers to pay a single monthly fee, in which all accruing expenses (car usage, maintenance, insurance and fuel) are included. As soon as the contract ends, the customer is returning the car and it is offered immediately to the next

customer. Through this business model, the customers can enjoy all the pleasures of a car but have none of the hassles that come along with car ownership (Riversimple, 2017).

In January 2018, the *Toyota Motor Corporation* has presented a rather revolutionary concept at the *CES* in Las Vegas. The *e-Palette* concept consists of an autonomous electric vehicle with an open interior design layout that can be outfitted with purpose-built interiors in accordance with the user's needs such as parcel delivery, ride sharing or on-the-road e-commerce for example (Banks, 2018).

Figure 21: The *Toyota e-Palette* concept as presented first at *CES 2018* (Source: slashgear.com)

According to *Toyota*, this new approach of an autonomous and electric MaaS-service was specifically designed to meet the demands of future multi-mode transportation and business applications. First alliance partners are *Amazon*, *DiDi*, *Mazda*, *Pizza Hut* and *Uber* and initial feasibility tests are planned for 2020 (Toyota, 2018). Besides the mobility services aspect, this innovative concept is also from specific relevance for the on-demand sector (see next chapter), as it brings various service products "on-demand" to the customer's home.

In the field of MaaS, research priorities currently focus on smartphone-based offerings, making it possible for a broad range of new service providers for entering the market. However, little research is being carried out in the newly emerging possibilities and value creation opportunities for other industry branches such as the insurance, energy or media for example. Furthermore, questions on data security are currently being discussed rather secondary.

3.4.3 On-demand systems

On-demand systems are transport services that can be ordered individually on demand by mobility users. In particular, road-based systems (e.g. *Uber*) have already established themselves on a large scale (Dvorsky, 2017). This was partly to such an extent that local public transport companies were completely suppressed (Shankland, 2017). Currently there are several efforts ongoing to allow these systems a complete autonomous operation for example in Singapore by the company *nuTonomy* (Peer, 2016) and by *Uber* in the USA (Bhuiyan, 2017).

An interesting new on-demand concept that has been presented in 2017 is the fully electric ride-pooling concept of the mobility start-up *MOIA* (owned by *Volkswagen*). Core of this concept is an electric vehicle with a capacity for six passengers that has been designed specifically for ride-pooling services in cities. Besides the vehicle, the concept also consists of a customer app, enabling passengers to book and pay for *MOIA* (see also chapter 3.4.2, Mobility as a service). A pooling algorithm groups passengers with similar destinations together

in order to increase the capacity for each car in operation and avoid detours. According to Ole Harms, CEO of *MOIA*, various operator models will be possible and can be developed together with cities and partners, helping them reach for example their sustainability goals while reducing urban traffic. The overall goal of *MOIA* is to remove one million cars from the roads of major cities across Europe and the U.S. by 2025. At the end of 2018, the concept is planned to be fully launched in Hamburg as the first European city (Intelligent Transport, 2017a).

It must be noticed, that on-demand systems are not limited to road traffic but can also be found in track-guided vehicle systems for example: New South Wales in Australia is considering the introduction of variable timetables, depending on weather conditions or current demand of buses and trains (Railway Pro, 2016). In the aviation sector as well, some interesting and innovative new on-demand offers are currently developing. The US helicopter manufacturer *Bell* for example introduced its innovative concept of a fully autonomous air taxi first at CES Las Vegas in 2018. According to *Bell*, this innovation was specially designed for urban environments and includes in its interior curved screens for watching news or holding a video conference during the flight. With this innovative and futuristic project, *Bell* aims to change considerably the way people will move around in cities and agglomerations by air transport in the future (Repko, 2018).

In the field of on-demand systems, several new business models are currently emerging and many new service providers are entering the market. Research priorities lie primarily on autonomous operation of on-demand transport concepts. However, as already mentioned in the field of MaaS, little research is being carried out in the newly emerging possibilities and value creation opportunities for other industry branches such as the insurance, energy or media for example. In addition, several experts assume a counterproductive effect regarding the targeted traffic reduction.

3.4.4 Outlook

In the field of **sharing systems**, our desk research has pointed out that newly emerging sharing systems concentrate mainly on the bicycle sector. While various car-sharing companies have been able to establish themselves in Europe over the past few years, bike sharing still has a lot of potential for expansion. Trend researchers therefore assume that bike sharing will boom in Europe in the coming years - a trend, which (in contrast) already seems to be over in Asia. In recent months already, several bike-sharing providers such as *Mobike*, *Byke*, *Obike* or *Limebike* have been pushing into this highly competitive market in Europe, with more or less success so far (Kugoth & Weimer, 2017). With regard to the automotive sector, future development of sharing systems will probably strongly depend on further technological innovations. It is assumed that in particular electric cars and autonomous driving will be the main drivers for fundamental changes in the car sharing market (Schiller et al., 2017). Besides these technological drivers, high energy prices, demand for innovative solutions, road congestion and raising levels of awareness are some other important factors for a further expansion of car-sharing systems in the future (Shaheen et al., 2006).

In the field of **MaaS**, our desk research has pointed out that there is a lot of activity on different levels going on. Even though there is a certain dominance in smartphone-based applications to observe, several other innovative concepts and business-models are currently emerging that are expected to have a big disruptive potential on our understanding of mobility. In addition, new MaaS-offers are predicted to induce large financial benefits to the society and an overall positive impact on the sustainability of the transport system through more efficient

traffic processes and a general reduction in the number of vehicles on the roads. Several experts assume therefore an utilisation rate of more than 50% of shared cars by the year 2030, mainly due to a large-scale adoption of MaaS offers (Intelligent Transport, 2017b). According to a recent study, global MaaS revenues are expected to exceed $1 trillion by 2030 (ABI research, 2016). Although integrated platforms will play a major role in the mobility system of the future, the question arises who will control these platforms and thus gain access to a large amount of (personal) data. Experience from other industries (e.g. media) has shown that it is possible to make a lot of money from operating the platforms, and no longer primarily from producing its content (Vögeli, 2016). For this reason, new mobility providers who do not fit into the classic "mobility scheme" (e.g. Google) will come a great responsibility regarding ethics and data security in the future.

In the field of **on-demand systems**, our desk research has pointed out that several new concepts are currently emerging and that the focus of research and development activities lies primarily on an autonomous operation of these systems. Automated driving is expected to radically change the efficiency of vehicle use and urban transport systems, and future local transport services will therefore be as intelligent and comfortable as today's taxi drives (Rauch, 2017). Besides that, there are also some beneficial advantages expected with these newly emerging systems. According to a recent study, complete autonomous operation of on-demand systems could massively reduce individual travel expenses in the future (Wadud et al., 2016). However, it is still unclear, what impact on-demand systems will have on the overall traffic volume within the transport system and whether instead of a reduction, an increase is being induced (Reichel, 2018).

3.5 Policies influencing the transport sector

The rapid developments in the mobility sector are increasingly presenting politicians with major challenges. This raises a growing number of questions such as how much development and innovation must be allowed in order not to limit a country's competitiveness or how many restrictions are necessary in order to be able to achieve, for example, the urgently needed climate targets in the coming decades. To react on all these issues, policy and legislation will be in high demand at global, interregional and national levels.

3.5.1 Global environmental agreements

One major milestone **on a global scale** that will affect transportation industry significantly (with regard to a shift towards more sustainability) is the **Paris-Agreement**, ratified by 169 of 197 parties until 2017 (UNFCC, 2017). According to the United Nations Framework Convention on Climate Change, the Paris Agreement’s central aim is: “to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. Additionally, the agreement aims to strengthen the ability of countries to deal with the impacts of climate change.” (UNFCC, 2017). This means in specific, that the European Union will have to reduce transport emissions until 2050 by at least 60% compared with 1990 level, if global warming shall be limited to just 2 degrees Celsius (EU, 2016).

In the field of global environmental agreements, the main focus lies currently on a reduction of CO_2 emissions in order to reach the global climate protection targets set. The Paris Agreement is currently the only and most groundbreaking global environmental agreement with a potentially significant influence on the transport sector in the future.

3.5.2 EU transport policies

The overall objective of the European Union transport policy is to create a single European transport area for all modes of transport, which will contribute to the long-term sustainable competitiveness of Europe by optimising the performance of the transport sector as a whole and to the benefit of all member states. To achieve this, access to high-quality transport infrastructure and excellent transport services must be guaranteed on the basis of research, innovation and a solid long-term funding (European Commission, 2014, 2011). In addition, the European Commission aims to develop and promote transport policies that are efficient, safe, secure and sustainable. These objectives set the framework conditions to ensure long-term competitiveness in the European transport sector (European Commission, 2018d).

With regard to the infrastructure network, the EU faces the challenge of further developing the infrastructure, particularly in the EU enlargement countries, in order to adapt their infrastructure networks to the level of development of the long-standing member states. A long-term and ambitious project to face this challenge is the *TEN-T (Trans-European Network – Transport)* project. With the *TEN-T* programme, the EU intends to establish a core network by 2030, by which time the lack of cross-border connections will be eliminated and the transport network will become "smarter". The next step in its development is to ensure by 2050 that the vast majority of European citizens and businesses are less than 30 minutes' drive away from this comprehensive transport network (European Commission, 2014, 2011).

Another key element of EU policy is the reduction of emissions from transport. CO_2 emissions from the transport sector alone account for at least 20% of EU greenhouse gas emissions. In order to achieve the objective of reducing global greenhouse gas emissions by 80%, which is considered necessary to limit climate change to a safe level (i.e. a temperature increase of no more than 2°C), the transport sector must reduce its emissions by 60% by 2050. The European Union is addressing this problem by promoting research and innovation in clean fuels and measures to further increase market acceptance for sustainable and renewable energy sources (European Commission, 2014, 2011).

The major challenges identified for the European transport sector can be summarized as the following (European Commission, 2018d):

- **congestion** affects both road and air traffic. It costs Europe around 1% of annual GDP – and freight and passenger transport alike are set to grow.
- **oil dependency** – despite improvements in energy efficiency, transport still depends on oil for 96% of its energy needs. Oil will become scarcer in future, increasingly sourced from unstable parts of the world. By 2050, the price is projected to more than double compared to 2005.
- **greenhouse gas emissions** – by 2050, the EU must cut transport emissions by 60% compared with 1990 levels, if we are to limit global warming to an increase of just 2ºC.
- **infrastructure** quality is uneven across the EU.
- **competition** – the EU's transport sector faces growing competition from fast-developing transport markets in other regions.

In the field of EU transport policies, the focus of current research and development activities lies primarily on the transnational standardisation and harmonization of the transport systems, to enhance high-quality transport infrastructure, excellent transport services and better connectivity. This requires in the near future increased investments in the infrastructure sector (especially in the EU enlargement countries).

3.5.3 National policies

Besides the previously described policies on a large-scale, there are also some examples of countries currently trying to implement their transport policies in restrictive manners such as **prohibitions** of ICE-technologies for example. Singapore recently made public that the number of private vehicles (buses and goods vehicles excluded) will not be allowed to grow further from next year due to shortage of land and the expansion of investments in public transport. In the past, the state transport authority had already set the annual growth rate for the number of cars and motorcycles in its fleet at 0.25 percent (Hucko, 2017).

In China, 553 car models are no longer allowed to be manufactured since January 1st 2018, as they fail to comply with the local fuel consumption regulations. The ban affects some large Chinese manufacturers as well as joint ventures such as *FAW-Volkswagen* or *Beijing Benz Automotive* with German participation (Wilkens, 2018). A further example illustrates how restrictive China's policies are in order to transform their transport system towards sustainability: In 2010 already, the Chinese city of Shenzhen has been chosen to take on a pioneering role in the field of electro mobility. In 2015 then, the head of the communist party ordered the entire public bus fleet to switch to electro mobility. In turn, this transformation was supported by high subsidies on electric buses and investments in infrastructure (e.g. charging stations, etc.). Recently, the local government of Shenzhen announced, that diesel-powered

buses are no longer in use throughout the city. In a next step, the city of Shenzhen aims for a conversion of the entire taxi fleet to electric drivetrains (Müller, 2018).

South Korea recently announced that government officials are considering the implementation of a nationwide “no-driving” day, in order to tackle the temporarily extreme air pollution mainly in urban areas. Although in the beginning, the no-driving program would only apply to public servants and employees of state-run organisations, this measure is expected to make a significant contribution to cleaner air conditions in South Korea. In addition, the government plans to impose fines of up to $ 93 to anyone who drives on designated off days. However, several experts constrain that this measure is just a part of a much larger air pollution issue in the region – the pollution coming across the border from their neighbourhood country China (Nolan, 2018).

In Europe, major cities such as Paris are considering more and more requirements for motorised private transport. For example, all passenger cars with internal combustion engines are to be banned from the French capital by 2030 because transport is the main cause of greenhouse gases (Hucko, 2017). Furthermore, Paris is already planning to ban diesel cars from the metropolis after the Summer Olympics in 2024 (Stockburger, 2017a). In Stuttgart, it has already been decided that from 2018 onwards, certain roads will be banned for diesel vehicles on days with high particulate matter exposure (particulate matter alarm). However, there should be exceptions, including for craftsmen, delivery services and taxis (Steffen, 2017). In addition to the efforts being made in some European cities, there is also a visible change in the way national authorities are treating this topic. The French government for example wants to prohibit the registration of diesel and petrol cars throughout France from 2040 onwards. The UK is pursuing a similar goal and the Netherlands aim for a banning of new registrations of cars with internal combustion engines by 2030. In Germany, the party of the Greens are campaigning for a ban on the registration of new cars with petrol and diesel engines from 2030. Norway has even set itself the target of making all new cars emission-free by 2025 (Stockburger, 2017a).

Another policy instrument to exert pressure on the automotive industry and accelerate the transition to clean transport systems are changes in **emissions standards** on a national level. In Germany in particular, pressure on manufacturers has increased with the introduction of the new "Euro 6d-Temp" exhaust emission standard in September 2017. This means that all new registered cars must comply with this directive, which aims to achieve more realistic fuel consumption values (value estimation under real-time conditions) and lower emissions (Bock, 2017). Besides these political commitments, there are also some strong signals coming from the automotive industry to turn away from gasoline and diesel engines. Various car manufacturers made announcements lately to change their development and production strategy towards e-mobility in the near future (Stockburger, 2017b).

Besides the previously described policies which mainly focus on restrictions and prohibitions of conventional gasoline vehicles, there also some interesting examples to find, which try to promote clean vehicle technologies with incentives, such as **subsidies** for example. The federal province of north Rhine Westphalia in Germany recently launched a new programme to promote electro mobility: it supports private individuals who want to install a charging station for electric vehicles on their property. The country covers 50 percent of the costs up to a maximum of 1’000 euros for each privately used charging point. Publicly accessible loading points are even subsidized with up to 5’000 euros (ElektroMobilitätNRW, 2017).

Another very prominent measure to pass on the costs of pollution to the polluter itself are **mobility-pricing** policies. At the heart of these policies stands the principle: those who consume mobility should also pay for it. Transport policies however violate in many ways the truth about costs and the polluter pays principle. Mobility pricing would therefore be a suitable solution for these structural errors (Müller-Jentsch, 2013). In this context, newly emerging information and communication technologies facilitate congestion charging and road pricing by transforming roads from public goods into payable services. However, acceptance in a broad public and missing political willingness for implementing the policies are still the greatest obstacles to overcome (Geels, 2012). Nevertheless, there are some good examples in which road-pricing was successfully applied. The Scandinavian capitals of Oslo (Norway) and Stockholm (Sweden) are among the European pioneers of a city toll. Both cities charge a fee for driving to the city centre in order to cope with the notorious traffic jams and to improve the environmental quality in the city (Müller-Jentsch, 2013).

Another policy measure to support clean transport technologies are **quotas**. China is regarded as one of the world's largest market for electric mobility. Electric vehicles are massively subsidised in this rapidly growing country and a production and sales quota - valid from 2019 - obliges car manufacturers to realize ten percent of their annual sales with so-called New Energy Vehicles (NEVs). The quota is set to rise to 12 percent by 2020. By 2025, China aims to reach - regarding new car sales - at least 20 percent of the cars to be pure electric or partially electric hybrids with plug-ins (Ecomento, 2017). Such a quota can indirectly also be achieved via **CO_2 limits**. In the EU, for example, vehicles will not be allowed to exceed a CO_2 limit of 95 grams per vehicle from 2021 onwards. If this value will be exceeded, a penalty fee of 95 euros for each gram above the limit must be paid to the EU - a penalty that probably will be far too high for a price-sensitive industry such as the automotive (Schwarzer, 2017).

On a local level, the city of Atlanta was recently in the headlines by passing an **infrastructure ordinance** to builders of new buildings in order to support electric vehicle charging. Under the new regulations, builders are committed to install a certain amount of electrical infrastructure in order to support EV chargers in each new residential and commercial building. In addition to this measure, each new commercial parking facility needs to ensure that 20% of the parking spaces are ready for electric vehicle charging (Pyzyk, 2017).

With regard to traffic deaths and safety in transports, an ambitious traffic safety movement that has spread on a large-scale in the last 20 years (e.g. Sweden adopted the first concept in 1997) and that is now increasingly being adopted in the U.S. and the UK is the ***Vision Zero***. Main purpose of *Vision Zero* is a safety-focused redesign of city streets resulting in no more traffic-related deaths. In recent years, at least 18 U.S. cities have set goals to stop all traffic deaths within the next decades as part of their *Vision Zero* plans. In many places, this requires a fundamental shift in how cities plan and design their streets in order that *Vision Zero* remains not only a catchy name of a well-meaning concept (Leber, 2016). In addition, newly emerging technologies (e.g. autonomous vehicles) offer a great opportunity to enhance better safety on the roads and to reduce traffic-related deaths. However, there is still a lot of research and development in autonomous technologies needed until such concepts will be integrated in the transport system. (Fatal) accidents, like the one during an autonomous test drive of the vehicle service *Uber* in Arizona in 2018, are not conducive to widespread public confidence in autonomous systems (Veitinger, 2018).

In the field of national policies, our desk research has pointed out that various political instruments are currently being applied in order to reduce congestion and to improve the overall environmental conditions (e.g. due to air pollution caused by conventional drivetrains). In this context, bans and prohibitions are two of the major instruments that are currently in several countries under discussion. However, these measures are generally limited to urban areas or affect only a certain group of mobility users (e.g. commuter traffic). Large-scale measures to improve sustainability in the transport system are rather neglected in current discussions (e.g. air transport).

3.5.4 Outlook

In the field of **global environmental agreements**, our desk research revealed that apart from the Paris Agreement, no other (groundbreaking) global agreements can be identified that would affect the transport system in the future and favour a transformation of the latter towards sustainability. Since political decision-making processes are very lengthy and sometimes unsteady due to unpredictably changing framework conditions, forecasts of future developments are in this field of research rather uncertain.

In the field of **EU transport policies**, our desk research revealed that a special focus lies currently on a transnational standardisation and harmonization of the transport system. Through this specific political focus, the European Union aims to enhance high-quality transport infrastructure, excellent transport services and better connectivity within Europe to ensure long-term competitiveness in the European transport sector. In summary, the European transport policy will mainly focus within the next few years on the following future goals (European Commission, 2014, 2011):

- To place a Europe-wide focus on achieving optimal connectivity between different forms of transport: road, rail, air and waterborne travel (sea and inland waterways).
- To advance with work on the Trans-European Transport Network and build the smooth high-quality interconnections needed for the development of the internal market, thereby improving the lives of the travelling public.
- To promote investment in transport by making sure that the national and European regulatory environments are appropriate and in place.
- To develop innovative financing instruments for transport infrastructure; to make the best use of instruments already available within the Connecting Europe Facility; to find ways to complement national and regional funding from the European Structural and Investment Funds.
- To promote integration across different transport sectors which is increasingly based on a non-discriminatory approach of general infrastructure costs being funded by those who use them: the ‘user pays’ principle.
- To develop common European standards for transport safety and security; to strengthen Europe’s role and influence in international transport.
- To advance work to complete the Single European Sky project and complete negotiations on the Fourth Railway Package.
- To work with major sector companies in public-private partnerships such as SESAR and Shift 2 Rail, in order to bring innovation to the aviation and rail markets that will benefit citizens and business.

Finally, our desk research revealed that there are several policies emerging on a **national level** to tackle air pollution, traffic jams, safety issues (e.g. Vision resp. Road to Zero) and other externalities relevant to mobility. However, we also see that political initiatives depend in their restriction on the country and the respective political framework conditions. Bans and prohibitions of ICE-technologies are two of the major instruments that are currently in several countries emerging (although primarily in urban areas). In Asia in particular, several states are banning conventional combustion engines with such instruments from the roads or simply prohibit their production or import into the country. Also in Europe (e.g. in France, the Netherlands or Germany), several political initiatives are underway to make the transport system more sustainable in the future. On the other hand, there are many economically interesting approaches, such as pricing models for example, which often fail in their practical implementation due to political will or lack of acceptance among the broad public. Nevertheless, public policy will have an increasing role to play in ensuring an efficient and structured delivery of connected transport systems in the future. Forward-thinking mayors and city administrators will therefore have to show leadership in helping to put innovations, smart technologies and political instruments at the heart of transportation, to obtain a transformation of the transport system towards sustainability (Hitachi Ltd., 2016).

3.6 Economic production & organisational structures

In the course of rapidly advancing technological developments, traditional economic sectors are increasingly confronted with new challenges. New growth markets are emerging in the most diverse segments of the economy. Current examples are renewable energies, alternative mobility services, autonomous vehicles, industrial and household robots and the Internet of Things. According to a study of the strategy consulting firm *Oliver Wyman*, the new product and service markets could be worth more than a trillion dollars by 2025 (Konradin Mediengruppe, 2017).

3.6.1 Industry 4.0

In this newly emerging Industry 4.0, production processes are interlinked with modern information and communication technologies. The driving force behind this development is the rapidly increasing digitalisation of economy and society, resulting in so-called "smart factories" (Eisert, 2017). The technical basis for this development is provided by intelligent, digitally networked systems, which enable largely self-organized production in which people, machines and products communicate and cooperate with each other. In addition, production and logistics processes between companies in the same production process can be intelligently interlinked, to make production even more efficient and flexible (Bundesministerium für Wirtschaft und Energie, 2018). These operational efficiency gains can be further enhanced by the use of new technologies. As already mentioned in chapter 3.1.3, Material Technologies, additive manufacturing processes (3D-printing) are becoming increasingly popular in the manufacturing industry and allow local production (e.g. of individual parts) what could eliminate the need for large warehouses for example and therefore bring significant changes in existing organizational structures of manufacturing companies (e.g. just-in-time production, etc.). These examples indicate that several traditional industries are expected to facing major challenges in the near future associated with the ongoing developments of Industry 4.0.

Figure 22: Industry 4.0 dependent components in an industrial manufacturing company (Source: vdma.org)

Another area that is undergoing major changes associated with the ongoing developments in Industry 4.0 is the logistics sector. In this context, the term Transportation 4.0 is being used

more frequently. Logistics companies such as *Amazon*, *DHL* or *UPS* are already today planning the commercial use of driverless delivery vans and drones (see chapter 3.1.1, Vehicle technologies). Several experts assume that we will see already in the near future some practical solutions in this field (Lixenfeld, 2017).

Besides these developments on a rather technological level, several innovative business concepts - mainly from start-up companies - emerged recently in association with Transportation 4.0, to make supply chains more efficient. One of these innovative concepts has been presented in 2017 from the Swiss start-up *Pickwings*. The core idea of the concept is, to improve the loading rate of cargo trucks by bringing trucks and cargo shippers together. Through digitization of vehicle fleets and GPS, dispatchers are able to see in real time whether there is a truck with free loading capacity nearby or not. This results in considerable efficiency gains and environmental benefits through fewer empty runs (Huwiler, 2017). Another concept - focussing on the maritime and aeronautic sector - is *Freighthub*, an online management system that processes container transports by sea or air freight completely electronically. The online service allows customers to book and manage their shipments and track the location of containers until its delivery. Until today, there are 14 major shipping companies in partnership, including for example *Hamburg Süd*, *Maersk* or *Evergreen* (Weimer, 2016). Another big player that has recently entered the market is the US start-up *Uber* with its service *Uber freight*. Similar to the regular driving service app, logistics companies can search for available loads within the application and accept orders provided they accept the quotation. One major advantage compared to other services is the payment system, which is handled directly in a smartphone application. The service will initially focus on self-employed drivers and small businesses (Schlenk, 2017).

In the field of Industry 4.0, current research and development activities focus primarily on mechanization of operational processes and the associated restructuring of individual workflows. Large-scale effects on mobility supply and demand (also due to an increasing mail order business in the course of Transportation 4.0), however, are being discussed rather secondary.

3.6.2 Economic structural change

In the course of the emerging Industry 4.0 and its new technological opportunities, the automotive industry will very likely be challenged through the increased automation and electrification of conventional drivetrains. Compared to a conventional combustion engine with approximately 1’200 components, an electric engine has just about 25 different components. This makes an electric engine much more efficient in construction and design compared to a conventional one, which will probably have a severe impact on the future number of employees in the automotive industry. According to a study of the *Institute for Economic Research (ifo)*, about 450’000 of the total 900’000 jobs in the automotive industry in Germany could be in danger if a ban on the registration of cars with internal combustion engines should be enforced from 2030 onwards (Kröger, 2017). Similar results have been published in a forecast of the German *Institute for Employment Research (IAB)*, which predicted that 490’000 jobs in the manufacturing (mainly automotive) industry in Germany are about to disappear by 2025 as a result of increasing digitalization. However, as by contrast new job opportunities will be created (especially in the IT and education industry) only 60’000 jobs are expected to be lost in total. According to the authors of the study a relatively tolerable amount with regard to an economy with more than 43 million employees (Siems, 2016).

The predicted changes and developments in the automotive industry (particularly the electrification of conventional engine technologies) will also face the oil industry with major challenges. A recently published study of the *Organization of the Petroleum Exporting Countries (OPEC)* has shown, that demand for oil could decline significantly from 2030 onwards, in case of an ongoing boom in electric vehicles (Shankleman, 2017). This will open up new markets, especially for mining companies and raw material traders (e.g. for lithium, cobalt or vanadium). Several experts already suspect that the "green revolution" could lead to a new super-cycle for raw materials (Hosp, 2018). However, this development is anything but unproblematic. According to industry insiders, the danger of a shortage of cobalt is great, partly because the majority of the known cobalt reserves are extracted in Congo, a politically very unstable region (Delko, 2018). In addition, critics constantly denounce the poor working conditions in the producing countries. Ultimately, there is still the conviction that a decline in demand for oil will not come for many years and will be rather moderate. As a result, the raw materials industry would be in the best of all possible situations, either way in terms of demand (Hosp, 2018).

In the field of economic structural change, the focus of current research and development activities lies primarily on cross-sector change scenarios for employee numbers. By contrast, there are still too little discussions about retraining opportunities to prepare employees at an early stage for the consequences of the predicted structural change (in the course of digitisation and Industry 4.0). Moreover, too little attention is being paid on the development of new industrial sectors in areas severely affected by the forecasted structural change. Finally, questions such as who will exactly benefit from the forecasted raw material boom (in the course of electrification of conventional drivetrains) and what regulatory framework conditions may need to be created (with regard to labour-political issues such as labour exploitation, child labour, corruption, etc.) should be increasingly addressed in the future.

3.6.3 Green Economy

Current trends in economy are at least partly taking up sustainability as a paradigm for future-oriented development. The overall goal of the Green Economy is to create a sustainable economy that conserves natural resources and is less harmful to the environment. In this context, Green Economy combines ecology as well as economy: the economy must be internationally competitive, but also environmentally and socially compatible. In addition, Green Economy increases social welfare, combats poverty and strives for social justice (UNECE, 2018).

The concept of the Green Economy concentrates mainly on political sustainability agendas. The *Federal Ministry of Education and Research* in Germany for example provided a total of 350 million euros in the past few years for research on the Green Economy. This mainly due to the new high-tech strategy of the Federal Government, which aims to secure the quality of life through a sustainable economy (Bundesministerium für Bildung und Forschung, 2018). However, a critical reception of this Green Economy trend must be maintained as it is considered financially profitable. It therefore needs periodic review to ensure, that measures taken actually do support a sustainability transformation of the current system and not just individual financial interests (Brand, 2012).

A further concept in this context is the **Circular Economy**. In a Circular Economy, growth and prosperity are decoupled from natural resource consumption and ecosystem degradation. Instead of throwing away used products, components and materials, they are reused and put

in value again, thus aiming to create a society with a healthy economy that is in balance with the natural resources supply. It is therefore a system, in which reduction, reuse and recycling of resources prevails (Vos et al., 2016). Several experts assume a variety of advantages coming from a movement of a traditional linear economy towards a circular economy. According to a recent study by the *Club of Rome*, carbon emissions could be cut by almost 70% if a key set of circular economy policy measures (including renewable energy solutions, energy efficiency and material efficiency) were adopted. In addition, there are significant beneficial impacts on the labour market to expect coming from repair, maintenance and remanufacturing of items instead of throwing them away (Wijkman, 2015).

With regard to sustainable mobility, the car manufacturer *Toyota* and the energy supplier *Chubu Electric Power* announced in 2018, to start a joint battery project that involves a stationary storage battery system for used electric car batteries in second life, followed by an investigation into the recycling of finally used batteries. A similar practical example already exists in the *Johann Cruijff Arena*, a soccer stadium in Amsterdam (Netherlands), where (used) battery cells with a total capacity of 3 megawatts were coupled as a storage system to compensate for differences in energy supply and demand (Elektroauto-News, 2018b).

Figure 23: Model of the Circular Economy (Source: europaparl.europa.eu)

The European Commission as well adopted in 2018 a new set of measures to implement the ambitious Circular Economy Action Plan and to stimulate Europe's transition towards a circular economy. The proposed actions contribute to "closing the loop" of product lifecycles through more recycling and re-use of materials. The measures include in detail (European Commission, 2018b):

- A Europe-wide EU Strategy for Plastics in the Circular Economy and annex to transform the way plastics and plastics products are designed, produced, used and recycled.

- A Communication on options to address the interface between chemical, product and waste legislation that assesses how the rules on waste, products and chemicals relate to each other.
- A Monitoring Framework on progress towards a circular economy at EU and national level.
- A Report on Critical Raw Materials and the circular economy that highlights the potential to make the use of the 27 critical materials in our economy more circular.

The European Structural & Investment Funds (ESIF) will support financially the desired transition with investments in waste management for about 5.5 billion Euros. Further support for about 650 million Euros will be provided under Horizon 2020 and national investments (European Commission, 2018c).

In the field of Green Economy, the focus of current research and development activities lies primarily on (political) initiatives in waste management (including recycling and re-use of materials). However, especially in the course of the sustainability transformation of the transport system (e.g. from conventional drivetrains to electric drivetrains) and with growing demand for raw materials, several basic principles of the green economy (e.g. social justice, fair working conditions, environmental compatibility, etc.) are still being threatened.

3.6.4 Outlook

In the field of **Industry 4.0**, our desk research has pointed out that in the course of digitisation and with newly emerging technologies, an entire reorganization of the economy can be expected, comparable to the economic structural change of industrialization or tertiarisation. This is expected to have a significant impact on the labour market, industry development or the spatial organisation of the economy, with the corresponding consequences for mobility and transport.

Related to changes in the course of Industry 4.0, our desk research revealed that in the field of **economic structural change**, some drastic changes in traditional manufacturing industries can be expected in the coming decades. The automotive industry for example will probably minimize the overall number of workplaces, mainly due to digitalization and the associated changes in work processes. The entire industry, however, can most likely expect massive sales growth in the upcoming years. According to a study by the consulting firm *McKinsey*, industry revenues could almost double from 3.4 trillion to 6.6 trillion US dollars by 2030 due to new mobility services and the predicted shift towards autonomous driving and alternative drivetrains (Finanzen.net GmbH, 2017). With the predicted transition towards electric drivetrains, there arise, however, severe questions (e.g. fair working conditions, environmental compatibility, etc.) that put the entire sustainability of the transformation of the transport system into question.

In the field of **green economy**, our desk research revealed that there are several concepts currently emerging that, however, concentrate mainly on political sustainability agendas. The European Commission as well has addressed this topic with a new set of measures that focus on plastic products, critical raw materials, waste management and a monitoring framework. However, the future development in this field is rather difficult to predict.

3.7 Spatial organisation & structures

Due to a steadily increasing population growth and the concentration of financially strong industries in urban agglomerations, Urbanisation is - from a global perspective - one of the major (mega-) trends in the coming decades whilst in already heavily urbanised regions, suburbanisation and densification of the city centres are expected to dominate the scenery. Today, about 75% of Europeans live in cities and this percentage is expected to increase to 85% by 2050 (Delle Site et al., 2012). This creates enormous market potential, especially for providers of mobility services.

3.7.1 Smart Cities as new "planned cities"

The term Smart City can be used as a generic term for integrated development concepts that make cities efficient, technologically advanced and more sustainable. An essential characteristic of Smart Cities are the strong innovation activities especially in the fields of economy, society, technology and ecology (Wikipedia, 2017). According to Giffinger et al. (2007), the holistic concept of Smart cities can be divided into the six sub-areas Smart Economy, Smart People, Smart Governance, Smart Environment, Smart Living and Smart Mobility. In this context, Smart Mobility can be understood as a modern form of mobility, which aims for more efficient traffic flows, emission reduction and cost-savings for the mobility users. This is being achieved mainly by information and communication technologies and, more generally, digital networking (Brünglinghaus, 2013). A practical example are Smart Parking solutions, where sensors in the parking spots provide information to a general system, whether the parking spot is free or not. The car driver on the other hand can retrieve this information via smartphone app and thus find a free parking space more efficiently.

The European Union (EU) as well is striving to develop a strategy to achieve intelligent urban growth for its metropolitan regions. A number of programmes have therefore been developed in the past few years within Europe's "Digital Agenda", such as for example the implementation of measures to improve the connectivity within the European Union or the creation of an inclusive digital society (European Commission, 2018a). Smart City technologies and programs have been implemented so far for example in Stockholm, Barcelona, Amsterdam or Southampton.

Nevertheless, digital transformation processes to convert a city into a Smart City are still relatively sluggish, especially because of the variety of players with different interests involved or a lack in technologies available (e.g. autonomous vehicles or 5G technology). For this reason, efforts are being intensified worldwide to build up intelligent cities from scratch in specially planned areas. Saudi Arabia for example plans to build on a 26.500 square kilometres large area a digital mega-industrial zone in the middle of nowhere. This flagship project called *Neom* is to become a kind of a separate state territory in which almost everything will be automated and IT-based - transportation as well. This includes for example electro mobility, autonomous road transportation and new multimodal mobility concepts such as passenger transport by drones. Up to now, this futuristic industrial zone has only existed in ideas and plans and an initial cost estimation assumes overall costs from up to 500 billion US dollars. Nevertheless, the first construction phase is expected to be completed in 2025 already (Eisenkrämer, 2017). Another project has been presented by the *Alphabet-Holding* (parent company of *Google*) in 2017, which aims to create a brand new and futuristic city district in Toronto, Canada. According to the project partners, use of the latest technologies (e.g. autonomous driving) will play a central role on the newly designed 50’000 square meter large

construction site, to solve the major urban challenges of our time and thus inspire other metropolitan areas all over the world. Overall project costs are estimated at approximately 1 billion US dollars (Lindner, 2017).

Figure 24: Vision of the Saudi Arabian smart city project *Neom* (Source: weetas.com)

According to a recent study, there are currently about 1’000 Smart City projects emerging or already successfully running around the world. With around 500 projects, China has currently the largest number of Smart City pilot projects running. China has a particular interest in creating smart cities, which is why the industry receives more support in financing such projects. Furthermore, there is also more support from the government for Smart City projects (CIIC, 2018).

In the field of smart cities, our desk research revealed that in many cities around the world, research and development efforts are underway to mature into a “smarter” city. This is mainly achieved by investing in new technologies such as intelligent light poles for example. Integrated smart cities (with complete networking of all elements in the city) that were built from the scratch, however, are still rather future music, especially because of high investment costs, planning barriers (e.g. many players with different interests) and a lack in technologies available.

3.7.2 Eco-cities

In connection with the in the previous chapter described green economy concept, several green or eco-city projects are currently emerging around the world, aiming for zero-carbon emissions. What started out as a few experimental projects for testing new green urban design and sustainable technological systems has nowadays turned into a large-scale construction movement, especially across Chinese cities. About 285 projects are currently emerging in around 80% of all prefectural-level cities in China – and even more are expected to come. There are several factors supporting this rapid growth in China such as a basic willingness to create large areas of open space for urban projects, an authoritarian regime, vast amounts of money and a generally spoken positive vision of the future (Shepard, 2017).

One of the initial eco-city projects in China is running in the city of Tianjin since 2007. The main objective of this project is to address two of the most urgent problems in China: Urbanisation and environmental pollution (Schwan, 2015). The environmental standards are accordingly strict and range from limits on daily water consumption to maximum carbon dioxide emissions in relation to the GDP. However, the eco-city project in Tianjin faces severe problems regarding financing and potential future residents (Belz, 2013).

Another popular project was launched in 2006 about 30 km east of the city centre from Abu Dhabi: a new planned eco-city called Masdar City. The ambitious project foresees to be entirely powered by renewable energy sources. In addition, the entire city aligns according to a strict sustainability guideline that aims for zero CO_2 emissions and virtually no waste through consistent recycling. Completion of Masdar City was initially planned for 2016. However, only a fraction of the town has been built yet (mainly because of delays due to financing problems) and the completion date has therefore been pushed back to 2030. Several critics already fear that the project could become the world's first green ghost town instead of a showpiece for sustainable planning and construction (Goldenberg, 2016).

Another new concept in the context of eco-cities that appears to be the first (again) to develop in China are **forest cities**. Forest cities aim to improve the poor environmental conditions caused by urban areas on a large-scale. The world's first forest city is currently under construction in the city of Liuzhou in China, including nearly 1 million plants of more than 100 species and 40'000 trees that together absorb almost 10'000 tons of CO_2, 57 tons of pollutants and produce approximately 900 tons of oxygen annually. As a positive side effect, forest cities help in decreasing the average air temperature, improve local air quality, create noise barriers, generate wildlife habitats and improve therefore local biodiversity (Lant, 2017).

Figure 25: The forest city concept in the city of Liuzhou in China (Source: stefanoboeriarchitetti.net)

A similar project was realised in Europe a few years ago, albeit on a smaller scale. The project called *Bosco Verticale* consists of two skyscrapers in the city of Milan, whose façades are completely planted with 730 specially cultivated trees, 11'000 groundcover plants and 5'000

shrubs. Stefano Boeri, one of the main architects of the project, sees in this new approach a promising alternative to the cold steel and glass surfaces of current architectures (Babbs, 2013).

In the field of eco-cities (including forest cities), our desk research revealed that there is a spatial concentration in research and development activities in Asia and the Arab region, mainly due to large available areas and the corresponding framework conditions and (political) structures. In Europe however, there is currently little activity going on in this area. In addition, none of the projects implemented so far have proved for being groundbreaking.

3.7.3 Geographical disparities

In addition to the many advantages that the previously described trends and developments are expected to bring, there are also some negative effects that will probably have severe impacts on the future spatial organisation. As described in chapter 3.1.1, Vehicle technologies, autonomous vehicles are expected to have an overall positive effect on the transport system due to smoother traffic flows and a general improvement in road safety. However, according to the urbanist Richard Florida, autonomous vehicles will probably reinforce geographical disparities and not (as expected) counterbalance them. Florida expects a new exodus from the city, mainly from non-privileged strata, due to rising prices of rents and condominiums. It will therefore not be the rich using autonomous vehicles to commute from the countryside to the urban areas, but cheap autonomous buses for example, that transport the workers and low-income earners from the cheap countryside to the city and back. Autonomous driving therefore tends to reinforce, rather than weaken, gentrification (Rötzer, 2017).

According to our desk research, a certain emphasis is visible in the connection of newly emerging technologies with spatial development issues. However, there is only little material available and further developments in this field of research are therefore rather uncertain.

3.7.4 Outlook

In the field of **Smart Cities**, our desk research revealed that in the course of the megatrend urbanisation and with further technological progress, many new smart city projects are currently emerging – especially in Asian countries. However, processes for digitizing entire cities are highly time and capital consuming but there are many promising approaches emerging, mainly in the course of technical innovations. Since technology can be seen as a basic requirement for smart cities, a lot of research is being carried out for example in new vehicle technologies (e.g. autonomous vehicles) or in enhanced ICT-technologies, especially in the implementation of 5G technology. Through a large-scale implementation of 5G technology, Smart City systems are expected to receive the amount of data resp. information needed to further reduce uncertainties and to make the smart city systems generally more efficient (Schorer, 2018). The higher bandwidth due to 5G technology should make it possible to combine things in the tens of billions. This will probably result in a completely reshaped information and communication network with seamless and consistent connectivity. The first 5G networks are expected for full operation in 2019. By 2023, this technology should already be accessible to a fifth of the world's population (Pöschl, 2018). Besides these technological trends that are expected to favour building of smart cities on a large scale, several doubts arise, which mainly focus on social aspects. Developing smart cities requires necessarily the integration of a social level, since cities are also places of encounter and interaction. In reality, however, this level is almost completely neglected in today's discussion about smart cities due

to the one-sided focus on technology. In addition, monitoring, data misuse and technical vulnerability are other frequently cited arguments against smart cities. Given all these issues coming up, it will be crucial for city planners to include a social component in the development of smart cities so that they do not become the ghost towns of tomorrow. Therefore, it is quite possible that smart city technologies will not be used in a completely networked application, but will rather be limited to certain road sections or functions (Schmidt, 2018).

In the field of **eco-cities** we have seen, that mainly in Asia and the Arab region, a lot of efforts are being put into the development of sustainable cities from the scratch. This depends primarily on the political structures and framework conditions and therefore also explains why there is not yet so much going on in Europe. Nevertheless planted high-rises for example have a big potential to radically change our future cityscapes in Europe and several Experts recommend a de-urbanisation as a radical alternative to improve sustainability of urban environments instead of investments in expensive technologies (Babbs, 2013).

In the field of **geographical disparities**, our desk research revealed several negative impacts on spatial structures due to newly emerging technologies and the related changes in mobility demand/behaviour. Predictions of future developments are therefore rather uncertain.

3.8 Society

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 can be observed. In the mobility sector however, there is still a lot of room for improvement with regard to individual mobility behaviour or changes of current mobility paradigms. In this context, newly emerging technologies (e.g. autonomous vehicles) offer a great potential for a shift in the personal behaviour patterns towards sustainability. Various theories and approaches describe already today, under which conditions this behavioural change could occur. Nevertheless, it cannot yet be predicted whether the mobility users will be willing to adapt these new opportunities in the future and ultimately escape the familiar.

3.8.1 Mobility behaviour

One of the main (mega-) trends, having a significant impact on the mobility sector and the behavioural patterns of the mobility users in the future is the ageing population. Traditionally seniors travelled significantly less than the younger generations. Daily mobility decreases generally with increasing age, mainly due to health aspects and the drop out of work related travel (Scheiner, 2006). Nowadays, improved health together with increased wealth, travelling options and language skills support a more active lifestyle including international travelling. The total demand for mobility within this age group is therefore expected to grow further in the coming decades (Rudinger et al., 2006). However, the mobility behaviour of the elderly strongly varies and depends on individual needs and abilities (Scheiner, 2006).

In addition to the expected (age-induced) growth in demand for mobility, further growth must also be expected in all other areas of life due to a large number of driving factors. The development of low-cost mass transport for example has led to an acceleration in tourism, which is reflected in more frequent and shorter journeys but with increasing distance (OECD, 2017). The expected development of tourism indicates a further increase in international tourist arrivals. According to the World Tourism Organization (UNWTO), international tourist arrivals worldwide are expected to increase by 3.3% a year between 2010 and 2030 to reach 1.8 billion by 2030 (see Figure 26). Furthermore, arrivals in emerging destinations (e.g. Myanmar, Sri Lanka or Hong Kong) are expected to increase at twice the rate of those in advanced economies between 2010 and 2030 (+4.4% a year in emerging destinations and +2.2% a year in advanced economies). Market share of emerging economies is therefore expected to increase by 57% until 2030, equivalent to over 1 billion international tourist arrivals (UNWTO, 2016).

The ongoing digitization of all areas of life, new technological possibilities as well as societal trends will also affect our leisure behaviour in the future. Autonomous vehicles for example offer a great opportunity to open up new spaces that can be used for playing and spending its leisure time. It is also conceivable that in the future we will work less due to increasing automation and therefore have more free time, which would in turn have an impact on the overall mobility demand resulting in a shift in the behavioural patterns. Above all, urban spaces and an increasingly experiential society are expected (in connection with new technological possibilities) to create new forms of play: physically, digitally expanded and virtually (Schiffer et al., 2017).

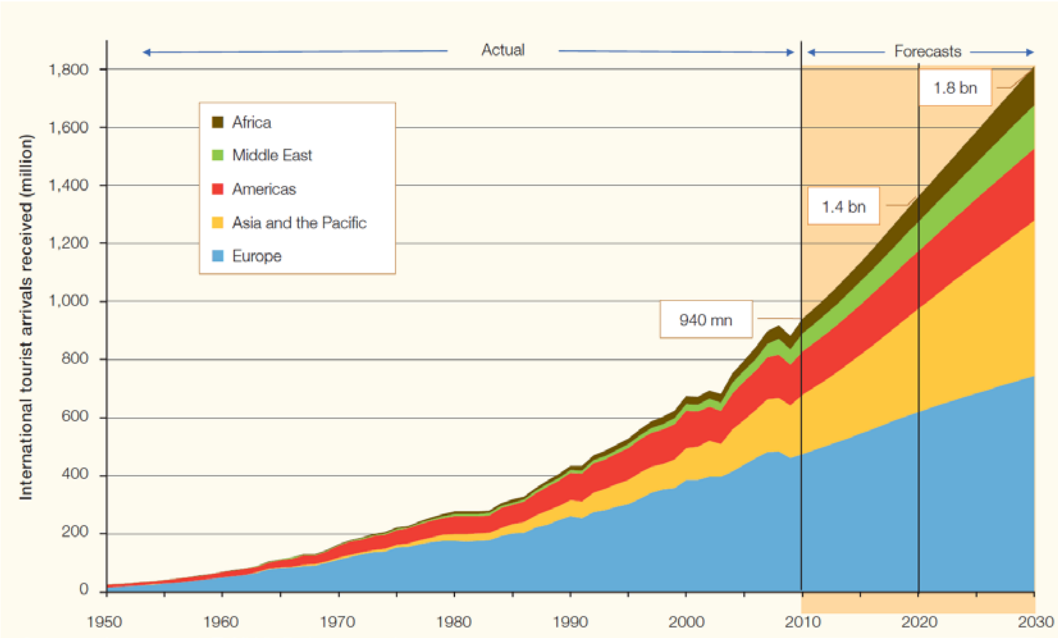

Figure 26: UNWTO Tourism towards 2030: Actual trend and forecast 1950-2030 (Source: UNWTO, 2016)

3.8.2 Behaviour change theories

Behaviour change theories may play an important role in transport research by explaining this decision-making mechanism of travellers and the effect of measures that aim to influence it (Bamberg et al., 2011). A thorough literature review from Hoppe et al. (2017b) revealed that out of the 83 existing behaviour change theories listed by Michie et al. (2014), only 17 have been used to analyse travel behaviour. In this context, reduction of car use is the most frequently targeted behaviour, but recent mobility concepts such as electro-mobility, eco-driving, bike-sharing and intermodality have already started being investigated under the lens of behaviour change theories.

In a further step, Hoppe et al. (2017b) applied ten behaviour change theories to evaluate the impact of interventions on travel behaviour towards more sustainable mobility. In this context, the **Theory of Planned Behaviour**[6] is by far the most applied behaviour change theory. Especially the cognitive approach of this theory might be especially suitable for the transport sector because it assumes that experiment participants did not ask for help to change behaviour and their intention to change behaviour is not formed yet (Hardeman et al., 2002), which is normally the case in mobility related experiments.

In a second part, Hoppe et al. (2017b) identified six categories of interventions, which apply behaviour change theories to change travel behaviour. These are: 1) providing information, 2) fostering self-experience of travel alternatives, 3) planning travel behaviour, 4) rewarding travel alternative, 5) dissuading negative travel behaviour and 6) improving conditions (e.g. service, fee, infrastructure) of the travel alternatives. Furthermore, Hoppe et al. (2017b) found that pull measures, i.e. interventions that aim at dissuading from a negative travel behaviour, have lower acceptability than push measures, i.e. interventions that aim to convince about a new

[6] According to Ajzen (1985), behaviour depends on intention, which is determined by three constructs: attitude toward the behaviour, subjective norms and perceived behavioural control. These constructs are affected by corresponding beliefs concerning the three constructs.

travel behaviour. However, most of the studies reviewed did not analyse the impact of implemented push measures, but just a subjective assessment of experiment participants regarding a hypothetical implementation. Their opinion therefore might become more favourable after the implementation of the coercive measure and after the positive effects. Nevertheless, it is recommended to combine both push and pull measures to increase the success of supporting individuals towards establishing new travel behaviour (Eriksson et al., 2008).

To conclude, Hoppe et al. (2017b) identified the following seven issues that are especially relevant to change travel behaviour:

1. to make individuals question their mobility habits
2. to offer attractive goals
3. to maximise motivation and reduce effort of the positive travel behaviour (or vice versa)
4. to enhance personal aptitudes and positive attitudes
5. to strength the link of the targeted behaviour to related social groups
6. to show the consequences of behaviour
7. to provide a satisfactory experience with the positive travel alternative

In the field of mobility behaviour, our desk research revealed that there has been some research carried out on behaviour change theories in relation to mobility. However, broad studies on the impact of implemented push measures on mobility behaviour are still missing. Furthermore, it is still difficult to predict, how technological developments (e.g. virtual reality, etc.) and resulting new forms of leisure activities will affect future mobility behaviour.

3.8.3 Mobility paradigms

According to Pillkahn (2007), a paradigm can be understood as a prevailing thinking pattern, which is widely accepted but does not necessarily have to be correct. Kuhn (1996) argues, that Paradigms are accepted until phenomena occur that are no longer compatible with the previously valid doctrine. A paradigm shift includes therefore a radical qualitative change of prevailing thinking patterns, after which the original way of thinking is replaced by a radically different one (Pillkahn, 2007). Based on these assumptions, there are several predominant paradigms in the field of mobility, which are gradually coming under pressure due to emerging new mobility products and services, technological developments and a fundamental new way of thinking future mobility.

One of the most prominent topics in the field of mobility paradigms is a changing awareness to cars and mobility in general, shifting towards **sharing instead of owning** means of transportation. In mature economies societies, vehicle ownership and vehicle use are since a couple of years in decline, especially among younger generations (Moraglio et al., 2014). Tightening CO_2 regulations on a global scale have further forced the industry to develop innovative vehicle technologies and new mobility products and services (Cornet et al., 2012). These developments are expected to significantly reduce car ownership by 2030, but private transportation will probably continue to increase. Congested roads will therefore not necessarily be a thing of the past simply by substituting conventional vehicles with autonomous cars and providing sharing systems and highly developed networking solutions (Stürmer, 2017). For a transformation towards sustainability (including less traffic and the associated positive impacts on the system), it will be crucial that the value of a car will be defined in its use and no longer in its possession (Burfeind, 2017). The question arises, however, whether

the broad public will be willing to share its car with foreign people or not since the advantage of cars over public transport services is that you can move in the masses, but isolated from everyone else and physically separated from the others (Rötzer, 2017). The accrued habit and behaviour of private ownership of cars and low occupancy needs therefore to be overcome to reduce the overall number of cars. Only the technological leap towards autonomous vehicles and sharing systems will not be sufficient for solving the problem of too many vehicles on the roads (Roberts, 2017). It takes a change in the behavioural patterns on a large-scale, to transform the current transport system towards sustainability. In this context, younger generations offer a great opportunity since they are seen as more open to changes and having a great potential to function as driver in this desired transformation process (Schäfer, 2017c).

Another expected paradigm shift (that is also related to the previously described shift from sharing to owning) will probably occur in the individual mobility preferences, shifting **from a single mode of transport to multimodal options**. In the centre of this shift will be smart cities, promoting the use of integrated mobility networks offering a greater choice of (multimodal) mobility solutions and information services, particularly in the context of growing issues of congestion and pollution exacerbated by rapid urbanisation and private motorisation (Vidyasekar, 2017). Already today, it can be observed how social and demographic changes, urbanisation and urban sprawl are transforming the way people are on the move and interact with transportation. In several megacities, the proportion of mass transit exceeds nowadays that of private transportation due to its well-developed infrastructure networks that makes public transport quicker, cheaper and more comfortable. For example, in London, just 34% of trips are made by private car and in Germany, applications for driving licenses amongst 16-29 year olds over the last decade have declined by 14%. These developments stand for the shift in people's attitude towards public and collective modes of transport, with greater acceptance of these options than ever before (Hitachi Ltd., 2016). Finally, budget constraints and new travel attitudes are expected to lead to new mobility behaviours, forcing the industry to implement new partnerships, joint ventures and other forms of collaboration to match those changing demand patterns with corresponding multimodal options (Moraglio et al., 2014).

In the field of mobility paradigms, a potential willingness for a shift towards multimodal travel options is currently visible. However, there is still a big lack in the value definition of a car, where car ownership still dominates over its use. Furthermore, paradigms of growth (e.g. growth equals prosperity) must be questioned against the background of a system transformation towards sustainability – in mobility as well! However, this topic is still being neglected in today's research activities.

3.8.4 Outlook

In the field of **mobility behaviour**, our desk research revealed that future mobility demand will be strongly influenced by societal trends, technological developments and the resulting new options for leisure activities. Especially the megatrend digitalization will probably open up many far-reaching new possibilities that could also lead to a restructuring of recreational space as we know it up to now (e.g. through virtual reality). However, as the data on expected future travel activity have shown, a continuous increase in leisure and travel traffic must also be expected. This will have far-reaching consequences for the environment, especially since large shares of this growth will be attributable to air traffic. In this context, there are several approaches in research, which apply behavioural theories in relation to mobility. Nevertheless, there are still no detailed studies focusing on the push factors and their impact on mobility

behaviour in a real-life setting. Such research would, however, be an imperative condition for better understanding the expected growth in mobility demand and for steering it in a more sustainable direction (with appropriate measures).

In the field of **mobility paradigms**, our desk research pointed out that two major currents are currently prevailing: *1) a shift towards sharing of means of transportation instead of owning* and *2) a shift from a single mode of transport to multimodal options*. Both of these paradigm shifts could have far-reaching consequences for the mobility system, especially from a sustainability perspective. Nevertheless, future developments in this field of research are currently difficult to predict, especially since it is still unclear what effects technological innovations such as autonomous driving for example will have on the currently prevailing paradigms (e.g. domination of ownership of cars over their use). It could therefore be desirable to strive for a more sufficiency thinking in which the population will limit in its decisions increasingly to what is necessary.

4 Expert's assessment on evolutionary developments in the transport system

According to our initial desk research about trends and developments in the transport system, various innovative technologies are currently emerging, having the ability to influence significantly existing structures in the transport system. In order to characterize these structural changes and to refine our sketch of the future transport system, expert interviews were conducted about future trends and developments within the transport sector. This formed the basis to create in a next step hypotheses about the evolutionary development of the transport system, which were finally verified in a broad online survey with transport related representatives from the academia, industry and policy sector. The survey focused on innovations in transport technologies and their impact on the transport system, the changing transport market, the sustainability of the transport system and the role of the policy with regard to emerging technologies and sustainability.

4.1 Characteristics of the sample

The results of the online survey were analysed across all categories of actors together. To get an overview of which category the participants belong to, participants of the survey were asked in an open question to allocate their sector affiliation. For a better overview, the information provided by the survey participants was aggregated in a further step into the three main categories (1) Academia, (2) Industry and (3) Policy.

Results show that the stakeholder-category "Academia" is the most represented one with 50% of the 106 completed questionnaires. With 37% of all survey participants, the category "Industry" represents the second strongest stakeholder category and 13% can be assigned to the category "Policy".

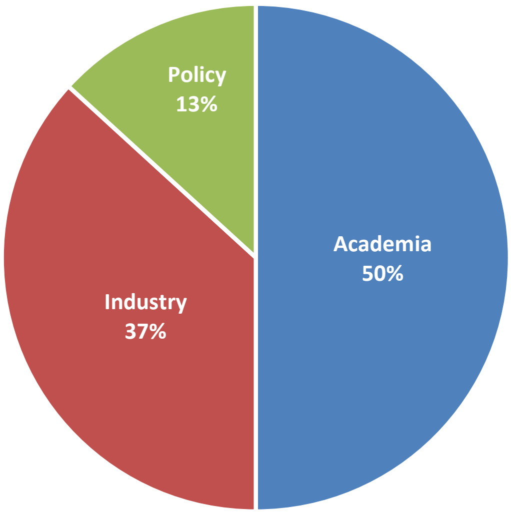

Figure 27: Sector affiliation of the survey participants (Data: ZHAW / n=106)

Besides the sector affiliation, the origin of the survey participants was of particular interest. To facilitate the analysis, the major structure of Europe, as recommended by the Standing Committee on Geographical Names (StAGN) of the Federal Office of Cartography and Geodesy of Germany, was applied.

Results show that the majority of the survey participants (41.5%) come from Central Europe. About one third (34%) of the survey participants come from Southeastern Europe and further 19.8% from Western Europe. Significantly fewer survey participants were mobilised in Southern and Northern Europe with 2.8% respectively 1.9% of the total of 106 survey participants.

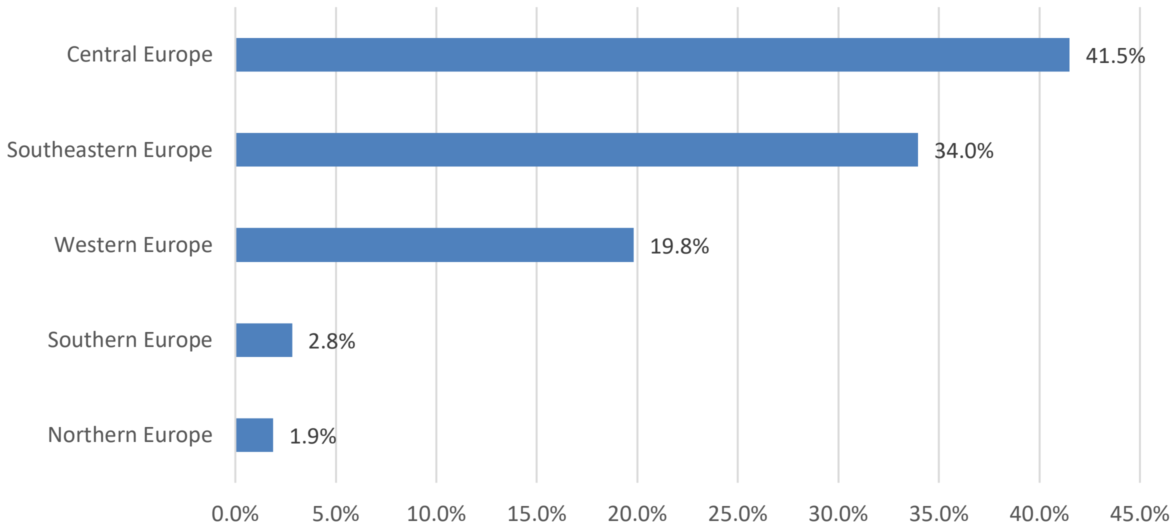

Figure 28: Origin of the survey participants according to the major structure of Europe as recommended by the Standing Committee on Geographical Names (StAGN) (Data: ZHAW / n=106)

4.2 Innovation in Transport Technologies

As shown in the initial desk research about trends and developments in the transport system, innovations in transport technologies are of particular interest in the investigation of systemic transformation processes. Autonomous driving systems in particular offer a huge potential to disrupt the current structures within the transport system. For this reason, participants of the survey were asked to give their personal opinion regarding various forward-looking scenarios related to autonomous driving systems and UAV technology (e.g. drones).

4.2.1 Applications of autonomous driving systems

Regarding the deployment of autonomous driving systems in the future, the survey participants assessed, in what cases or applications they estimate the technology first to be implemented on a large scale.

Results show that there is no clear assessment, whether autonomous systems will prevail first in passenger or in cargo/freight transportation. Around a quarter of the participants (23.6%) estimate that autonomous vehicle systems are very likely to develop first in cargo/freight transportation. Another 22.6% estimate the same development as rather likely. On the other hand, 13.2% of the survey participants estimate a deployment first in passenger transportation as very likely respectively 18.9% as rather likely. The remaining 21.7% of the 106 survey participants are indifferent to this question. This results in a slight but not significant tendency in the direction of a deployment of autonomous vehicle systems first in cargo/freight transportation.

A similar picture emerges in the assessment of an implementation of autonomous vehicle systems first in urban or rural areas. Around a third of the survey participants (30.2%) estimate that autonomous vehicle systems are very likely to develop first in urban areas. Further 23.6% of the survey participants estimate a deployment in urban areas as rather likely. On the other hand, 12.3% of the survey participants estimate a deployment first in rural areas as very likely respectively 20.8% as rather likely. The remaining 13.2% of the 106 survey participants are indifferent to this question. This results again in a slight tendency in the direction of a deployment of autonomous vehicle systems first in urban areas.

Ultimately, the survey participants assessed, whether autonomous vehicle systems will be in use rather in private ownership or as mobility service of a transport provider. According to the survey participants, there is a clear tendency visible that autonomous vehicle systems will be in use rather as mobility service than in private ownership. Around a quarter of the survey participants (24.5%) assess this development as very likely, another 39.6% as rather likely. On the other hand, only 9.4% of the survey participants assess autonomous vehicle systems in private ownership as a very likely scenario in the future another 16% which consider this as rather likely. The remaining 10.4% of the 106 survey participants are indifferent to this question.

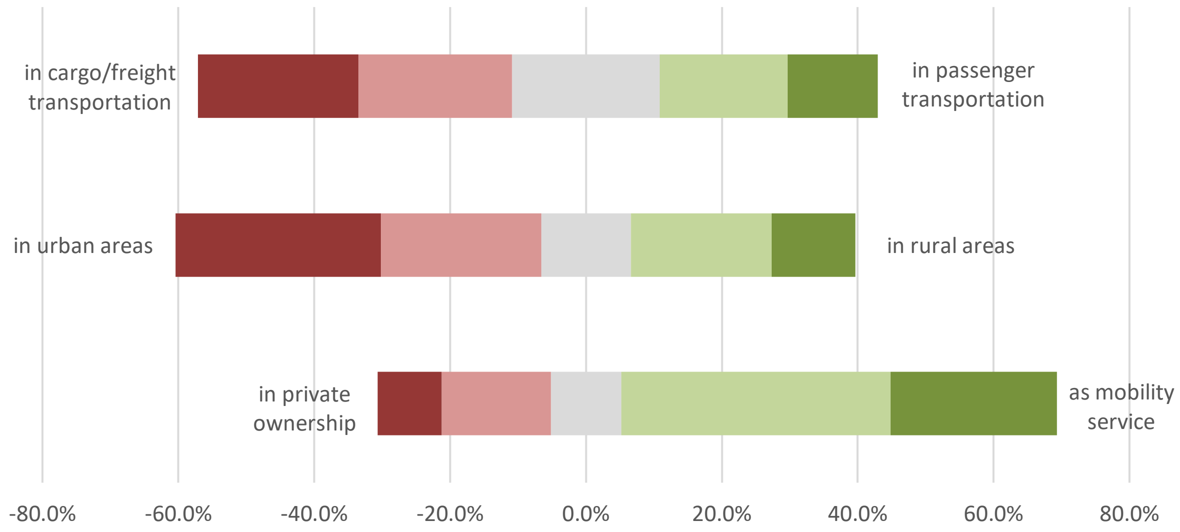

Figure 29: Participants' assessment on the deployment of autonomous vehicle systems in different cases and applications (Data: ZHAW / n=106)

4.2.2 Impacts of autonomous driving systems

Regarding the impacts of autonomous driving systems, the survey participants assessed in a first step, whether the overall impacts of autonomous driving systems are expected to be rather positive (e.g. due to more efficient traffic flows) or rather negative (e.g. due to an overall increase in traffic volume) on the future transport system.

Results show, that there is a clear tendency that autonomous vehicle systems are expected to have rather positive than negative impacts on the transport system in the future. However, a large proportion of the survey participants (41.5%) expect those impacts to be rather moderate, compared to 18.9% of the survey participants who are clearly convinced that the impacts of autonomous vehicle systems on the transport system will be positive. On the other hand, 7.5% of the survey participants estimate it as very likely that the overall impacts of autonomous

driving systems on the transport system will be negative, respectively 19.8% as rather likely. The remaining 12.3% of the 106 survey participants are indifferent to this question.

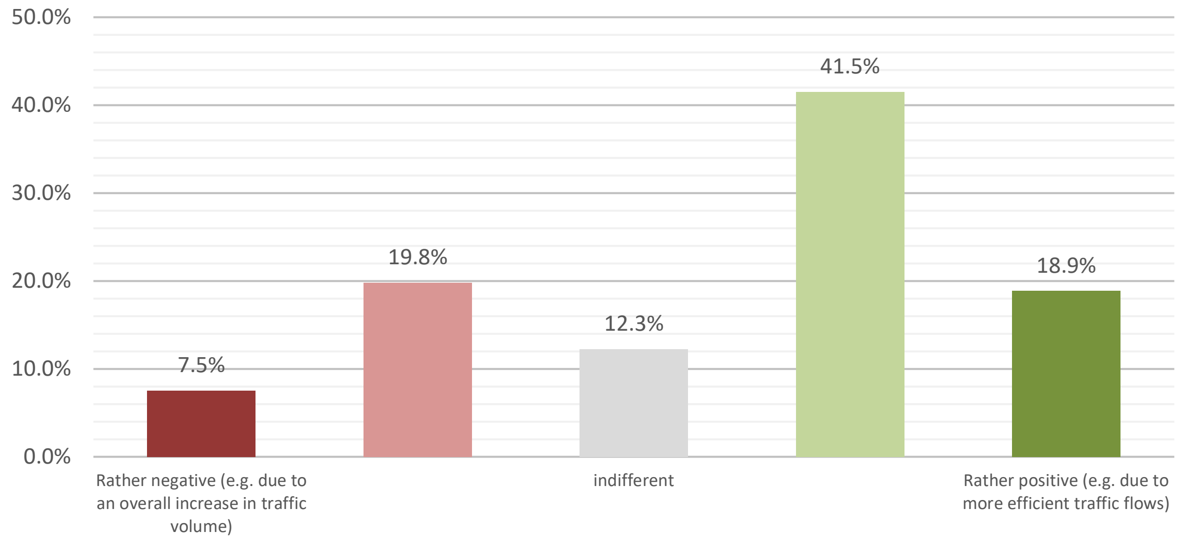

Figure 30: Participants' assessment on the overall impact of autonomous vehicle systems on the future transport system (Data: ZHAW / n=106)

In a second step, the survey participants assessed, whether autonomous driving systems are expected to have a big impact on the spatial development (e.g. decentralised development with increasing traffic flows from rural areas) or rather a low impact, since the technology will be mainly used in a centralised setting (e.g. in urban areas).

Results show that there is no clear tendency visible, whether autonomous driving systems will have big or low impacts on the future spatial development. 14.2% of the survey participants expect low impacts on the spatial development, another 24.5% assess the same effects as rather likely. On the other hand, 13.2% of the survey participants expect autonomous driving systems to have a big impact on the spatial development in the future. Another 28.3% assess the same development as rather likely. The remaining 19.8% of the survey participants are indifferent to this question. This results in a very balanced assessment what impacts autonomous driving systems will have on the spatial development in the future with no clear tendency visible at the moment.

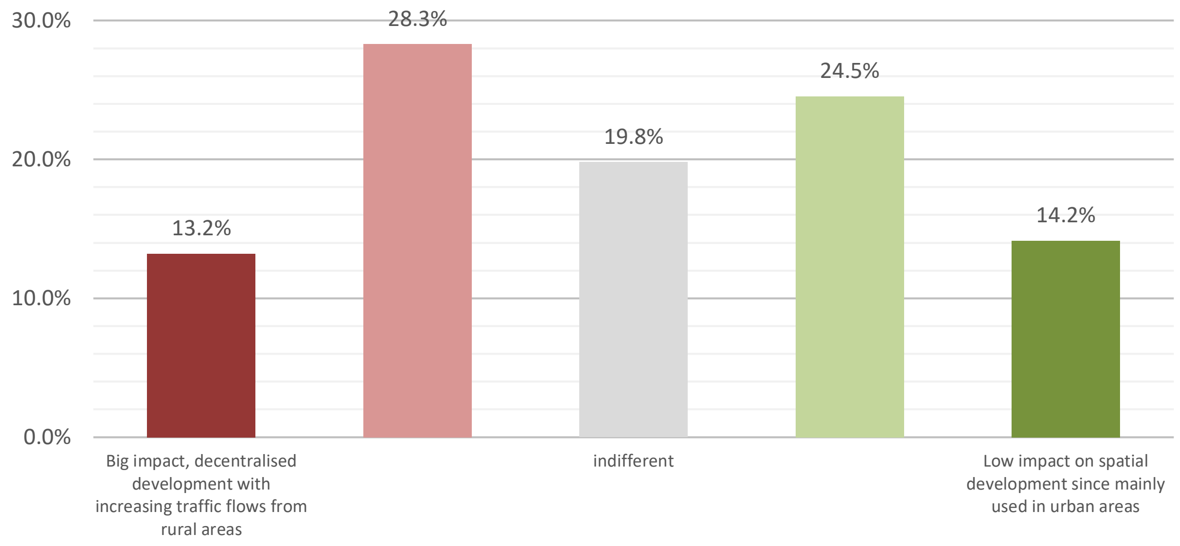

Figure 31: Participants' assessment on the impact of autonomous driving systems on the spatial development (Data: ZHAW / n=106)

4.2.3 UAV technologies in the transport system

Regarding the deployment of UAV technologies in the transport system, the survey participants assessed three different scenarios according to their probability of occurrence in the future.

Scenario 1: "Drones will be used exclusively in cargo/freight transportation (e.g. due to safety constraints in passenger transportation)"

Results show that there is a clear tendency for respondents to rate this scenario as very likely for the future. Around 16% of the participants estimate it as very likely, that drones will be used exclusively in cargo/freight transportation. Another 41.5% estimate the same development as rather likely. On the other hand, 9.4% of the survey participants estimate an exclusive use of drones in cargo/freight transportation as very unlikely respectively 19.8% as rather unlikely. The remaining 13.2% of the 106 survey participants are indifferent to this question.

Scenario 2: "Drones will play a substantial role in passenger transportation and thus significantly reduce congestion on roads"

Results show that there is a clear tendency for respondents to rate this scenario as very unlikely for the future. Around a quarter of the participants (25.5%) estimate it as very unlikely, that drones will play a substantial role in passenger transportation in the future. Another 38.7% estimate the same development as rather unlikely. On the other hand, only 2.8% of the survey participants see the use of drones in passenger transportation as very likely respectively 18.9% as rather likely. The remaining 14.2% of the 106 survey participants are indifferent to this question.

Scenario 3: "Drones will not prevail in either passenger of freight transportation and thus remain a niche technology"

Results show that there is no clear tendency visible whether drones will remain a niche technology in the transport system or will be able to assert on a large scale in the future. In each case, 23.6% of the survey participants estimate this scenario as very unlikely respectively

rather unlikely for the future. On the other hand, 10.4% of the survey participants estimate it as very likely that drones will remain a niche technology both for passenger and cargo/freight transportation. Another 20.8% estimate this scenario as rather likely. The remaining 21.7% of the 106 survey participants are indifferent to this question. This results in a slight but not significant tendency that drone technology will probably have a certain potential to overcome its niche existence in the future.

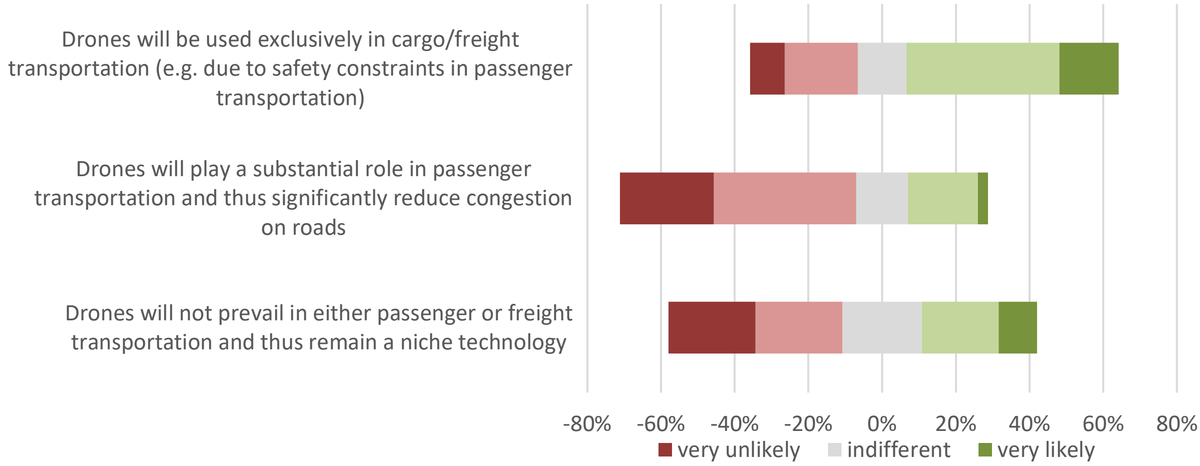

Figure 32: Participants' assessment on three development scenarios for the drone technology (Data: ZHAW / n=106)

4.3 Future changes in the transport market

The initial desk research revealed that newly emerging technologies form the basis for the development of new business models. This could lead to the emergence of new players within the transport market and radically change the competitor's landscape in the future. However, some of these emerging trends and developments also call into question prevailing and established mobility paradigms, which makes it rather difficult to predict future developments within this field of research. For this reason, participants of the survey were asked to give their personal opinion regarding various forward-looking development scenarios related to future changes within the transport market.

4.3.1 Vehicle ownership

Regarding the future development of private car ownership, the survey participants assessed, whether private car ownership will decrease due to newly emerging mobility services (e.g. ride on-demand) or if private car ownership will remain the dominant paradigm in the future.

Results show that there is a significant tendency, that survey participants expect private car ownership to decrease in the future due to newly emerging mobility products and services. With 31.1%, around a third of the survey participants assess this development as rather likely while another 23.6% are clearly convinced that the car in private ownership may no longer prevail in the future. On the other hand, 15.1% of the survey participants estimate private car ownership to remain the dominant paradigm in the future, another 21.7% consider this as rather likely. The remaining 8.5% of the 106 survey participants are indifferent to this question.

These results coincide with the previously described assessment of the survey participants on the impacts of autonomous vehicle systems on the transport system, where a significant tendency is visible that autonomous vehicle systems will be in use rather as mobility service than in private ownership.

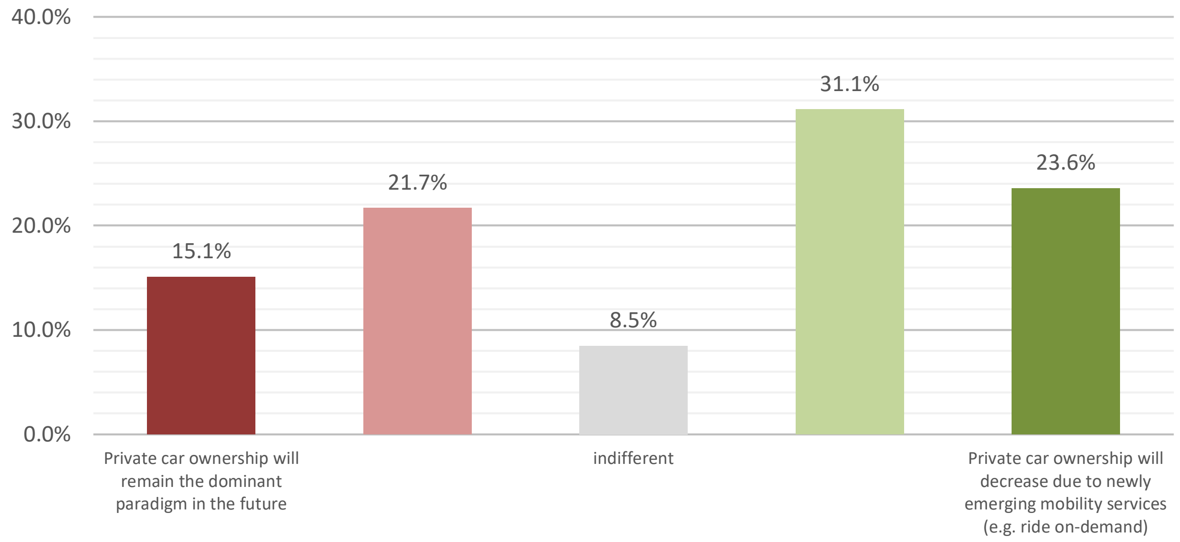

Figure 33: Participants' assessment on the development of private car ownership in the future with regard to the increasing automation of vehicles (Data: ZHAW / n=106)

4.3.2 New business models

Regarding newly emerging business models, the survey participants assessed, whether new players will enter the transport market and change the competitor's landscape or if traditional mobility providers will maintain their position within the market.

Results show that there is a significant tendency that the competitor's landscape will change in the future according to the assessment of the survey participants. 45.3% of the participants estimate that new players will enter the market and challenge traditional mobility providers. Another 36.8% estimate the same development as rather likely. On the other hand, only 1.9% of the survey participants estimate a maintaining leading position of traditional mobility providers as very likely respectively 12.3% as rather likely. The remaining 3.8% of the 106 survey participants are indifferent to this question. These results coincide again with the previously described assessment of the survey participants on the impacts of autonomous vehicle systems on the transport system, where a significant tendency is visible that autonomous vehicle systems will be in use rather as mobility service than in private ownership.

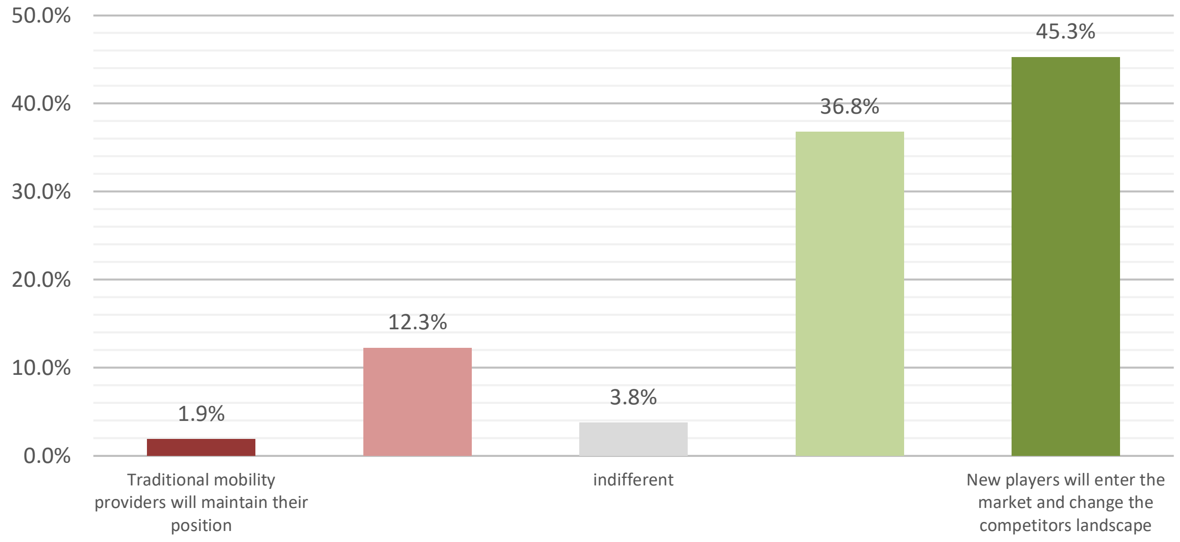

Figure 34: Participants' assessment on the future development of the transport market with regard to newly emerging business-models (Data: ZHAW / n=106)

4.3.3 Mobility sharing

Regarding the future of mobility sharing, the survey participants assessed, whether sharing concepts may have a high potential in the future with lots of people switching to shared mobility rides or a rather low potential, due to a missing willingness to share a car with other people.

Results show, that survey participants see a high potential for sharing concepts in the future. However, around a third of the survey participants (33%) estimate this scenario only as rather likely while 20.8% consider this as highly probable. On the other hand, only 4.7% of the survey participants see a low potential respectively willingness of people for shared mobility rides in the future while another 19.8% consider this development as rather likely. The remaining 20.8% of the 106 survey participants are indifferent to this question and 0.9% have evaded the answer.

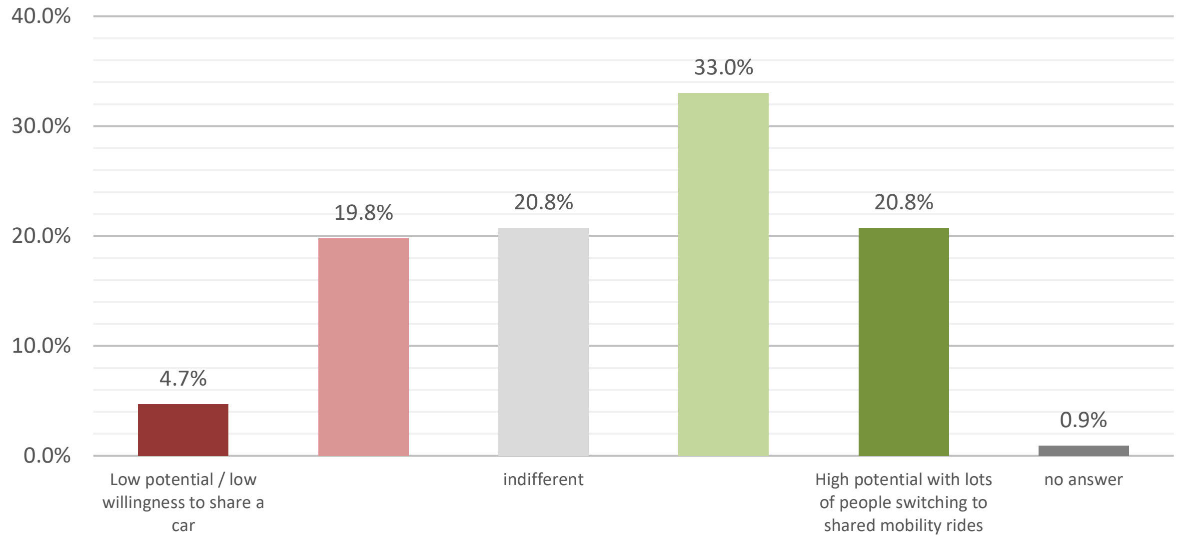

Figure 35: Participants' assessment on the future of mobility sharing (Data: ZHAW / n=106)

4.3.4 Revolutionary transport concepts

Regarding the integration of revolutionary transport concepts such as the *Hyperloop One* into the transport system, the survey participants assessed, whether such concepts may be integrated as an essential part of the transport system in all ranges of distance or only on heavily frequented routes in the medium-distance segment.

Results show, that survey participants do not see a high potential for an integration of such concepts on a large-scale into the transport system. Only 9.4% estimate this scenario as highly probable while 21.7% consider this as rather likely. On the other hand, around a third of the survey participants (30.2%) estimate an integration of the *Hyperloop One* only on heavily frequented routes while another 18.9% consider this development as rather likely. The remaining 19.8% of the 106 survey participants are indifferent to this question.

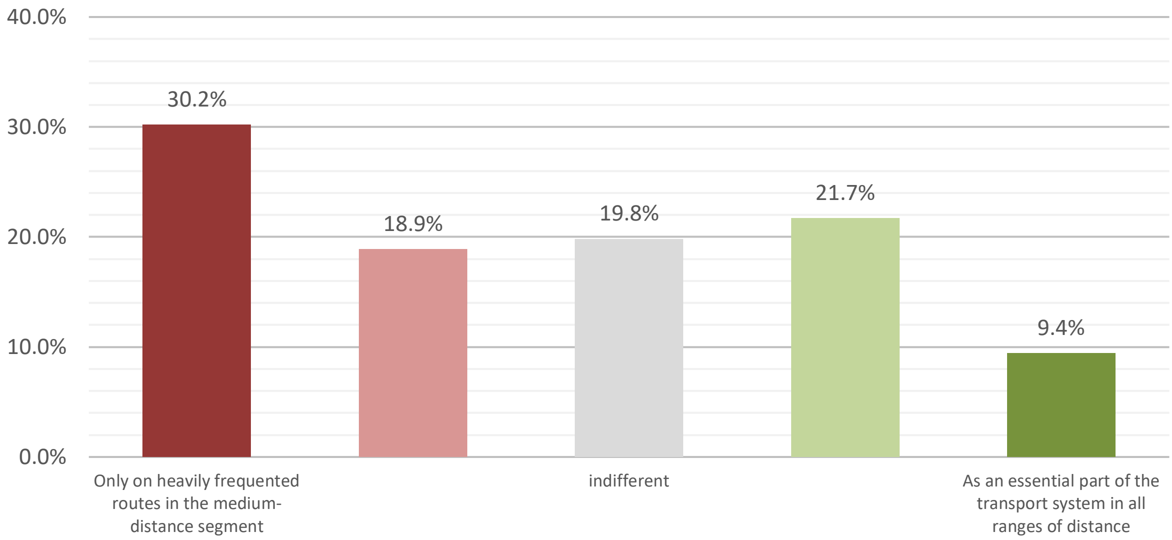

Figure 36: Participants' assessment on the integration of revolutionary transport concepts such as the *Hyperloop One* into the transport system (Data: ZHAW / n=106)

4.4 Impacts on the sustainability of the transport system

Technological innovations offer a huge potential for supporting a sustainability transformation of the transport system in the future. As shown in our initial desk research, several trends and developments are currently emerging, especially in new drivetrain and material technologies. However, it is controversially discussed, whether all of these innovations will have the expected positive impact on the transport system as widely anticipated. For this reason, participants of the survey were asked to give their personal opinion regarding the impact of electric drivetrains and lightweight construction on the sustainability of the transport system.

4.4.1 Electric drivetrains

Regarding the impact of electric drivetrains on the sustainability of the transport system, the survey participants assessed, whether these impacts can be expected to be rather positive (e.g. due to lower emissions from internal combustion engines) or rather negative (e.g. due to the energy-intensive battery production).

Results show, that there is a significant tendency, that survey participants assess electric drivetrains to have a positive impact on the sustainability of the transport system. 37.7% of the

survey participants expect from electric drivetrains positive impacts on the transport system. Another 34.9% would rather expect these advantages. On the other hand, only 1.9% of the survey participants expect rather negative impacts resulting from a widespread electrification of drivetrains while another 5.7% consider this as rather likely. The remaining 19.8% of the 106 survey participants are indifferent to this question.

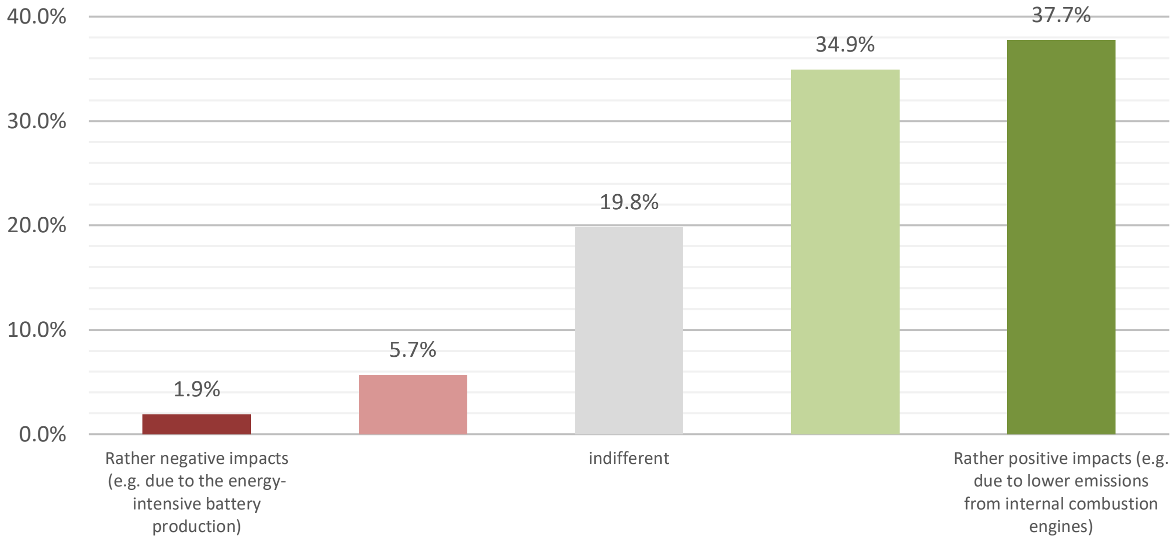

Figure 37: Participants' assessment on the impact of electric drivetrains on the sustainability of the transport system (Data: ZHAW / n=106)

4.4.2 Lightweight construction

Regarding the impact of lightweight construction on the sustainability of the transport system, the survey participants assessed, whether lightweight construction can be expected to be relevant (e.g. due to various synergies) or generally not relevant for the sustainability within the transport system.

Results show, that there is a significant tendency, that lightweight construction could have a strong impact on the sustainability of the transport system in the future. However, the majority of the survey participants is not completely sure about this. That is why 47.2% of the survey participants assess lightweight construction only a rather positive impact while 24.5% assess this technological innovation as clearly relevant for a sustainable transport system. On the other hand, only 2.8% assess lightweight construction as not relevant for the transport system while another 6.6% consider this as rather likely. The remaining 16% of the 106 survey participants are indifferent to this question.

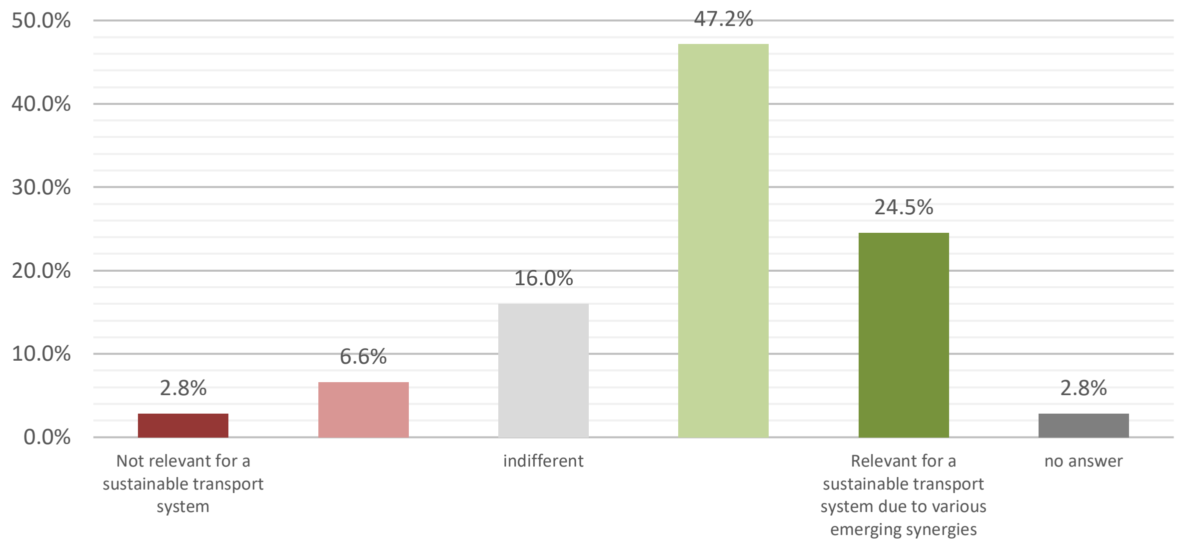

Figure 38: Participants' assessment on the impact of lightweight construction on the sustainability of the transport system (Data: ZHAW / n=106)

4.5 Role of the policy

The policy sets the regulatory framework conditions in which trends or innovations may unfold in the future. As shown in our initial desk research, various trends and developments are currently emerging on a global and national level, to meet the challenges posed by the transforming transport system. However, it is not quite clear whether these actions are strong enough, to meet the targets set in the future. For this reason, participants of the survey were asked to give their personal opinion regarding the current attitude of policy with regard to newly emerging technologies as well as the desired influence of the policy on the transport system to reach more sustainability.

4.5.1 Attitude to newly emerging technologies

Regarding the policies attitude to newly emerging transport technologies, the survey participants assessed, whether policy is aware of the technological development or lagging behind with correspondingly obsolete regulatory framework conditions.

Results show that there is a clear tendency that policy is currently lagging behind and the corresponding framework conditions are not up to date. Around 37.7% of the survey participants assess a clearly missing awareness of the policy with regard to newly emerging technologies. Another 21.7% would rather estimate this circumstance. On the other hand, only 3.8% adjudge the policy sufficient awareness of the technological development and appropriately adapted framework conditions. Another fifth of the survey participants (20.8%) see the regulatory framework conditions as rather well adapted. Another 13.2% of the 106 survey participants are indifferent to this question and 2.8% have evaded the answer.

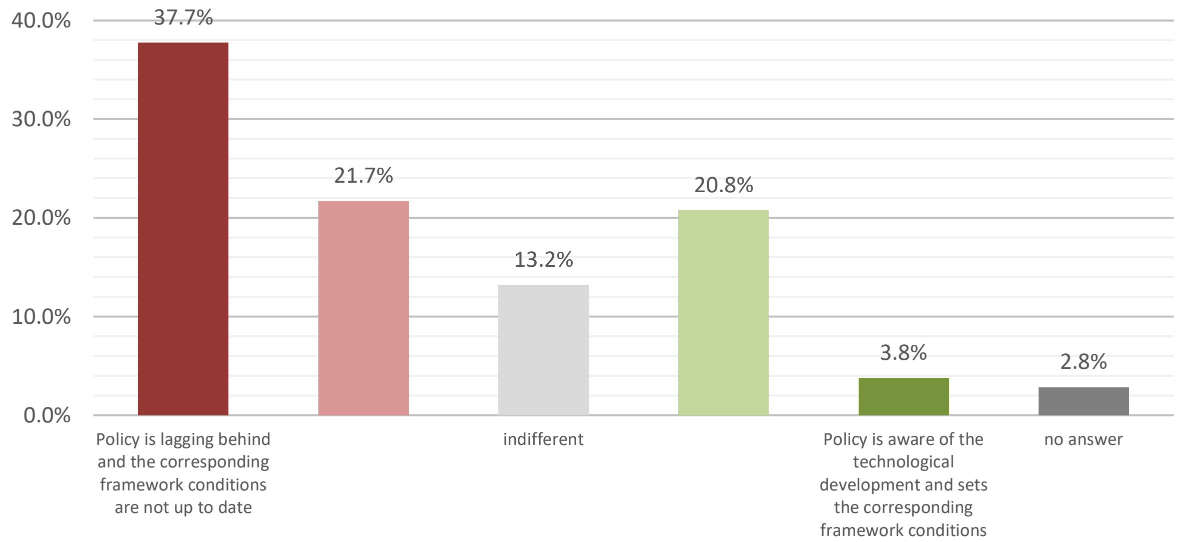

Figure 39: Participants' assessment on the attitude of the policy against innovations (Data: ZHAW / n=106)

4.5.2 Influence for a sustainability transformation of the transport system

Regarding the desired influence of the policy for a sustainability transformation of the transport system, the survey participants assessed, whether the policy should internalise negative external effects or rather guarantee a free market economy, to let the system regulate itself.

Results show, that there is a significant tendency towards the internalisation of negative external effects in order to achieve sustainability in transport. 39.6% of the survey participants state, that the policy should intensify its activities to internalise negative external effects resulting from transport. Another third of the participants (31.1%) would rather welcome this development. On the other hand, only 9.4% are firmly convinced that free market economy will be able to cope with the loss of sustainability in the transport sector in the future. Another 12.3% would rather share that view. The remaining 6.6% of the 106 survey participants are indifferent to this question and 0.9% have evaded the answer.

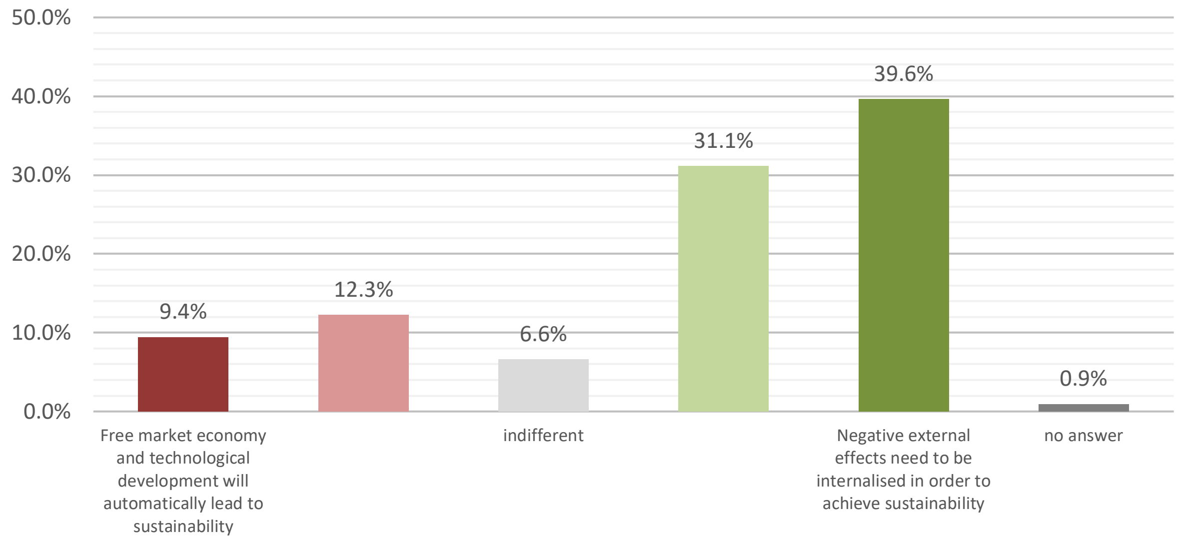

Figure 40: Participants' assessment on the desired influence of the policy on the transport (Data: ZHAW / n=106)

4.6 Conclusion

Results from the online survey show, that autonomous vehicle systems are expected to have rather positive than negative impacts on the transport system in the future, for instance due to more efficient traffic flows and better capacity utilization. However, large-scale implementations of autonomous driving systems are expected to be implemented first in cargo/freight than in passenger transportation and probably also in urban rather than in rural areas. With regard to passenger transportation, there is a strong tendency visible, that autonomous vehicle systems will be in use rather as mobility service than in private ownership. However, it remains unclear what effects autonomous driving systems will have on the spatial development and whether they will reinforce a decentralised spatial development in the future or not. In the field of UAV technology, it is expected that drones will be used more likely in cargo/freight transportation than in passenger transportation in the future.

Regarding future changes in the transport market, there is a significant tendency visible, that private car ownership will decrease in the future due to newly emerging mobility products and services. This assessment also coincides with the experts' expectation that the competitor’s landscape in the transport market will change in the future because of new players entering the market and challenging traditional mobility providers. In addition, the sharing of mobility rides is expected to have a high potential in the future whereas revolutionary transport concepts such as the *Hyperloop One* are not expected for being implemented on a large-scale. An integration into the transport system is therefore rather likely on heavily frequented routes in the medium-distance segment.

Regarding the impact of technological innovations on the sustainability of the transport system, there is a strong tendency visible that the increasing electrification of drivetrains could have positive impacts on the sustainability. However, the negative impacts resulting from the battery production are generally seen as less relevant within this context. In addition, there is a significant tendency visible, that lightweight construction could have a positive impact on the sustainability, for instance due to synergies with electric mobility.

Ultimately, survey results show that - with regard to newly emerging technologies - the policy is lagging behind and the regulatory framework conditions are not up to date at the moment. In addition, internalisation of negative external effects are expected to be crucial in the future, in order to achieve sustainability within transport (in contrast to a free market economy, which is expected to fail in this context).

5 Sketch of the future transport system

Summarizing results of the trend analysis on future technologies in transport, relevant social and economic developments, policy strategies as well as the perspectives of experts on the future of mobility and their assessment of main important innovations, the future transport system will be fundamentally different from today.

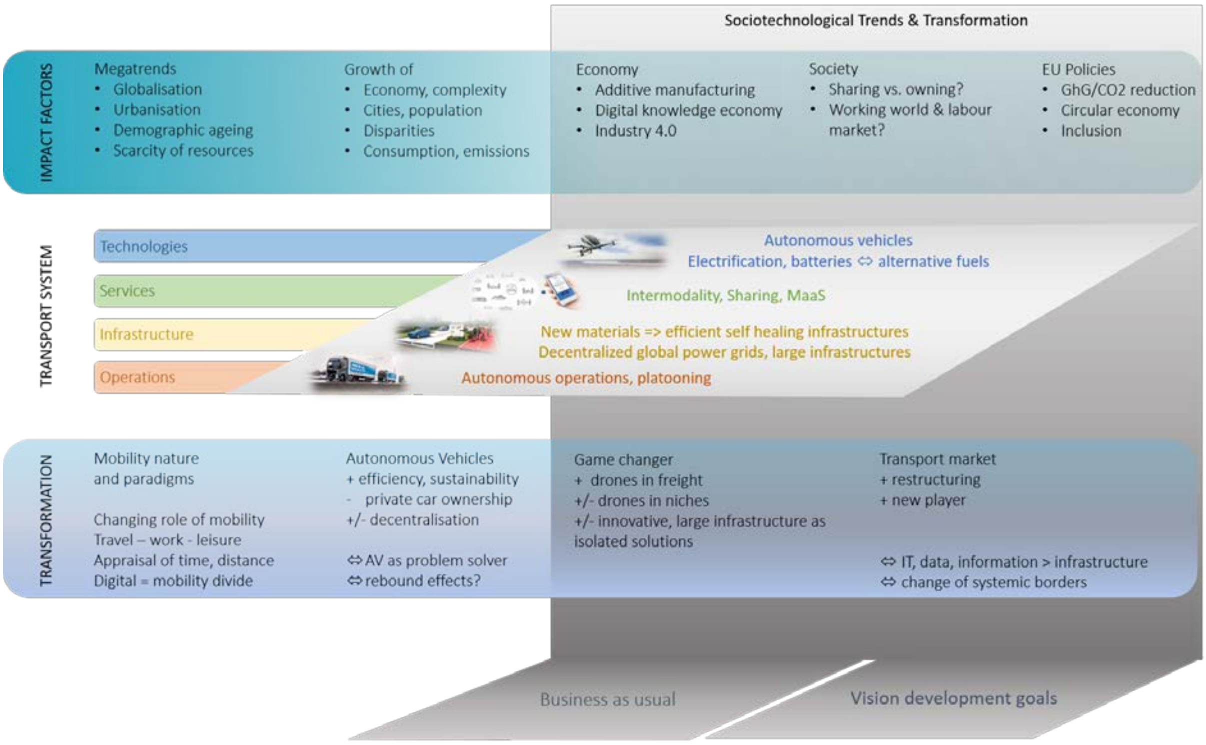

Figure 41: Sketch of the future transport system (Source: ZHAW)

On the level of impact factors for transport, related to megatrends of globalisation, urbanisation, demographic ageing and related scarcity of resources especially the main tendency of future development is about growth, in different respect. Growth of population and the global economy will increase resource consumption and related emissions. As developments will not be evenly distributed, social, income and economic disparities as well as the shift of population towards cities are likely to be accentuated.

Besides the general overall trends there is a structural change going on in the economy, related to digitalization. This change can be considered to be as fundamental as the industrialisation transforming production, industrial sectors and retail as well as organisation of the economy. All these trends will be reflected in social developments the labour market and working world will change, besides developments of lifestyle and towards a sharing (or still ownership-based) society.

Effects of all these influencing factors on mobility demand and supply are still difficult to estimate – even if it is likely that an increase of transport will result due to growth. In the past increasing efficiency lead to rebound effects. If gains in production and transport in efficiency based on optimized, technologically supported organization of the systems will lead to decreasing resource consumption and emissions will depend on political strategies and

measures. Thus, efforts in emission reduction and towards a circular economy from the political side will be crucial and serve as game changer, determining the effects of innovation.

Besides demand and supply related effects on the transport system recently many technological innovations are about to be developed and implemented showing a high potential to serve as game changers. Above all, autonomous driving enabling technologies are expected to dominate the future transport system. Not only cars, but also airplanes, trucks and buses, drones and operations will work increasingly autonomous. Another fundamental change will be the increasing electrification; batteries and vehicles such as electric- cars, buses, trucks, boats and drones are being developed and will shape the future transport system – these developments might be accompanied by the supply of alternative electric energies or alternative fuels running in parallel. IT-based mobility solutions will provide more intermodality, enabling shared mobility and MaaS services in general. Developments within this field are related to autonomous driving operating systems. Game changer such as innovative, large infrastructures are likely to be implemented. For many of the innovations in transport, basic technological developments are crucial. One of the main fields is new materials, which could not only support batteries, but also lightweight vehicles, new infrastructures etc. Even if the described technologies will be part of the future mobility system and shape it in a different way compared to today, change is quite unclear as effects on mobility demand are depending on many aspects. Prices for new solutions, users' and decision makers' acceptance, usability, resilience and safety of technologies, regulations, investment and cooperation will influence to which extend the described innovations will be integrated within the transport system. But also interaction of the manifold developments of the different areas will shape the future transport system. Convergence of different technologies and the impact of such fundamental changes are difficult to estimate.

In the end, the implementation of new solutions will be based on decisions of decision makers involved in development, operation, policy and planning of the transport system. Thus, expert opinions serve as a valuable source to create a picture of the future transport system, as not only these experts base their opinion on profound knowledge but will also base their decisions on their opinion. Based on an expert survey, some technologies will rather stay in a niche of the transport system, like drones, which are expected to be used rather for freight then for passenger transport or innovative large infrastructures. To the opposite, autonomous vehicles are expected to fundamentally change the transport system, even if it is less clear in which kind – shared or private owned – they might be integrated in the system. A majority of experts' opinion reflect strong believe in positive effects of technological development, e.g. they see positive effects of autonomous vehicles in terms of efficiency and sustainability as well as a decrease in private car ownership; similar, electric mobility is linked with increasing sustainability. Related to the upcoming innovations, experts see a process of restructuring on the transport market with new players entering the system. Together with the described technological developments for the future transport system, information technology, data and information would gain importance, while traditional infrastructure would relatively decrease in importance – still serving as a basis.

A basic aspect and driving force for the development of the transport system into the future is the mobility paradigm, guiding strategies and decisions on investment, implementation and regulation. The trend analysis and expert survey revealed a strong technology driven mind set shaping the vision of the coming developments and the future transport system in terms of

positive effects (e.g. emissions, resources). A strong believe in technology as problem solver is apparent, although gains in efficiency and innovation have been overcompensated by rebound effects in the past. Especially the convergence of different new technologies as well as their interaction with users and decision makers is unknown, including their potential effects on supply and demand. In this context, also the changing nature of mobility – still considered as travel time or rather used for working, entertainment, social activities and leisure – remains unclear. The same applies for structure of the transport market, new player and range of their services and technologies as well as needs and forms of cooperation. These open questions give a first idea about potential blind spots in today's perspective on what is relevant for the future mobility system and potential gaps in innovation and research.

6 Conclusion

Based on the analysis of trends in technologies and mobility related fields as well as from the expert consultation and online survey as preliminary conclusions concerning future research needs in transport, three main directions can be identified. The three directions differ in terms of uncertainty and impact of their related trends concerning transformation potential for the mobility system as well as the way research would need to be organized, done and subsidised within this fields.

1. **Continuing mobility and transport research**: recently strong research and development activities are going on in several technological fields within or related to transportation. Related to the technological developments – like autonomous and electric mobility, new materials and infrastructures, IT-based organisation and supply etc. – is research dealing with new mobility concepts and solutions, like sharing services and intermodality as well as every combination of technologies and solutions. Future research needs in this direction are mainly towards enabling continuation of R&D towards products ready for the market, implementation and integration into the given mobility system. Even if the focus of this direction is continuation of existing research streams, it includes developments which could serve as game changers in the near future. Thus, room for disruptive developments and risk capital is also necessary here.

2. **Research on socio-technical transformation in mobility**: developments within mobility and transport research take place within a broader system and are interlinked with different factors affecting systems development, supply and demand side. Related to technological developments trends in the economy, society as well as in political frame conditions affect the transport sector and stimulate both research and development needs and activities. Growth of global population and the economies, disparities between countries as well as between cities and rural areas, increasing globalization, related scarcity of resources, climate change and other environmental issues together with global policies set the frame for research trying to address these problems. Research and development in transportation within this context is and has to happen in interaction with these trends, leading to a socio-technical transformation of the mobility system. In this regard, many aspects are still unclear and have to be addressed. Research plays a big role in answering the pending questions of: which are the dynamics between different trends, how could socio-technical development be directed towards sustainability, how can different fields of research be connected to each other and how can they be directed to support political goals of the EU, etc.

3. **Research on disruption**: even if the above described research directions include a potential of disruption, e.g. when it comes to certain technologies related to autonomous mobility, another more fundamental change of the whole mobility system might happen. Due to the yet unknown developments of different technologies and especially their synergies, technological convergence (e.g. like in smartphones) is likely to occur. Potential of these kind of products and services to contribute to solve problems of increasing mobility demand and system complexity might be high – but is difficult to estimate. Thus, this direction of research requires risk capital at the same time proving high, but uncertain, potential.

Due to technological innovation and a variety of trends affecting the mobility system in a fundamental way, all three directions of research include a high level of uncertainty concerning benefits, likely developments and potential for implementation of research and development on new solutions. The complexity of the situation makes it difficult to pre-define all research fields and action plans for research as overview is missing. Thus, within the context of a complex system and high dynamic of innovation with unknown synergies, side effects and interrelations, more than before different perspectives are necessary. Allowing bottom-up problem driven research and development by providing subsidies for research questions identified by researchers themselves would be necessary, for all of the described directions and fields of research.

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Annex 1 - Interview guide for expert interviews

Nr.	Main question	In detail
1	What will be the most important trends regarding a change of the transport system in the future? (→2030)	- Passenger vs. freight
2	What are the most important emerging trends (resp. potential game changers) in TRANSPORT TECHNOLOGIES?	- Passenger vs. freight - Vehicle Technologies (autonomous vehicles, drones, etc.) - Engine Technologies (electric vehicles, fuel cell vehicles, magnetic lev.) - Material Technologies (3D printing, lightweight, aerodynamic, etc.)
3	What are the most important emerging trends (resp. potential game changers) in INFRASTRUCTURE AND OPERATION TECHNOLOGIES?	- Passenger vs. freight - Charging Infrastructure (inductive charging, V2G, etc.) - Transport Infrastructure (e.g. solar roads, self-healing roads, *Hyperloop One*) - ITS-Technologies (V2I/I2V, Truck Platooning, swarm/collective intelligence)
4	What are the most important emerging MOBILITY PRODUCTS AND SERVICES?	- Passenger vs. freight - Sharing systems - MaaS - On-demand systems
5	What trends you see in the field of POLITICS that will affect the transport system in the future?	- Passenger vs. freight - Global policies - EU transport policies - National policies - With regard to sustainability?
6	What ECONOMICAL trends will be of particular relevance for the transport system in the future?	- Passenger vs. freight - Mail-order business - Industry 4.0 → reorganisation - Economic structural change - Sustainable concepts (e.g. Green Economy)

7	What SOCIETAL trends will be of particular relevance for the transport system in the future?	- Passenger vs. freight - Mobility behaviour (Travel- and leisure behaviour) - Changing mobility paradigms (sharing vs. owning & from single to multimodal options)
8	What SPATIAL trends will be of particular relevance for the transport system in the future?	- (Passenger vs. freight) - Smart Cities - Eco Cities (e.g. forest cities) - Growing disparities
9	Would you like to add something else that is of particular interest to you regarding the discussed topic?	
10	In your opinion, what is too short in EU research funding? What are under-represented areas/fields in EU research?	