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# Smart Mobility in Smart Cities: Chances and Challenges of Autonomous Passenger Transport


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# Abstract

Cities account for a large share of global energy consumption and are responsible for a significant proportion of greenhouse gas emissions. Making cities "smart" is one approach to enhance the resource efficiency of transport systems in urban areas. Improvements could be achieved by generating and sharing data, information, and knowledge that influences decisions using technology to enrich vehicles, infrastructure and services. People mobility in urban areas is one of the most discussed fields of smart city research and in the course of technological progress, autonomous vehicles seem to become viable in the future. To identify the external macro forces, current market conditions, and future developments that affect smart mobility and especially autonomous passenger transport, we apply the Political, Economic, Social, Technological, Environmental, and Legal (PESTEL) framework. Besides general statements applying to the worldwide market of smart mobility and autonomous vehicles, the paper's primary objective is to analyze the current situation in Germany and to compare it to the conditions in other countries. In general, computer-controlled transport offers enormous potential for reducing emissions and the amount of space used in cities. Germany is on a good to very good path towards integrating innovative and intelligent mobility concepts, based on the good position of the automotive industry with its existing technological advantages. Challenges are deficits in the digital infrastructure and the low acceptance of innovative mobility concepts.

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# 1 Introduction

Nearly four billion people worldwide are currently living in cities and this number rises continuously and at high rates (cf. WHO, 2016). Cities are therefore a fundamental element of human coexistence. They represent the social and economic centers of society, in which countless individual activities and various forms of interaction are concentrated in limited spaces creating highly complex systems. However, such an enormous concentration of private and public functions necessarily requires an effective interplay of individual tasks to configure efficient processes and to avoid confusion. In this context, the concept of smart cities has become a focus topic of scientific literature as well as international politics over the past. The aspect of mobility in urban areas has developed into one of the most prominent and frequently discussed fields of smart city research (cf. Mirri et al., 2016).

One reason is that cities are not only social and economic agglomerations, but their ecological importance also extends far beyond their own geographical boundaries. Cities account for 60 - 80% of global energy consumption and consequently also for a large proportion of greenhouse gas emissions (cf. UN, 2008). However, it is precisely from this perspective that urbanization also represents a great opportunity, as the increased concentration reduces unnecessary long transport distances. $CO_2$ emissions per capita are therefore demonstrably decreasing as urban density increases (cf. Hammer et al., 2011).

In this context, the research objective of the paper is to describe the chances and challenges of smart mobility and especially autonomous passenger transport in urban areas, focused on the situation in Germany. To reduce the complexity and scope of the topic to an appropriate level, the analysis is limited to private mobility. In the first step, we present scenarios that are emerging from the developments in mobility according to the current state of knowledge, which concrete characteristics these scenarios reveal, and which technological developments they are based on. Particular attention is paid on autonomous driving, which is explained and assessed in detail as this paper progresses. After designing a scenario that is derived from the most important current trends in mobility in the context of smart cities, opportunities and challenges of autonomous passenger transport are then examined using Germany as the field of application. Due to the breadth of the topic, a multidimensional approach is applied. In the course of a structured analysis, namely the PESTEL analysis, the topic is examined from a political, economic, socio-cultural, technological, ecological and legal perspective to investigate the opportunities and risks for various actors and to derive recommendations for required actions. The findings are discussed and integrated to generate comprehensive conclusions regarding the long-term development of personal mobility solutions in urban areas in Germany.

# 2 Theoretical Background

What is Smart Mobility?

Regarding the future of urban mobility, cities are expected to enhance and to change in general. As a basis, the term *smart city* is important, which is frequently being quoted and discussed and which originated in the context of mobility as early as the 1990s, when technology-based mobility systems had been emerging as a topic to be considered (cf. Papa and Lauwers, 2015).

However, smart cities can be defined based on many different dimensions and perspectives, which is why the term is being used very inconsistently and lacks a common understanding or unique definition (cf. Albino et al., 2015). Because of this ambiguity, it is initially important to adequately limit the focus of this work and to clarify an understanding of smart cities in the context of the research question to be dealt with.

According to a widespread definition, a city with an interplay of economy, citizens, administration, environment and mobility based on intelligent networking and individual freedom that is oriented towards a good and sustainable quality of life, can generally be considered as a smart city (cf. Giffinger and Gudrun, 2010).

Lombardi et al. (2012) define six main aspects of smart cities: smart economy (industry), smart people (education), smart governance (e-democracy), smart mobility (logistics & infrastructures), smart environment (efficiency & sustainability) and smart living (security & quality). As explained above, the object of this study are mobility concepts for private individuals. We therefore focus on the aspect of smart mobility in urban areas and thus exclude commercial transport such as last mile delivery logistics, waste management, etc.

Lyons (2018) characterizes *smart urban mobility* by means of three functions:

• „using technology to generate and share data, information and knowledge that influences decisions;

• using technology to enhance vehicles, infrastructure and services; and

• deriving improvements for transport system operators and users and for shareholders."

Basically, this means that very different designs in concrete mobility concepts are conceivable, for example by applying different technologies, using different data or expanding different types of infrastructure. In addition, various stakeholder groups are mentioned, whose interests may be contradictory and can be weighted differently. For example, a distinction is made between the "techno-centric" approach and the "consumer-centric" approach (cf. Papa and Lauwers, 2015). The former is thus characterized by the adoption of a technological perspective and a primary focus on technology and technological infrastructure as a decisive building block for smart mobility. Thus, the supply side of the new services to be created is considered as a priority. The latter, on the other hand, is characterized by a special focus on people themselves as a critical factor for the successful development of new mobility systems and the understanding of applied

technology as an "enabling tool" (cf. Papa and Lauwers, 2015). This approach emerged in the second half of the 2000s and made customers and their needs the key paradigm in the development of new innovations (cf. Papa and Lauwers, 2015).
To gain an idea of the future perspective of urban mobility according to the current knowledge base, it is necessary to look at how smart mobility is expected to be implemented in practice. For this purpose, the following five key components are of particular importance (cf. Docherty et al., 2018):

**1. Mobility as a Service**: The shift from ownership of vehicles towards usership in terms of access rights to a set of services that is potentially covering different means of transport as well as integrated payment platforms and that is designed to serve individual customer needs in the best possible way, aiming to provide a superior user experience (cf. Thakuriah et al., 2016).

**2. Exploitation of data**: The integration and use of new user-generated information which enables specific additional functions by processing crowd-sourced, real-time data (cf. Toole et al., 2015).

**3. Intelligent infrastructure**: Connected systems and vehicles with real-time communication between different objects to coordinate functions and optimize decisions to increase performance and realize gains in efficiency (cf. Alam et al., 2016).

**4. Electromobility**: The replacement of vehicles with internal combustion engines by those using alternative powertrains, namely electric vehicles, that are integrated within a smart energy distribution grid (cf. Coronado Mondragon et al., 2015) and do not produce local emissions to move towards more sustainable and environment-friendly forms of mobility (cf. Bakker et al., 2014).

**5. Autonomous driving**: Vehicles which are technically capable of moving through a city according to the needs of a passenger without requiring his/her operative assistance (cf. Fagnant and Kockelman, 2015).

Comparable assumptions can be found across many studies on outlooks on the future of urban mobility, some of which have already been translated into practical applications (cf. Deloitte, 2017a). Therefore, these five aspects are used as a framework to define smart mobility in the context of this paper. Based on this definition, the next step is to translate them into a tangible mobility concept, which can be applied for the subsequent evaluation and to provide explanation about some important aspects of the corresponding theoretical background.

## Developing a Future Scenario

In order to approach the question of a holistic, efficient, and customer-oriented mobility concept, it is first necessary to deal with the predicted development of autonomous and networked driving. Before we can speak of autonomous driving at this point, certain prerequisites must be fulfilled and certain scenarios must already have been run through, with which the different stages of automated driving come into focus. The step model of autonomous driving is based on an evolutionary development of vehicle automation. The continuous further development of driver assistance systems by the automotive industry and the technology sector will initially focus on increasing comfort and safety (cf. Beiker, 2015a). At present, continuous research and targeted cooperation between various sectors (primarily the automotive and IT industries) are aimed at increasingly intelligent assistance systems that can take over the complete driving function and thus optimize efficiency. This evolutionary scenario is based on the natural dynamics of vehicle automation and is influenced by time restrictions in the chronological development of technological components. Regarding the constructed view of the future of passenger transport that this work is intended to provide, and to gain an understanding of the current status of automated driving, the following section covers the SAE International step-by-step model.

This model serves to conceptualize the different phases of automation progress and is basically divided into six autonomy levels. This will allow the standardization of different understandings and approaches of the term "autonomous driving" by developers and manufacturers, since "it refers to very different levels of assisted and automated driving that are still far removed from a real autonomous vehicle" (Greis, 2015).

The first stage or stage 0 is characterized by SAE International (2018) as "the performance by the driver of the entire [dynamic driving task (DDT)], even when enhanced by active safety systems". This means that the driver takes full control of the vehicle on his/her own and that the vehicle does not make any interventions or have any technical requirements.

The first model stage includes all vehicles in which assistance systems are integrated that support the driver in various tasks. According to SAE International (2018) a specific feature is "the sustained and [operational design domain (ODD)]-specific execution by a driving automation system of either the lateral or the longitudinal vehicle motion control subtask of the DDT (but not both simultaneously) with the expectation that the driver performs the remainder of the DDT".

The second stage describes the technical components of semi-automated driving, which is characterized by only partially transferring driving functions from the driver to the system (Wiesinger, 2017). SAE International (2018) describes this category as "The sustained and ODD-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation that the driver completes the [object and event detection and response (OEDR)] subtask and supervises the driving automation system".

The driver assistance systems of the third stage enable a revolutionary step towards fully autonomous driving, since highly automated driving for the first time makes it unnecessary for the driver to lay his/her hands down in a relaxed manner and does not

have to permanently observe the surroundings. Although it is assumed that the driver is always ready to take control of the vehicle, he/she can also devote himself/herself to other activities, such as surfing the internet, etc. If the system cannot handle a situation independently, it prompts the driver to take control of the vehicle (Wiesinger, 2017).
Vehicles that have integrated level four systems can take over the control of the vehicle permanently and reliably in predefined applications (e.g. on the motorway, in car parks, robotic taxis, etc.) (welt.de, 2016). In those situations of fully automated driving, a driver is no longer necessary.
According to SAE International (2018) these are systems with the following characteristic: "The sustained and ODD-specific performance by an [Automated Driving System (ADS)] of the entire DDT and DDT fallback, without any expectation that a user will respond to a request to intervene".
Fifth stage vehicles can perform all tasks themselves in any situation, at any speed and in any environment, and thus represent the highest degree of autonomy (welt.de, 2016). This can be ensured by a significant advance in technology, networking, communication and sensor technology, enabling the complete absence of the driver (Drees, 2017). SAE International (2018) defines the level of full driving automation as "The sustained and unconditional (i.e., not ODD-specific) performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to a request to intervene".
Now that the different stages of automated driving have been examined more closely, it is necessary to develop a scenario that is at one of these stages. Today, road traffic still depends primarily on the human ability to drive a vehicle and the decision-making power of each road user. The current situation can be described with the transition from "partially automated" to "highly automated", the latest models are already completely on the latter. While most people steer the car alone, various driver assistance systems support them casually and often subliminally, so that a pleasant driving experience is perceived. However, an interaction of different assistance systems can also achieve a state in which both control functions of the vehicle (acceleration/braking and steering) are taken over for a certain period of time. For example, it is possible that both driver assistance systems, cruise control and lane departure warning, can temporarily leave the control to the technology, but only if the driver can intervene at any time.
In view of the fact that the current state of affairs already permits the technological influence in road traffic and the potential that is already given today by the progress of technology, this work should focus on the state of the last stage of this model and use it as a basis for scenario design. This serves to shed light on and assess possible potentials of autonomous passenger transport regarding social, ecological and economic impacts. Now that some fundamental hurdles and stages have been overcome, this paper can fully concentrate on the future picture of fully autonomous driving (stage 5 of automated driving).

To create a realistic future scenario, it is first necessary to dissolve some mental obstacles resulting from the current traffic structure and usage behavior. These are predominantly "in the sharp separation between car, train and bus" (cf. Baumann and Püschner, 2016). Instead, future developments envisage a blurring of traditional boundaries or the merging of these spatially separated modes of transport, so that an intermodal transport system can be assumed, which favors the emergence of so-called mobility platforms (cf. Schnieder et al., 2016). These form the basis for a functioning and, above all, holistic "Mobility on Demand" transport system that focuses on the customer's desire to get from point A to point B as quickly, conveniently, cost-effectively and sustainably as possible. Conversely, this means that "mobility thus becomes a service and less dependent on a specific mode of transport" (cf. Baumann and Püschner, 2016). But what exactly are mobility platforms and how do they influence the usage behavior of means of transport?
"A mobility platform combines a large number of data sources: anonymised user profiles, vehicle and environmental data from map services, data from intelligent transport infrastructures and weather forecasts [...]. Such platforms form the foundation for a wide variety of smart services: For example, for an intermodal route optimization with [situational suggestions in case of unpredictability - author's note]. (Kagermann, 2017). Information and communication systems and comprehensive networking are fundamental prerequisites for mobility platforms to be able to provide the range of functions and information needed to enable fast and easy access to vehicles, services and data via the internet and smartphones.
The functionality seems to be as simple as it is ingenious: first they show the user the optimal route by entering a certain address. What is special and innovative about mobility platforms is their ability to interact with the user and to react to spontaneous circumstances and incalculable situational circumstances. Thus, they enable the user to book tickets for all modes of transport and, integrated into the navigation of a vehicle, suggest not only an alternative traffic route in the event of a traffic jam ahead, but also a switch to alternative means of transport (e.g. underground, suburban or regional trains) (cf. Baumann and Püschner, 2016). If the user decides to change trains, the system immediately navigates him/her to the next point of contact, such as the nearest railway station, books the required ticket in the meantime and makes it available on the smartphone or smartwatch (cf. Baumann and Püschner, 2016). The consumer only perceives a fraction of the processes, almost all of which are organized in the background. The primary goal of the mobility of the future is to satisfy the customer to the highest standards. He/she must therefore be offered the most efficient mobility package of his/her planned trip within the shortest possible time, tailored to his/her needs (cf. Baumann and Püschner, 2016). This journey begins when he/she crosses his/her front door. For the providers of mobility platforms, this in turn means that the route must already be optimized at this point. The user can conveniently order an autonomously running public transport shuttle from home via a mobile application, for which only some essential

information is necessary, such as the current location, the destination of the journey, and user-specific preferences (cf. VDV, 2015). He/she can then board the shuttle at one of the numerous nearby virtual stops marked on an online map (cf. Baumann and Püschner, 2016). "The driverless vehicle is part of a fleet of "robot minibus taxis". Ideally, such a system should be integrated into a hierarchical network concept for public transport. It complements efficient traffic systems that are oriented towards bundling effects (bus systems with high capacity, or city and suburban railways) in the sense of a carrier" (Schnieder et al., 2016). These public transport shuttle services vary in the number of places available; depending on purpose and demand, they can comprise two to ten places (cf. Baumann and Püschner, 2016). If other people have registered on or near the planned route at the same time or have ordered a public transport shuttle, this can be considered in the selection of the size of the shuttle. Other passengers can then also board or alight at the virtual stops. The travel costs will be charged proportionately to the respective persons (cf. Hemmerling, 2011). Taking into account the position of all nearby passengers, the shuttle automatically calculates an optimal route combination and is supplied with current data and information from the mobility platform, so that the travel time for each passenger can be forecast in advance with very high precision (cf. Baumann and Püschner, 2016). "The advantage is that the planning effort is taken over by software. Corresponding parameters for trip calculation such as the maximum time by which a trip may take longer due to carpooling, the maximum number of passengers desired or whether carpooling is desired at all can be stored in the personal trip profile" (cf. Hemmerling, 2011). Since users of these "driverless shared taxis" often head for a higher-level public transport system (see Figure 1), these existing connection relationships must be considered in the routing and scheduling algorithms of the mobility platform (cf. Schnieder et al, 2016).

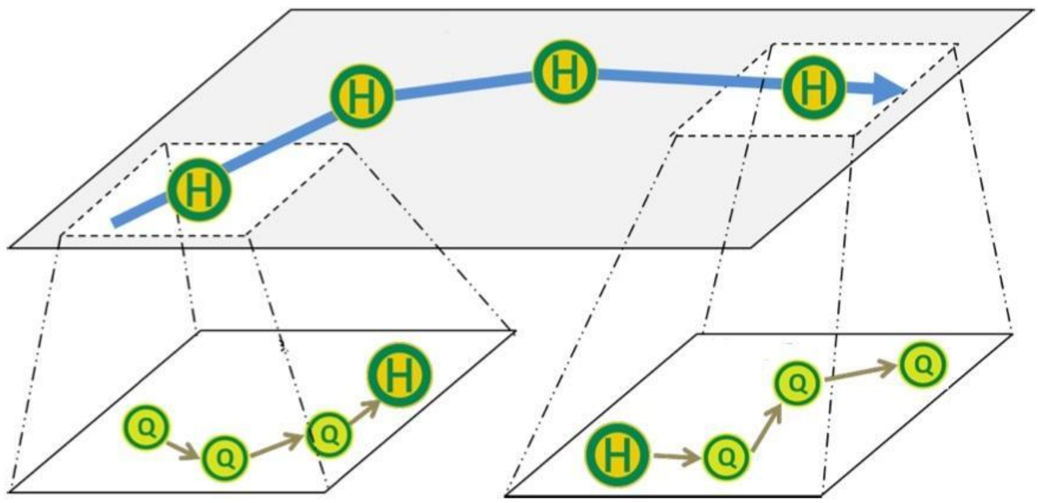

***Figure 1. Superior Public Transport System (Source: Schnieder et al., 2016)***

This route optimization is based on real-time data collected by digital map services and made available to the user in the form of current traffic information (cf. Baumann and

Püschner, 2016). An important component for real-time route recording is motion data collected by other road users during the use of digital maps (cf. Baumann and Püschner, 2016). For example, traffic jams can be detected early and avoided using alternative route suggestions (cf. Baumann and Püschner, 2016). With the help of this information, the optimal route can be visualized and displayed to the user on his/her smartphone. However, specific user preferences based on historical movement data, current weather and environmental data, data on leisure and cultural activities, geodata or the availability of charging points can also be included in intelligent route planning and visualized (*smart data*) (cf. Baumann and Püschner, 2016). "At the heart of a map-based mobility platform is the utilization of data, i.e. large amounts of unfiltered information are evaluated and bundled according to their usefulness. The user of digital maps is only provided with the information that is relevant for them in their respective situation" (Baumann and Püschner, 2016). Here again, the restrictions of the existing connection relationships and any passengers in the shuttle that restrict these services always apply.

The autonomous shuttle will then navigate along this calculated route and either be part of the regulated traffic or drive in the lane that is supposed for the fleet vehicle. For the use of driverless vehicles, several technical requirements are necessary to be able to control traffic completely autonomously. An essential component of networking is communication between vehicles and between vehicles with objects in the traffic infrastructure, so that physical data from the environment can be collected and made available locally and globally in real time (*smart products*) (cf. Baumann and Püschner, 2016). In order to ensure these real-time transmissions and to implement innovative services in the mobility sector, it is necessary to expand advanced information and communication technologies throughout the country, such as the 5G standard (*smart spaces*) (cf. Baumann and Püschner, 2016).

Thus, a high network coverage represents the foundation on which a customer-oriented mobility concept with the highest security standards can be built. At the end of this intermodal travel chain, the driverless vehicle takes over the task of returning the user to his/her desired location (cf. Schnieder et al., 2016). The planning process for this continues to be regulated by the mobility platform, after some information have been entered. This concludes the journey for the user. At this point it becomes clear which additional advantages and productivity optimization steps autonomous vehicle control reveals. Due to today's extremely high volume of vehicles, especially in urban and suburban areas, freely available parking spaces are scarce and searching for them is often time-consuming. Through valet parking, autonomous vehicles can independently find an available parking space and then be ready for the next order (cf. Baumann and Püschner, 2016). Even so-called one-way journeys, which were previously only possible to a limited extent with car-sharing concepts, are no longer an obstacle in times of driverless shuttles (cf. Hemmerling, 2011). After passengers get off the bus, the vehicle resumes its normal routine, enters the traffic autonomously and is thus available for other users.

The scenario developed here concentrates primarily on a so-called “shared economy”, in which people increasingly travel together in a highly networked system, so that one can speak of "hyperefficiency" (cf. VDV, 2015, cf. Henzelmann et al., 2017). In this constructed "shared economy" reality, a transport system exists that is characterized by active traffic flow management and collaborative control of autonomous vehicles (cf. Henzelmann et al., 2017). Above all, the focus here is on optimizing the so-called "first or last mile", i.e. "slow-moving and area-limited vehicles that complement privately used cars or public passenger transport" (Beiker, 2015a), which offer an extension of higher-level public transport services. Such user-friendly, productivity-enhancing and at the same time cost-efficient offers increase the attractiveness of using the "shared economy" advantages (car-sharing-swarm, ride-sharing, robot taxi, driverless minibuses), which is why the purchase of a private vehicle might require more powerful arguments in the future. Although the latter makes the highest degree of individual mobility superfluous, this variant is associated with significantly greater potential risks (e.g. liability issues) in addition to the high acquisition costs. Nevertheless, an exclusive development is not conceivable either in one direction or the other; user needs and requirements vary too strongly for this, so that a scenario in which the advantages of individual mobility and public transport converge, but always remain as two equal and mutually dependent components in a "smart mobility", appears most realistic (cf. Beiker, 2015b; cf. Baumann and Püschner, 2016).

# 3 Multidimensional Evaluation (PESTEL Analysis)

To identify the external macro forces, current market conditions, and future developments that affect smart mobility and especially autonomous passenger transport, we apply the Political, Economic, Social, Technological, Environmental and Legal (PESTEL) framework in the following.

Political Dimension

Regarding the political dimension, the extent to which the integration of smart mobility concepts with the described characteristics, i.e. primarily based on autonomously driving vehicles, into road traffic in Germany is politically desired and promoted is a question of particular interest. The German Federal Government is actively working on the integration of automated vehicles and connected mobility systems into the urban mobility landscape. This is a part of the responsibility of the Federal Ministry of Transport and Digital Infrastructure (BMVI), which has developed a comprehensive strategy for automated and connected driving at the end of 2015 and is pursuing its implementation since then. This agenda provides a broad approach towards a new style of urban mobility, which includes smart features as they have been described before.

In this context, for example, the *Digital Germany Network Alliance* has been established to coordinate public and private investments as well as initiatives aiming to promote a nationwide broadband expansion in Germany (cf. BMVI, 2015). In the short term, the goal is to ensure the seamless provision of 50MBit/s connections followed by a focus on the expansion of the 5G mobile communications standard as the basis for real-time data transmission in the next step (cf. BMVI, 2015). The involvement and participation of the private sector will thereby be complemented in a targeted manner by state subsidies (cf. BMVI, 2015). This policy is meant to accelerate the development of the necessary digital infrastructure that is required for the use of connected and autonomous vehicles. In close partnership with industry and science, specific testing areas are created, such as the "Digital Test Field Highway" for testing and evaluating the requirements of highly automated to fully automated and connected driving with car-to-car and car-to-infrastructure communication as well as corresponding new technological developments such as systems for high-precision cartographic technology and real-time communication (cf. BMVI, 2015). This offering addresses all stakeholders and innovation drivers from the automotive industry, the digital economy, and science and it intends to facilitate not only technological development but also knowledge transfer and the pooling of research activities. In this context, the Federal Government also provides direct financial funding for research projects in the field of automated and connected driving (cf. BMVI, 2015).

In addition, political effort has been articulated to adapt the national regulations of road traffic law in such a way that the vehicle systems themselves, as well as the driver, are entitled to carry out driving tasks without being restricted by issues such as duty of care or liability risks (cf. BMVI, 2015). The requirements for the acceptance of driver assistance systems for type approval are also to be extended to automated and connected vehicles, to which the BMVI is committed at international level for an extension of the European Code of Practice (cf. BMVI, 2015).

In addition to promoting the progress of automated driving through financing and legislation, the state also wants to provide technical support, for example by providing traffic-relevant mobility and geodata with an open source approach, distributing further traffic information locally via the digital radio standard "DAB+", and promoting the integration of the physical infrastructure such as traffic signs, signaling systems, etc. (cf. BMVI, 2015).

Also, the Federal Government is drawing up binding principles for manufacturers to protect against unauthorized external access (guidelines) and an extension of the ISO standard for the certification of the functional safety of safety-critical electronic components/systems in vehicles to ensure that IT security is also guaranteed within the development and implementation of new technical features (cf. BMVI, 2015).

These remarks show that autonomous vehicles and connected transport systems in Germany are desired by the government and are explicitly promoted by politics. This ambition is underlined by the strategic objective formulated by the BMVI to make

Germany the leading provider and lead market for autonomous and connected mobility (cf. BMVI, 2015). In the pursuit of these goals, Germany obviously competes with many other countries and it remains to be examined to what extent that political goal is actively implemented and Germany can achieve the desired pioneering role in the development and adaptation of these technologies or whether other countries are leading in this respect.

In Germany, the purchase of electric vehicles is supported by a financial incentive of 4,000 euros (cf. BMWI, 2016). In China, there is financial support in the double amount as well as a quota which obliges car manufacturers to cover a fixed share of their sold fleet on the Chinese market with electric cars (cf. Henzelmann et al., 2017).

Regarding mobility sharing, the USA is providing stronger incentives than Germany and is pursuing a more progressive strategy for political promotion. Ride-sharing providers are already being integrated into local public transportation in several American cities to offer customers mobility, including the "last mile", from a single source and to be able to avoid poorly utilized and unprofitable bus routes. In Tampa, for example, passengers from the last bus station can use *UberPool*, *Lyft* or similar services with their public transport ticket (cf. Henzelmann et al., 2017). In this regard, Germany is still in its early stages. However, the first concrete pilot projects have been launched to integrate private ride-sharing services into local public transport, for example in Duisburg with the Berlin-based start-up *door2door* (cf. Henzelmann et al., 2017).

As already explained, the development of autonomous driving is also financially supported in Germany. In particular, the German government has provided 80 million euros for the promotion of development work and test tracks (cf. Henzelmann et al., 2017). In Singapore, meanwhile, research projects for the technical development of autonomous systems of stages four and five were supported by state funding of a total of 350 million euros (cf. Henzelmann et al., 2017).

These remarks show that the economic policy impulses of the German Federal Government do not yet fully meet the self-proclaimed objective of becoming a lead market and a leading supplier. Regarding the focus topic of autonomous driving, these findings are underpinned by a study that breaks down the political conditions for this technology more precisely based on various criteria and compares them internationally. The results can be seen in the following Figure 2.

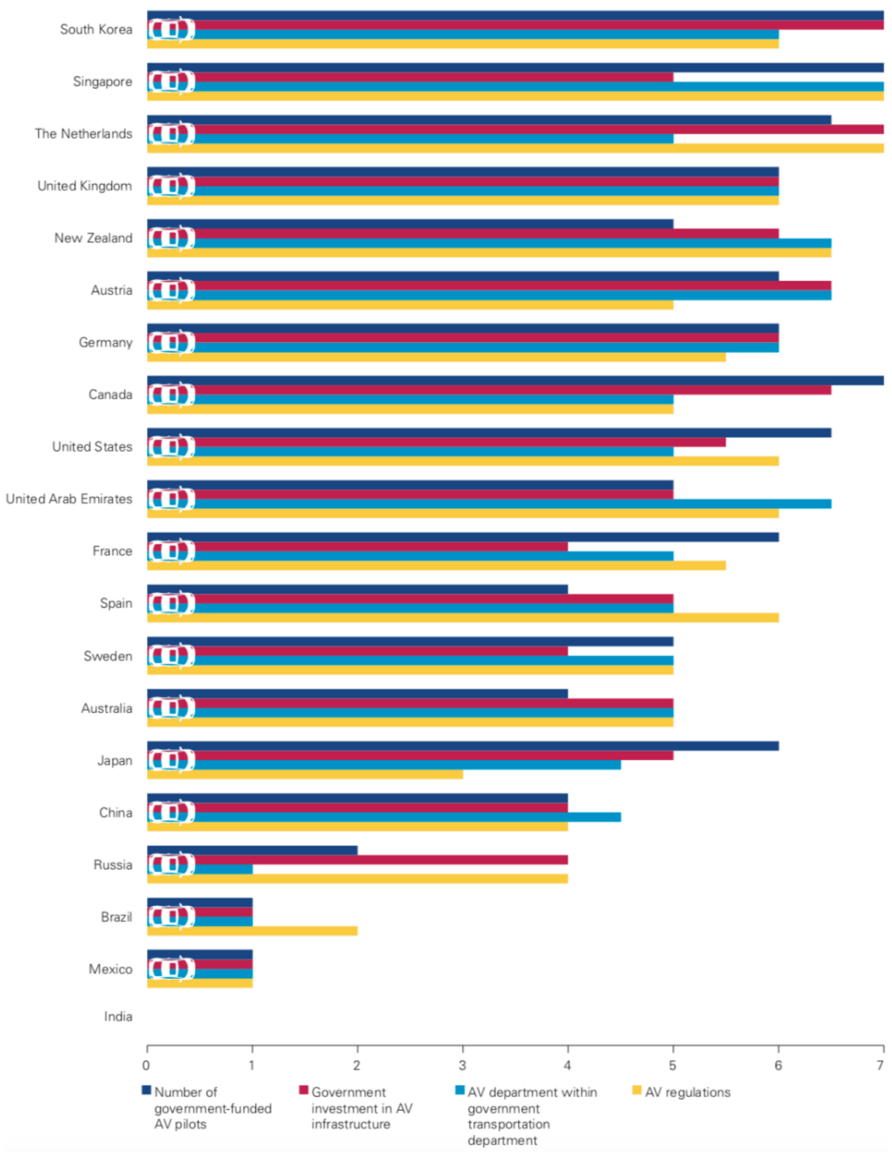


***Figure 2. Political conditions for autonomous mobility by country (Source: KPMG, 2018)***

This illustration demonstrates that on the one hand there are countries in which the development towards autonomous mobility is promoted even more intensively, but on the other hand it shows that there is some relevant political effort in Germany to develop autonomous mobility concepts and facilitate their application.

In summary, it can therefore be judged that the political framework in Germany - above all because the government has clearly committed itself to promoting this technology and is also taking appropriate action - is good, but not excellent compared to other countries.

<u>Economic Dimension</u>

With regard to the economic dimension, there is the question of which structural characteristics constitute Germany as a business location, how these determine the development of new mobility concepts and which opportunities and risks arise in the course of their introduction for the national economy, for companies and for consumers.

The automotive industry is often referred to as the most important sector of the German economy. Its special significance is primarily derived from its very high contribution to value creation, employment and exports by international standards. In 2017, the automotive industry in Germany generated a turnover of more than 400 billion euros and thus about a quarter of all turnover in the manufacturing industry (cf. VDI, 2018). Three quarters of all vehicles produced in Germany are exported and around 7.7% of Germany's total economic output is directly or indirectly attributable to car production (cf. Seiwert and Reccius, 2017). The automotive industry thereby has a relevance that is also reflected in the labor market: In 2018, around 833,000 people have been working for automobile manufacturers and their suppliers in Germany (cf. Statista, 2019). Other indirect employment effects, which further increase the relevance of the automotive industry for the labor market, are not considered here.

In addition to these well quantifiable effects in wealth creation and employment, there are also other positive implications for the performance and competitiveness of the German economy. The automotive industry, for example, is one of the technology- and innovation-drivers of the German economy. The German automotive industry invested a total of more than 40 billion euros in research and development and thus has the highest research and development share in the German economy (cf. BMWI, 2019). Due to this high importance of the automotive industry for Germany, opportunities and risks for the economy arise primarily from the implications of the mobility transformation for the automotive industry.

However, these implications are highly ambivalent, and there are both positive and negative perceptions of the consequences of the various trends, which are combined in the future scenario of urban mobility that is discussed here.

Regarding electromobility, for example, studies highlight the significantly lower degree of complexity of vehicle components compared with conventionally powered vehicles (cf. Kriener and Simons, 2017). In the future, the battery will account for a considerable part of the value added associated with a vehicle, and this is precisely where the relevant risk lies, because while the German automotive industry is a technology leader with regard to conventionally driven vehicles and their components - also due to a highly differentiated domestic supplier structure - there is a risk of a competitive disadvantage in battery technology compared with Asian manufacturers. For example, this could weaken the German automotive industry and cause relevant parts of the value chain to migrate out of the German economy (cf. Peters and Wietschel, 2012).

Beyond electrification, however, it is expected that the development of smart mobility concepts with all the features mentioned above will fundamentally confront the automotive industry with a disruptive change - car manufacturers face the challenge of reinventing themselves as mobility service providers (cf. Canzler and Knie, 2018).

The first essential factor is automated driving. In addition to alternative drives, the technology of automated driving is already established as the biggest driver of technological change in the industry (cf. VDI, 2018). One reason for this is the enormous value creation potential of the required components and systems. For example, the vehicles require high-quality, fault-tolerant sensor systems, efficient environmental interpretation and action planning, as well as safe actuators for steering, drive and brakes. Due to the strategic focus of the German automotive industry on the premium segment in the passenger car sector and the associated technological leadership in many areas as well as the corresponding expertise in the supplier industry, the German economy holds a very good position here. Among other things, this is illustrated by the fact that around 52% of global patents for automated systems currently come from Germany. This strong role therefore also presents a very great economic opportunity. For example, it is predicted that the contribution of value creation in Germany, which is accounted by driver assistance systems and highly automated driving, will increase sharply over the next few years and will amount to around 8.8 billion euros in 2025 (cf. Cacilo et al., 2015). These findings are illustrated in the following Figure 3.

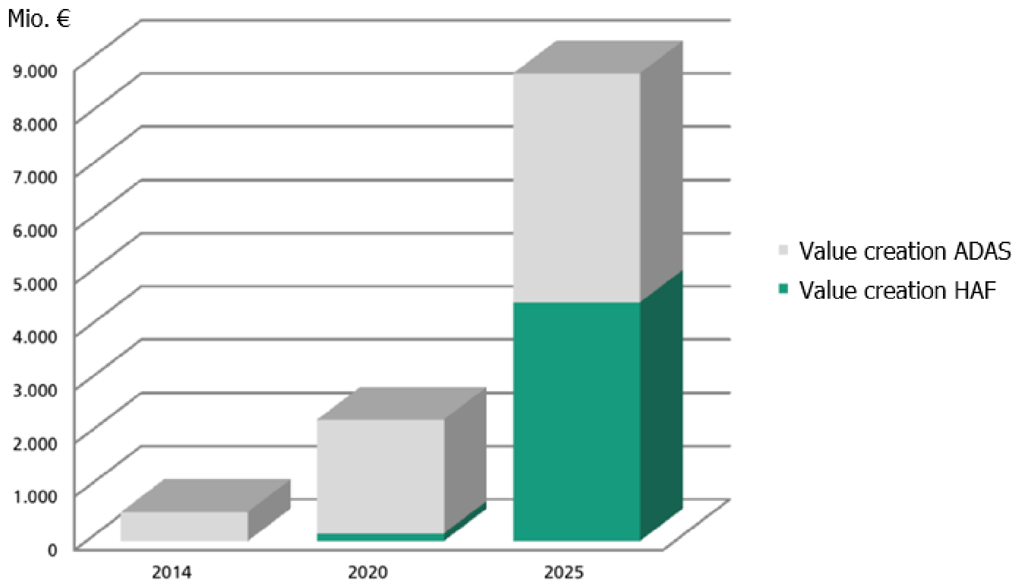


***Figure 3. Economic value creation through advanced driver assistance systems (ADAS) and highly automated driving (HAF) (Source: own representation based on Cacilo et al., 2015)***

According to this forecast, around 67,000 people employed directly in the automotive industry are expected to contribute to this, with a further 65,000 in the upstream supply chain, with the field of software contributing around half of the added value and employment volume (cf. Cacilo et al., 2015).

However, this development represents both an opportunity and a risk for the automotive industry and the German economy. In this financially very attractive business segment, which is being created or is growing by the increasing automation of vehicles, large software providers such as *Google*, *Microsoft*, and *Apple* have already been pushing their way into the market alongside traditional competitors (cf. Ritz, 2018). They are all currently working on autonomous driving and thus represent the inverse tendency - while traditional carmakers are increasingly trying to bring as much internet into the car as possible, they are bringing the car into the internet (cf. Canzler and Knie, 2018). Software producers and hardware manufacturers therefore increasingly face direct competition, and this creates a strong pressure to innovate. As a result, many large companies have already engaged in cross-sector cooperation and strategic partnerships and it remains to be seen who will ultimately be the winners and losers of this competition (cf. Ritz, 2018). Of similar relevance are the effects, which, according to current expectations, result from the change in the business model for private mobility in line with the scenario described above. In the digital urban environment, the attractiveness of the car as a privately owned good will be increasingly diminished (cf. Canzler and Knie, 2018). While the value created by the automotive sector today is primarily monetized by the personalized allocation of the vehicle to an end customer through leasing or purchase, a social trend towards a "shared economy" up to the service-oriented approach of mobility as a service is emerging (cf. VDI, 2018).

One reason for this lies in the expected price structure of these vehicles, which will gain further cost factors through the sophisticated components in the areas of software, sensor technology, etc. (cf. Ritz, 2018). Level five driverless vehicles, which, like those currently designed for private ownership, are intended to meet as many of the various requirements (short and long distances, variable numbers of passengers, etc.) as possible, will not have a market-penetrating effect in the short term, given the sales prices currently being assumed, as objects of purchase for individual customers (cf. VDI, 2018). In the short term, the price of an autonomous vehicle is expected to be approximately 25,000 to 50,000 US dollars higher than the price of a comparable vehicle today. In the medium term, this difference is to be reduced to around 10,000 dollars through further technological development, economies of scale, etc. (cf. Fagnant and Kockelmann, 2014). But for use in car-sharing fleets in urban areas, vehicles can be designed to be much more application-specific. For example, they do not have to be designed for collisions at very high speeds, which means they can use lighter materials and therefore consume less energy (cf. Ritz, 2018). In this way, autonomous car-sharing vehicles are expected to potentially generate a reduction in overall mobility costs of up to 80% when being compared to conventional privately purchased cars (cf. Burns et al., 2013). The shared economy or ride on demand approach in a 24/7 service operation, on the other hand, will therefore be suitable for an economically feasible scenario (cf. VDI, 2018). Driverless vehicles will thus make it possible to transport people and goods economically in the sense of mobility as a service and to integrate them comfortably into an intermodal transport system for the customer. The design of the vehicle interior in the sense of an experience space redefines customer experience in personal mobility by giving special emphasis on pleasure in being driven and is expected to lead to the development of significantly enhanced functionalities (cf. VDI, 2018). Accordingly, the entrepreneurial opportunity to create additional value also extends to the areas of data storage and processing as well as interaction in- and outside the vehicle (cf. VDI, 2018). For example, the autonomous vehicle could become a very attractive commercial platform through local integration into an urban environment and possible knowledge of behavioral patterns of the customers. Based on the time of day, destination, individual user preferences, and other user profiles, e.g., from social media, etc., the passenger can be offered individual activities, shopping opportunities, gastronomic and cultural attractions and many other possible elements, which can result in a very attractive marketing channel for local businesses (cf. Ritz, 2018). The integration of pure transport services into a comprehensive user experience links the value creation potential of automated vehicles with that of other transport modalities and a higher-level mobility service chain, thus enabling new business models (cf. VDI, 2018). It is also expected that new mobility concepts will cause major changes in user behavior and, above all, extensive new opportunities for interaction. The reason for this lies in the fact that passengers of autonomous cars, unlike passengers of conventional public transport, have an adequate level of privacy (cf. Ritz, 2018). Theoretically they are free to utilize their travel time however they want without disturbing or feeling disturbed by other people. Accordingly, the interior design of autonomous vehicles could be made more versatile and flexible. The car companies are not only competing for the best autopilot, but also for the most useful passenger compartments. It is precisely through the advantages of the interior that car manufacturers will probably try to set themselves apart from the competition (cf. Ritz, 2018).

Logistics services for freight transport are widely represented today. For such companies, the difference between passenger transport and goods transport lies in the additional consideration of the personalized requirement profile of the passenger and the associated possibility of binding this customer to the mobility service offer by addressing his/her individual needs (cf. VDI, 2018). Cooperation between suppliers from different sectors could therefore be decisive success factors.

Thus, a value creation configuration on three levels can be considered, in which "data refinement" to the higher-level lifestyle forms the upper level, based on the individual groups of service divisions such as mobility as a service, which in turn uses the vehicle product level as the lowest level of the value creation chain (cf. VDI, 2018).

However, the revenues of the automotive industry from the lowest of these levels, i.e. vehicle sales, are likely to fall dramatically as a result of the changes in mobility concepts, because with a widespread adoption of car-sharing, the demand for the purchase of cars, which forms the core of the current business model of car manufacturers, could be reduced by a factor of around seven in the long term according to current estimates (cf. Ritz, 2018). These projections imply a substantial risk for this industry. It could therefore become a decisive challenge for companies to develop their own services at the upper two levels and establish them on the market in order to continue to participate in vale creation to the maximum extent. Otherwise, the automotive industry could suffer an

enormous loss of economic significance as a result of the threats described above and the associated decline in sales.
From the perspective of the customer, however, the economic evaluation is more one-sided. As already explained, it is expected that the total costs for mobility providers will decrease considerably as a result of comprehensive car-sharing and as a logical consequence the same holds for the costs for the consumer - especially if the vehicles drive autonomously and mobility can thus be offered on demand without having to price-in costs for a human driver (cf. VDI, 2018). The very large capital stock, which is currently allocated in mobility primarily by the still very widespread private ownership, will probably be used much more efficiently in the future compared to the situation today (cf. Docherty et al., 2018). This results in a considerable economic advantage for consumers. In addition to these rather obvious cost saving potentials, there are other positive effects for the users of autonomous ride-sharing compared to the status quo. This is primarily due to time savings, since passengers can now also actively use their travel time and do not have to concentrate on driving themselves. In addition, the time that the driver must spend in the vehicle is reduced, as the car can potentially refuel/charge itself or search for an available parking space itself (cf. Ritz, 2018). The potential for connecting further services to the passenger transport process, which has already been described sufficiently from the manufacturer's point of view, also represents a possible benefit for the consumer, for example by obtaining information on personalized offers or reducing transaction costs.
Overall, it must be considered that the developments outlined here cannot yet be finally evaluated from an economic point of view. For the users of the new mobility offers, significant economic advantages seem to result from the realization of efficiency increases. It can be expected that citizens in urban areas will be able to move more flexibly, more comfortably, and more cost-effectively. For the automotive industry, on the other hand, which is very important for the German economy, this development will lead to a profound change in the value chain and the competitive structure in the medium term. As described above, this situation represents both an opportunity and a risk, because the existing business model of the automotive industry is threatened but enormous new value creation potentials are emerging at the same time. It remains to be seen whether positive or negative consequences will predominate over time. Due to the strong position of the domestic industry and technological leadership in important areas, Germany seems to be in a solid starting position. The successful integration of complementary skills and competencies, for example through cross-sector strategic cooperation, can become a critical success factor in this context.

Socio-Cultural Dimension
Regarding the socio-cultural dimension, mainly two questions arise: Are there patterns in cultural perception which influence the acceptance of the new technologies described here by consumers? Which conclusions can be drawn from this on the further perspective of

the emergence and adoption of new mobility concepts?. Therefore, this part focuses on the user perspective.

The attitudes of consumers towards various trends in mobility have been subject of several studies in recent years. For example, for 85% of German consumers, the practical benefit of driving a car, i.e. the flexible movement from location A to location B, is the most important factor, while the fun of driving as an emotional factor is only relevant for a small share. This priority is also reflected in the fact that 96% of them consider unrestricted personal mobility to be important or very important. Furthermore, a total of 87% rate owning a car as important or very important (cf. EY, 2017). These findings constitute a potential barrier to the spreading of new mobility services in Germany, as the use of these services naturally competes with the use of a privately-owned vehicle. In an international comparison, it becomes clear that the utilization of ride-sharing or ride-hailing services in Germany is currently still very low and that most consumers have never made use of such services (see Figure 4).

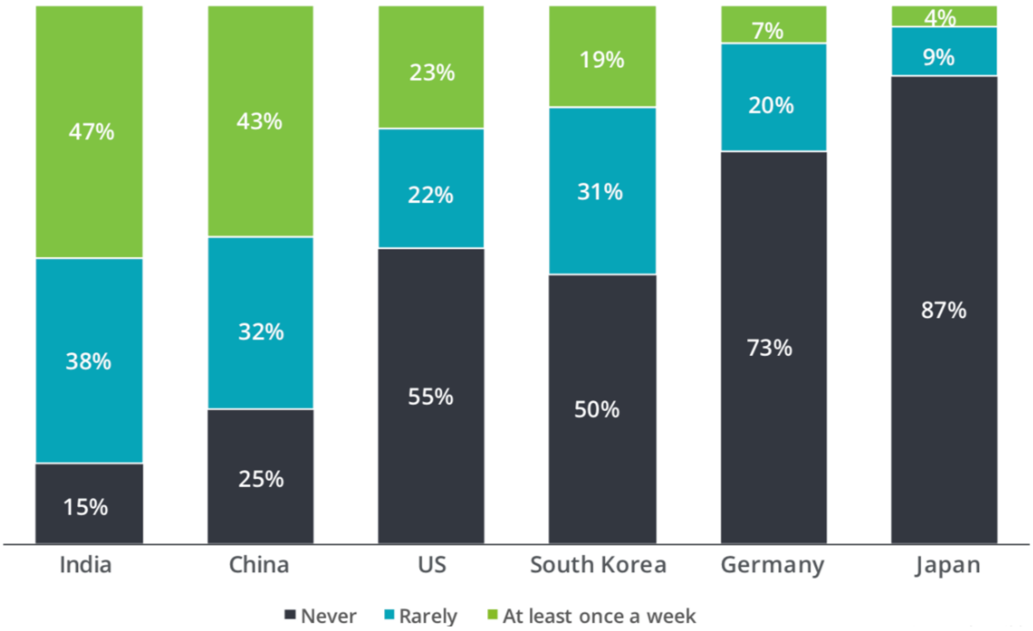


***Figure 4. Percentage of consumers who use ride-hailing/ride-sharing services, by frequency (Source: Deloitte, 2017b)***

In Germany, the adaptation and market penetration of mobility on demand is apparently progressing only slowly compared to other countries, which also seems to be due to cultural factors and user preferences. In addition, the use of autonomous vehicles in this context appears to be another important aspect of uncertainty and skepticism. About half of the consumers cannot imagine driving in a vehicle that travels without human control. The main reason for this broad rejection is clearly the fear of a loss of security, which is shared by around two thirds of all respondents (cf. EY, 2017). In this respect, parallel to the continuing development towards fully autonomous vehicles, a strong contrary movement in opinion is even apparent, as safety concerns regarding autonomous driving among German consumers increased sharply in 2017 compared to a survey in 2013 (cf.

EY, 2017). In an international comparison, however, German consumers are not the only ones with safety concerns about fully automated vehicles - in South Korea, Japan, and the USA, these concerns have been pronounced even more significantly in an international consumer study (cf. Deloitte, 2017b). Other studies have also identified widespread concerns among German consumers about the comprehensive collection and analysis of personal data and the vulnerability of the information systems underlying mobility services to external intervention, which could lead to traffic chaos and data fraud (cf. Fraedrich and Lenz, 2015).

Overall, it has also been found that the acceptance of German consumers for fully automated vehicles has declined slightly over the last few years with a return rate of about 3% (cf. Deloitte, 2017b).

In this context, it is also very noticeable that the acceptance of basic driver assistance systems in Germany is on an average level in international comparison, but declines at an above-average rate with regard to higher levels of autonomous driving, so that the acceptance of fully autonomous systems finally is very low in international comparison (cf. Deloitte, 2017b). This important finding is illustrated in the following Figure 5.

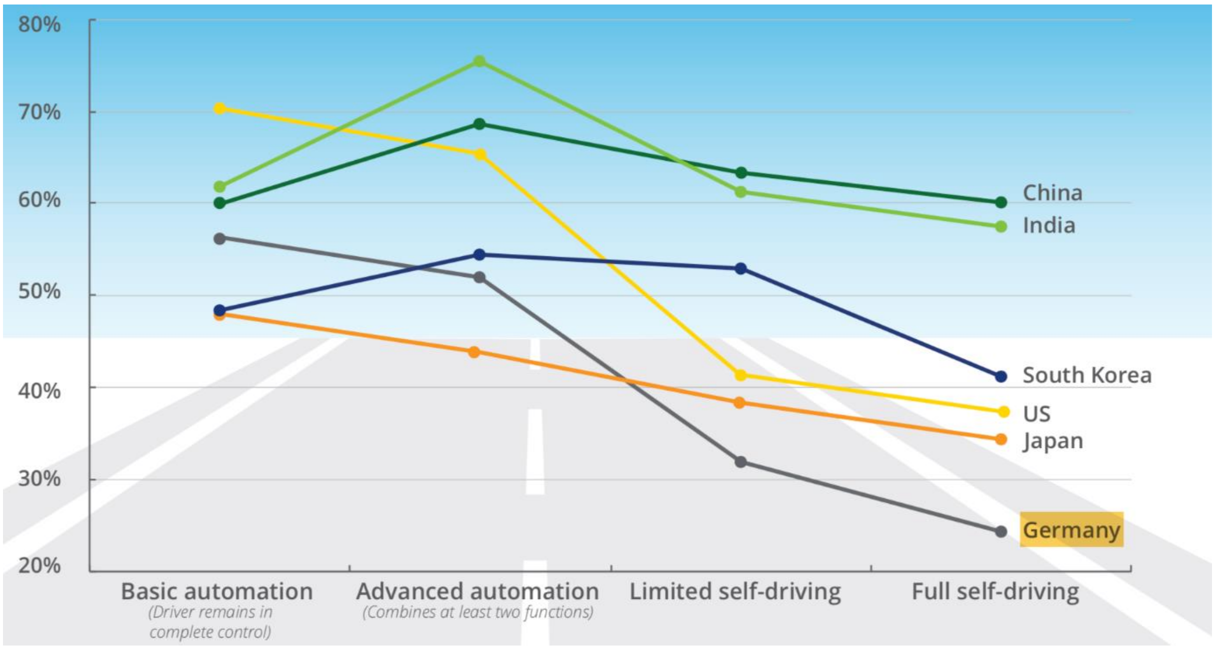


***Figure 5. Percentage of consumers who prefer different levels of vehicle automation (Source: Deloitte, 2017b)***

Overall, studies reveal an ambivalence in customer preferences: While the autonomous vehicle itself is assessed primarily positively, distrust and skepticism are pronounced simultaneously, including rejection of autonomous driving and the introduction of autonomous vehicles into the transport system, which is associated with the fear of negative social consequences or the loss of freedom in addition to the safety concerns outlined above (cf. Fraedrich and Lenz, 2015). Such an ambivalent attitude towards autonomous driving is a typical behavior pattern of Germans towards new technologies - and reflects the results of other studies on technology acceptance (cf. Renn, 2005).

These remarks show that cultural factors are currently to be recognized as barriers to the acceptance and dissemination of the mobility concepts discussed in this paper. For politicians and mobility service providers, these can be seen as a challenge that needs to be overcome in order to pursue and implement their interests in a target-oriented way. There is a need to find solutions regarding the reduction of uncertainties and fears in order to attract people in Germany as users of new mobility concepts despite their existing concerns in order to be able to exploit the great potential of autonomous driving on the market.

Technological Dimension

The technological dimension of this PESTEL analysis deals with the technical prerequisites and framework conditions regarding the feasibility of the mobility concept presented. For this purpose, an overview of infrastructural necessities for the implementation of autonomous passenger transport is given, while a differentiated consideration of two basic components for driverless driving, automation and connectivity, takes place. In this context, an understanding of the huge amounts of data that have to be processed in a holistically networked system is conveyed. In addition, the technical requirements that a vehicle must meet to be able to drive autonomously is examined. How these individual steps can pave the way for a turnaround in mobility and which third components are likely to play an immensely important role in the future is discussed in the following section.

*Connectivity and automation*

The introduction of an individually retrievable mobility concept for passenger transport based on autonomous vehicles requires a sophisticated and holistic technological foundation on which all process and optimization steps are based. Two elementary and inseparable components represent the basic prerequisites for this: automation and connectivity. Through the interaction of both, new levels are reached in the reliability of control systems or in the linking and use of real-time traffic information (cf. Kagermann, 2017). First the basic technical requirements of an intelligent transport system with regard to connectivity and automation will be examined in detail.

In order for various elements of a transport system to be networked at all, these elements or the processes must first be automated using algorithms, so that certain tasks, such as communicating data, can be performed by software or artificial intelligence. Today, billions of small computers are already installed in all areas of public life, such as vehicles, machines and infrastructure; the trend is rising (cf. Kagermann, 2017). The automotive market in particular has benefited extremely in recent years from the exponentially increasing progress of the IT industry. Increasingly complex and intelligent driver assistance systems are not only intended to increase driver safety and comfort, but also, in the long term, to relieve the driver of the task of controlling the vehicle. The aim of this accumulation of the smallest automation steps is to transform vehicles, which were previously passive and externally controlled objects in road traffic, into active, selfcommunicating units with the aid of embedded systems, which in the course of time will assume more and more driving tasks (cf. Kagermann, 2017). As one result, people, who are the most common source of error in accidents (>90 percent) (cf. Flügge, 2016), are gradually excluded from active participation in traffic, so that the highest degree of safety can be guaranteed. While assistance systems of stages two and three (e.g. lane keeping assist, parking assist, traffic jam pilot, etc.) are increasingly being installed as standard equipment, numerous projects are running simultaneously in which fully automated or even autonomous vehicles are being tested on test fields.

For example, the autonomous shuttle *EZ10* of the French manufacturer *EasyMile* has been running on the campus of the University of New England in Armidale since February 2019 transporting students and visitors (cf. autonomes-fahren.de, 2019). *Continental* and *EasyMile* will also be testing the *CUbE* (Continental Urban Mobility Experience) in Singapore in a cooperative project this year. This has already been tested in Frankfurt and Auburn Hills in the US state of Michigan (cf. autonomes-fahren.de, 2018). In Germany, several projects are also planned to test autonomous driving at locations such as Lower Saxony (test field Hannover - Braunschweig - Hildesheim - Wolfsburg) and Baden-Württemberg, but initially mainly on highways (DLR, 2019). The German Ministry of Transport intends to invest 80 million euros in the expansion of test tracks and further research (cf. Henzelmann et al., 2017).

The driver assistance systems are supported by sensors attached to the vehicle. These sensors not only detect collision-relevant objects and measure their movement, but also contribute to the control of driving maneuvers and the determination of position by measuring environmental parameters such as road inclination or the distance to various objects (cf. Maurer et al., 2012).

These sensors not only detect collision-relevant objects and measure their movement, but also contribute to the control of driving maneuvers and the determination of position by measuring environmental parameters such as road inclination or the distance to various objects (cf. Maurer et al., 2012).

In addition to active road users, objects that are responsible for coordinating and controlling the traffic system must also be automated and made readable for the vehicles, i.e. digitalized. Although systems for traffic sign recognition already exist today, they do not meet the requirements of foresighted traffic and route planning. As a result, all signals and elements of traffic control must be digitally available and retrievable at all times. Thus, intelligent traffic management can be ensured and Car2Infrastructure can contribute to a better traffic flow.

At this point, both intersections between the two main components of the technical implementation of autonomous traffic control and difficulties in unambiguously differentiating terms can be identified. Connectivity is largely conditioned by automation, whereby both components often go hand in hand.

*HD live maps*

Another example for the interaction of automation and connectivity, and at the same time a key component for autonomous driving, are high-precision maps. These provide the self-propelled vehicle with the ability to locate itself in its surroundings with centimeter precision. Conventional GPS-based positioning systems, however, are far from meeting the requirements of autonomous driving, as precise maneuvers would not be feasible due to excessive deviations. Navigation services such as *TomTom* and *Here* have addressed the resulting localization challenges and developed so-called High Definition (HD) maps. The latter use lidar sensors mounted on the roof of vehicles to successively record the road infrastructure as well as objects next to the road and relate their distances and dimensions to each other so that a detailed digital model of the environment is created (cf. Hammer, 2016). This contains all essential information about the road network and its surroundings, such as the number of lanes, the positions of gantries, crash barriers and other landmarks; even the curve radius can be calculated using this data (cf. Hammer, 2016). "Later, a vehicle driving autonomously in this section can calculate the vehicle position to an accuracy of 10-20 centimeters by continuously comparing its vehicle sensor data with the digital environmental data of the HD Live Map" (Hammer, 2016). A second layer is then placed over this first map layer, which contains dynamic information about the traffic flow, dynamically changing speed limits, construction stalls, accidents, but also traffic light information and weather conditions that cannot be captured by the vehicle sensors (cf. Hammer, 2016). By means of the analysis and meaningful processing of big data, the information obtained can be transformed into real-time traffic data to create added value for users and make intelligent traffic planning more efficient (cf. Flügge, 2016). In the last layer of this model, personalized speed profiles for each road user can be integrated, according to the manufacturer. From these, a context-related speed can then be determined individually for each vehicle for each specific situation and each route section, depending on the time of day, weather conditions, traffic density, vehicle model and the (speed) preferences of the occupants (cf. Hammer, 2016). From this comprehensive and detailed information, a highly precise and realistic, almost holistic, 3D-model of the road network and its surroundings is created (cf. Strijbosch and Kuther, 2017). This prototype of the *Here HD Live Map* already serves as a basis for further developments and improvements. In cooperation with *Here*, *Continental* is planning to add a fourth layer that can map the road course and topology as well as traffic signs and objects beside the road (cf. Hammer, 2016). *Bosch*, on the other hand, is currently using *TomTom* to carry out similar plans for precise road surveys and speaks of the integration of five layers (two static and three dynamic layers, which can even convey danger messages such as wrong drivers) (cf. Hammer, 2016).

This kind of efforts pursue a concept of "living streets" that uses cloud service to continuously summarize, process, analyze and make available updated, sensor-based environmental data so that a detailed real-time image of the road structure and current traffic events is produced (cf. Zieblo, 2016).

*5G*

In order to meet the demanding requirements of autonomous passenger transport and to be able to process the immense amounts of data generated, powerful and reliable information and communication systems are necessary. Since today's 4G standard is neither engineered for this nor technically capable, preparations for the introduction of the high-performance 5G standard are in progress. With rapid improvements in key dimensions such as flowing data volumes, latency, and reliability, this standard promises to achieve new technological dimensions in the field of network technologies and thus forms the foundation for the comprehensive networking of society (cf. Granig et al., 2018). By means of 5G, the data rate accelerates into the gigabit range (up to 10 GBit/s) and is up to 100 times faster compared to today's LTE (Long Term Evolution) networks. The network can also provide 1000 times of the LTE standard’s capacity, so that significantly more terminal devices can be supplied within a cell - current projections say that the new network will be designed for device numbers of 500 billion and more. In addition, the network has very low latencies, allowing very fast reactions and control processes (cf. Rügheimer, 2017). This enables autonomous vehicles to communicate with other vehicles, the infrastructure, buildings, and other objects in real time. However, networked autonomous passenger transport also requires constant availability and high reliability of the communication technology used, for example to ensure continuous communication with the mobility platform and between vehicles. Therefore, it is necessary to invest in the expansion of mobile bases so that a high network density can be achieved. In hotspot regions, this can mean that a mobile base is required every few hundred meters (cf. Rügheimer, 2017). In addition to these performance improvements, the 5G network also holds potentials for higher energy efficiency by forcing lower consumption (cf. Granig et al., 2018).

In Germany, there is no complete mobile communications coverage so far, so there is a need for further action to expand the digital infrastructure, and the introduction of 5G is a major step in this direction (cf. BMVI, 2017).

*Communication*

With the introduction of the innovative and area-wide network standard, the comprehensive, and for autonomous traffic essential communication between individual vehicles and with the traffic control systems, can be guaranteed permanently. The so-called Car2Car communication comprises systems that enable the exchange of information between vehicles (cf. Reinisch and Fitzek, 2012), whereby each vehicle can operate as a transmitter, receiver or intermediary. This is supplemented by Car2Infrastructure communication, which represents an additional exchange with traffic guidance systems

(traffic light systems, traffic signs, etc.) and provides an even greater amount of information that contributes to the intelligent traffic system. This influences the navigation of vehicles through traffic and enables the optimization of the traffic flow.
The efficient and meaningful interaction of both types of communication offers the possibility of reducing accident risks and thus increasing safety or identifying congestion potential by providing the necessary information just-in-time. As a result, the vehicle can maneuver more cautiously or avoid potential danger points. In addition to the great potential in the security of comprehensive communication, this also reveals very serious dangers. To keep the threat of attacks from outside as low as possible and to close possible security gaps, the IT security systems should permanently meet the highest standards and be updated accordingly.
While Germany is a technology pioneer in the automotive industry due to its extensive know-how and the high availability of automated driving functions based on it, there is a great need for action in the seamless provision of available high-quality traffic information by infrastructure operators (cf. Henzelmann et al., 2017; cf. BMVI, 2017). Currently, the introduction of cooperative intelligent transport systems is being worked on at European level. Since Germany is actively involved in this project, there is great potential that the digital transport infrastructure and related communication with it will be raised to a new level in the coming year, so that one of the most important prerequisites for completely autonomous driving can be created (cf. BMVI, 2017).

*Electromobility*

Another elementary component in a future, holistic and efficient mobility concept is electromobility. This is an essential prerequisite for the initiation of a mobility turnaround, since electrically powered vehicles are the foundation of an environmentally friendly transport system. Especially since this change is inevitable in the long run, in view of the limited fossil fuels available for driving the means of transport. However, the market is still in its initial phase and is gradually beginning to grow strongly, especially in Germany. Since not only people's awareness of a sustainable future is increasing, but electric vehicles are becoming more and more suitable for the mass as there is a higher variety of models over the years which is associated with a larger range of the vehicles' price, range, power, etc. (cf. Kagermann, 2017). However, the increasing use of electrically powered vehicles also requires an appropriate charging infrastructure. A large number of fast charging points have to be installed throughout the country to make electromobility more attractive. These must harmonize with the intelligent transport system to guarantee the seamless and permanent availability of operational autonomous shuttles (cf. Kagermann, 2017).
Regarding the international comparison in the field of electromobility, Germany is in a chasing position behind China (regulatory framework conditions and economic impulses) and France (technological maturity) (cf. Henzelmann et al., 2017). In 2016, almost 1.4

billion euros were invested in research and development in Germany (compared to 4.8 billion euros in China) (cf. Henzelmann et al., 2017). These dimensions show that Germany is on the right track, but to become a pioneer in this field and to push the development even harder, a further rethinking of the focus on future drive technologies must take place.
If all aspects and technical necessities for the implementation of fully autonomous and networked driving are considered, it quickly becomes clear that this is a long-term process that comes closest to an evolutionary scenario. In addition to technological progress in the automotive industry, i.e. in the vehicle itself, it is primarily an infrastructural change that must be implemented to ensure the networking of all road users and traffic control systems. This raises efficiency to a new level and guarantees a new dimension of traffic safety. Shorter reaction times through computer-controlled systems and foresighted navigation through traffic, made possible on the one hand by the comprehensive networking and communication of vehicles and on the other by the development of intelligent HD live maps, are just some of the potential benefits that autonomous driving brings with it. In order to benefit from these, high investments in information and communication systems as well as the expansion of the infrastructure are necessary. At this point, Germany is in a moderate position by international standards, but in order to rise to the top and become a pioneer in this field, much more effort is required.

Ecological Dimension

A structural change that penetrates such many spheres as the forthcoming mobility turnaround will have far-reaching effects. Changing transport concepts, innovative drive technologies, holistic networking and newly defined sustainability goals are predestined to influence the environment and ecological factors in the long term. To be able to estimate the extent of these influences, a detailed and differentiated examination of future changes and redesigns of the systems is required.
The introduction of newly developed drive technologies based on renewable raw materials enables the development towards an environmentally friendly transport system. Today, the most promising of these technologies seems to be the electric motor, which draws its energy from a lithium-ion battery. Due to the trend towards electricity generated from renewable energy sources, the climate balance of road traffic can be significantly improved if electric cars are suitable for mass production and there is a corresponding demand. However, the extraction of the lithium required for today's electric motor and the associated environmental effects must not be neglected at this point. The extraction of one ton lithium salt requires two million liters of water, which constitutes an immense negative impact for the affected regions, that are among the driest in the world (e.g., lithium triangle Bolivia, Chile, Argentina) (cf. Lauerer, 2018). This lithium dismantling restricts the drinking water supply of these regions and destroys the habitat of many local animal species. For this reason, current electromobility projects are very controversial: on

the one hand, there are almost no local emissions which is positive for the areas where the electric cars are used, but on the other hand the manufacturing process of the products is very resource- and energy-intensive, negatively affecting its life cycle assessment.

Therefore, other alternative technologies exist, so that further progress can be made in this area towards environmental awareness. One of these can be the magnesium battery, since magnesium has a higher energy density which enables a significantly higher storage capacity per gram and could therefore reduce weight. On the other hand, this technology is still in its beginning, which means that a long service life cannot yet be guaranteed. Other possible drives, such as those based on fuel cells or hydrogen, might follow in the next few years, but are still in the development or optimization phase and therefore require further research (cf. Seibt, 2019).

In the course of the debate about renewable energy sources and influences on various ecosystems, the different emissions must be distinguished. In Germany, the most discussed type of emissions from road traffic is probably $CO_2$. In the case of a gradual switch to electric drive technologies, the process of electricity generation must be considered. If this is done using fossil fuels, there is only shift in $CO_2$ emissions from direct to indirect generation. This in turn implies that renewable energy sources should be used to keep emissions as low as possible. Electromobility thus has the potential for a sustainable turnaround in mobility if implemented with the proper conditions (cf. Kagermann, 2017). However, it takes time to completely switch the energy generation to renewable energy sources. This raises the question to what extent the desired autonomous transfer of persons also has an additional ecological impact.

Increasing automation and comprehensive communication between autonomous vehicles as well as the communication between the vehicles and the infrastructure can result in a significantly improved and smoother traffic flow. Congestion and the number of empty trips could be significantly reduced, the response time of computer systems improves, so that vehicles can react to changes in behavior within seconds, since information is sent to subsequent vehicles via Car2Car communication (cf. Hemmerling, 2011). In this way, significantly less energy and resources are required for road traffic and the resulting greenhouse gas emissions are also drastically reduced (cf. acatech, 2016). Energy savings of 10 percent can be achieved through a computer-controlled transport system and the resulting coordinated way of driving of autonomous passenger vehicles. An optimized traffic flow can contribute a further saving potential of 10 percent (cf. Hemmerling, 2011). In addition, electromobility contributes to a reduction of noise that can also be considered as one type of emissions. However, energy and emission reductions can be generated not only through more efficient mobility of externally controlled vehicles, but also through active participation in the shared economy. The consistent and permanent use of mobility platforms and the associated car-sharing services leads to a significant reduction in the number of vehicles required and a higher degree of utilization.

Besides the reductions in emissions and energy consumption, a much smaller area will be used by autonomous vehicles. This results from a dynamic distribution of vehicles in the traffic space, which means that parking areas are partly dispensable (cf. Heinrichs, 2015). Concentrated collection areas for the autonomous shuttles or robot taxis could make the classic car park in front of residential buildings or in front of workplaces unnecessary (cf. Pecanac, 2017). In addition, autonomous vehicles require significantly less traffic space due to efficient locomotion in the form of coordinated braking and acceleration behavior. As a result, lane widths or the lanes themselves could be reduced, which in turn would make it possible to restructure the areas freed up, for instance as cycle paths (cf. Pecanac, 2017). For example, a vehicle driven by a human being at 40 km/h requires an area of 60 m², while an autonomous vehicle at the same speed requires only 19 m², which could reduce the required road area by two thirds. These space savings are mainly due to the reactivity of human beings. In addition, traffic structures in urban areas occupy around 15 percent of the available space, which could be reduced to five percent by fully autonomous vehicle control (see Figure 6) (cf. Bjarke Ingels Group, 2010).

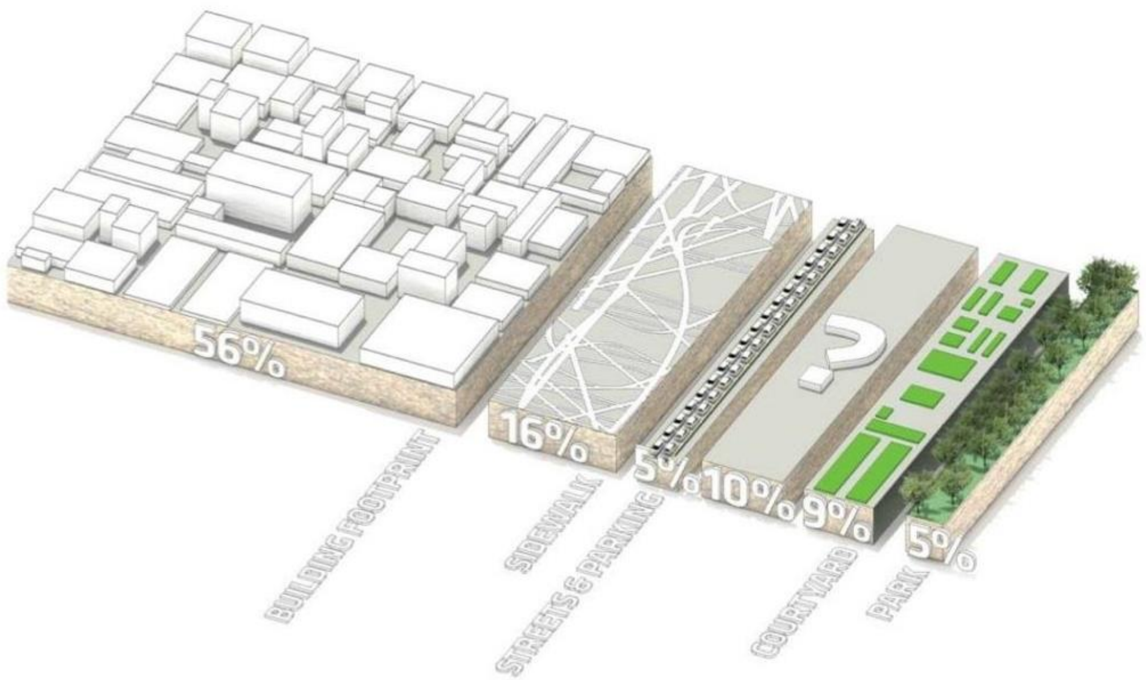


***Figure 6. Savings of Traffic Area (Source: Bjarke Ingels Group, 2010)***

Here, the positive influence of autonomous vehicle control on efficiency becomes visual. For example, the number of vehicles in road traffic can be reduced, which in turn has a positive effect on emissions, energy consumption, space requirements, and on the traffic flow. In addition, the increasing market penetration of electromobility can improve ecosystems. In the event of a complete conversion to computer-controlled systems in road traffic, enormous potential can thus be released, and a considerable contribution made to climate change mitigation.

Legal Dimension

Entering new, previously unexplored technological dimensions always requires a legal framework that limits the possibilities and scope at a meaningful and socially beneficial level but does not restrict the continuous further development and dissemination of technologies. In many cases, legal provisions represent obstacles to maintaining progress or even achieving a breakthrough. For example, long-lasting legislative procedures or a lack of future-oriented views often prevent innovations from progressing, even though the technical prerequisites are often already in place. This issue could also have an influence on the feasibility of autonomous passenger transport. If the legal conditions are not geared towards a successful and consistent introduction, autonomous road vehicles will not be implemented in the near future. Legal provisions must therefore be created or adapted to enable an automated vehicle to independently perform driving tasks without a driver carrying out permanent monitoring of the system and its environment (cf. vbw, 2018).

The international legal basis for national traffic law in Germany is the *Vienna Convention* adopted in 1968. Accordingly, this convention must be opened to autonomous traffic to enable autonomous vehicles driving on Germany's roads in future. A first step in this direction was already taken with the *Amendment Agreement* of 2014, which now permits systems that influence the driving of a vehicle, as long as they can be taken over or switched off by the driver at any time (cf. vbw, 2018). However, this does not include automated vehicles that navigate through traffic unsupervised. It is therefore necessary to facilitate the introduction of autonomous passenger transport, to draw up an additional amendment agreement which either extends or repeals the previous one, creating room for new, more forward-looking provisions.

A further hurdle is posed by vehicle registration, more precisely the European Directive 2007/46/EC, which refers to the rules of the Economic Commission for Europe (ECE), according to which ECE Regulation 79 currently permits autonomous steering systems only up to a maximum speed of 10 km/h (cf. vbw, 2018). This relatively low speed is justified by the driver's constant control of any traffic situation, so that the main responsibility for controlling the vehicle can be assumed at any time. Therefore, further changes are needed so that autonomous steering systems can also be approved at high speeds in future (cf. vbw, 2018).

As explained before, according to current road traffic regulations, the driver must be able to ensure permanent controllability of his/her vehicle. This in turn also includes the fact that taking control of a vehicle from assistance systems must go hand in hand with constant monitoring and readiness to take over control, so that other activities are not allowed while the vehicle is in motion, although it would be technically feasible (cf. vbw, 2018). Thus, assistance systems would become less attractive, so that in the future an adjustment of the road traffic regulations need to take place in order to further stimulate the market. For example, this can take the form of compliance clauses according to which the driver's behavior requirements are deemed to have been met if they are observed equally by an automated control system (cf. vbw, 2018). This would, for example, allow the use of mobile phones during autonomous journeys, which in turn would pave the way for other industries, such as online marketing, and thus create new potentials associated with autonomous passenger transport. In addition, the prerequisites for accident data storage are to be created by recording position and time data by a satellite navigation system when the driver has transferred the control to the system or vice versa (black box) (cf. vbw, 2018).

In contrast to traffic and licensing law issues, civil law provisions are intended to clarify the question of liability in the event of accidents. According to the statistics, 90 percent of accidents are due to human failure, nine percent to environmental causes, and only one percent is caused by technical errors or maintenance faults (cf. vbw, 2018). The question of the cause of the accident logically raises the question of liability. To do this, it must first be clarified whether the driver had full control over the vehicle or whether the control was completely transferred to the system. If the first case, no new liability regulations are required. However, the latter represents a new situation in road traffic and requires a comprehensive legal basis. If a collision occurs, the question arises, whether the driver, the owner, or the manufacturer is liable for the damage. Currently, there is no uniform regulation on this issue. However, it makes sense to redefine the manufacturer's liability and to link it to the changed conditions, since the manufacturer is currently liable according to § 1 para. 1 ProdHaftG "depending on fault for consequential damages resulting from the use of a product, if the damage has its cause in a defect of the thing" (vbw, 2018). A distinction is made between design defects, manufacturing defects, and instruction errors as well as violations of the product monitoring obligation (cf. vbw, 2018). In the case of autonomous driving by automated systems, the jurisdiction is likely to identify a construction fault more frequently, which would shift the clarification of liability towards the manufacturer. This could lead to disadvantages for the automotive, IT, and software industries. In the course of shifting liability from the driver to the manufacturer, accident data storage will be necessary at least to a certain extent to guarantee proper and neutral clarification (cf. vbw, 2018). Obviously, new legal provisions in liability law need to be introduced so that the requirements placed on manufacturers are not overstretched and in the worst-case scenario this will have a negative long-term effect on the market.

In addition, unavoidable so-called dilemma situations can arise in everyday traffic life. Since the road traffic regulations stipulate that the vehicle must follow the applicable traffic regulations, it must resolve conflict situations in principle within the traffic area assigned to it, in particular within its lane (cf. vbw, 2018). The extent to which moral decision-making principles still must be drafted and anchored in the algorithms for this purpose remains open and questionable. For example, an extreme situation can occur

where a collision with humans cannot be avoided and the algorithms must decide between different human lives (e.g., death of passengers vs. death of pedestrians).
It is also important to clarify what happens in the event of technical failures of the data network and attacks on it. In the case of disrupted communication, there are initially two fundamental questions: first, how should the autonomous vehicle react in such a situation (e.g., immediate braking or merely the request to the driver to take over control; limited functionality may be retained here) and second, can the network provider be liable in the event of a malfunction or failure (cf. vbw, 2018)? The former is also governed by the technical feasibility of autonomous driving without communication networks as well as the legal provisions on whether autonomous vehicle control without communication may be undertaken at all. For this reason, concrete legal bases must be created as quickly as possible so that those questions can be clarified before the introduction of autonomous passenger transport.
To conclude, it takes time before autonomous driving can be implemented due to the described legal situation in Germany and in the worst case, this can hinder a fast technological development. However, a marketable introduction of autonomous passenger shuttles will also take few years, which will benefit the implementation of legislative changes. In any case, responsible institutions and individuals will have to begin to set the legal course for autonomous driving, otherwise Germany could fall behind in this promising market compared to international standards.

# 4 Limitations & Recommendations

The presented analytical analysis of the mobility situation and the requirements for implementing the described future mobility concept is intended to enable an assessment of the current situation in Germany. However, there are some limitations to be considered. This paper assumes an evolutionary development of urban mobility, which reaches its zenith in the constructed future scenario. As a result, the subsequent PESTEL analysis concentrates exclusively on the perspectives outlined in this paper, which appear most likely due to the current situation. Since there are many scenarios that run in parallel, but some of them differ greatly in their implementation and expression, the analysis can only capture a certain spectrum of possible potentials. However, it is in the nature of this methodical tool that a multidimensional and thus comprehensive overview can be given from different perspectives, which is why this tool was deliberately chosen.
Furthermore, this analysis is based on a dynamic development of a very complex construct that is influenced by various factors. Accordingly, it is difficult to draw a reliable prediction of this development. The constructed scenario represents one of several possible futuristic outlooks, but the probability of a false conclusion has been kept as low as possible through

comprehensive research. In the case of a different development, findings from the analysis may have to be adjusted accordingly.
Besides the described limitations, there are several recommendations to be given based on the conducted analysis. In general, the German government has several opportunities to promote autonomous passenger transport and smart cities by setting a proper environment for companies and individuals. First, the physical infrastructure (traffic signs, signaling systems, etc.) must be modernized to enable Car2Infrastructure communication. Therefore, high investments in information and communication systems are necessary.
Regarding the sustainability of passenger transport, electromobility can be one crucial element of the transformation. Besides the financial incentive of 4,000 euros at the purchase of an electric vehicle, the government must still support the use of renewable energy sources at power generation in the future. Only a low emission factor enables a truly eco-friendly mobility.
Regarding the legal dimension of autonomous driving, a concrete basis must be created as quickly as possible so that the questions of liability and dilemma situations can be clarified before the introduction of autonomous vehicles. If relevant issues remain unanswered, it can hinder companies at the technological development.
Further, the social dimension of autonomous passenger transport must be considered. The government must prepare for the situation where traditional jobs are no longer required, e.g., taxi or bus drivers. On the passenger side, existing concerns about safety and reliability must be addressed at an early stage.
In general, the technological development of autonomous vehicles can be supported by providing appropriate subsidies and funding projects. To conclude, several dimensions must be considered by the government to promote a successful and a holistic shift towards an autonomous passenger transport in smart cities.

# 5 Conclusions

The opportunities and challenges in autonomous passenger transport are very diverse and therefore require investigation from a variety of perspectives. This in turn requires a suitable method to be able to capture the topic's multidimensionality. For this reason, the PESTEL analysis was used in this paper as a methodical tool to illuminate the mobility of the future from the six different dimensions. The scenario constructed in chapter two was used as the foundation on which the later analysis was based on, so that in this work a holistic and detailed picture of a possible, realistic future would emerge. This was subjected to a critical analysis with the aim of highlighting the opportunities and challenges of autonomous passenger transport in smart cities on a political, economic, socio-cultural, technological, ecological and legal level, so that an outlook on future urban mobility in Germany can be provided.

Regarding the integration of intelligent mobility concepts into political objectives and plans, Germany is proving to be a promoter of the future mobility turnaround in an international comparison, even though there is room for improvement. However, the basis for the actual successive implementation of the technological prerequisites for autonomous transport is already being created at the highest level. This is necessary, since the digital infrastructure in Germany shows clear deficits in comparison to other pioneers in this field, especially regarding network coverage. The demand for car-sharing services in Germany is also limited, which is due to the very low acceptance of innovative mobility concepts. It is therefore important to present proposals for solutions to reduce existing uncertainties and fears, so that these do not represent an obstacle to their dissemination in the long term. One problem in the possible implementation of these concepts may be the legal provisions. The legal situation in Germany has not yet been adapted to the introduction of autonomous means of passenger transport. Here, a consistent and timely rethinking is necessary, so that the implementation of the already existing technological advantages (predominantly in the automotive industry) is not slowed down by missing regulatory adjustments. In the event of a consistent and holistic change in mobility, an immense economic potential can be revealed. These range from a much cheaper and more comfortable journey through efficiency and productivity gains with the new mobility offers, to a far-reaching change in the value-added network of the automotive industry. However, such value creation potentials should be approached cautiously and strategically, so that possible risks are minimized. On the other hand, only a few risks on the ecological dimension seem to exist in the course of the mobility turnaround. Only electromobility, which seems to be environmentally friendly at first glance, brings a few downsides that mainly affect developing and emerging countries. Computer-controlled transport, on the other hand, offers enormous potential for reducing emissions and the amount of space used, especially in cities. Thus, Germany can also send a significant signal about climate change mitigation by striving for a change in mobility.

Overall, it can be said that Germany is on a good to very good path towards integrating innovative and intelligent mobility concepts. Especially the supremacy in the automotive industry can be a decisive factor for a timely and successful realization of autonomous passenger transport with all its facets. However, there are risks that implementation will be delayed due to a lack of regulations, lengthy legislative procedures, and insufficient social awareness. Therefore, these obstacles are challenges that need to be addressed as quickly as possible to fully exploit the potential of autonomous passenger transport revealed by the different dimensions.

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