Technology Assessment of Autonomous Driving – Are Shared Autonomous Vehicles Ecologically and Socially Sustainable?

DISSERTATION

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ABSTRACT

Since its advent, the sustainability effects of the modern sharing economy have been the subject of controversial debate. While its potential was initially discussed in terms of post-ownership development with a view to decentralizing value creation and increasing social capital and environmental relief through better utilization of material goods, critics have become increasingly loud in recent years. Many people hoped that carsharing could lead to development away from ownership towards flexible use and thus more resource-efficient mobility. However, carsharing remains niche, and while many people like the idea in general, they appear to consider carsharing to not be advantageous as a means of transport in terms of cost, flexibility, and comfort.

A key innovation that could elevate carsharing from its niche existence in the future is autonomous driving. This technology could help shared mobility gain a new boost by allowing it to overcome the weaknesses of the present carsharing business model. Flexibility and comfort could be greatly enhanced with shared autonomous vehicles (SAVs), which could simultaneously offer benefits in terms of low cost, and better use of time without the burden of vehicle ownership. However, it is not the technology itself that is sustainable; rather, sustainability depends on the way in which this technology is used. Hence, it is necessary to make a prospective assessment of the direct and indirect (un)sustainable effects before or during the development of a technology in order to incorporate these findings into the design and decision-making process. Transport research has been intensively analyzing the possible economic, social, and ecological consequences of autonomous driving for several years. However, research lacks knowledge about the consequences to be expected from *shared* autonomous vehicles. Moreover, previous findings are mostly based on the knowledge of experts, while potential users are rarely included in the research.

To address this gap, this thesis contributes to answering the questions of what the ecological and social impacts of the expected concept of SAVs will be. In my thesis, I study in particular the ecological consequences of SAVs in terms of the potential modal shifts they can induce as well as their social consequences in terms of potential job losses in the taxi industry. Regarding this, I apply a user-oriented, mixed-method technology assessment approach that complements existing, expert-oriented technology assessment studies on autonomous driving that have so far been dominated by scenario analyses and simulations.

To answer the two questions, I triangulated the method of scenario analysis and qualitative and quantitative user studies. The empirical studies provide evidence that the automation of mo-

bility services such as carsharing may to a small extent foster a shift from the private vehicle towards mobility on demand. However, findings also indicate that rebound effects are to be expected: Significantly more users are expected to move away from the more sustainable public transportation, leading to an overcompensation of the positive modal shift effects by the negative modal shift effects. The results show that a large proportion of the taxi trips carried out can be replaced by SAVs, making the profession of taxi driver somewhat obsolete. However, interviews with taxi drivers themselves revealed that the services provided by the drivers go beyond mere transport, so that even in the age of SAVs, the need for human assistance will continue – though to a smaller extent.

Given these findings, I see action potential at different levels: users, mobility service providers, and policymakers. Regarding environmental and social impacts resulting from the use of SAVs, there is a strong conflict of objectives among users, potential SAV operators, and sustainable environmental and social policies. In order to strengthen the positive effects and counteract the negative effects, such as unintended modal shifts, policies may soon have to regulate the design of SAVs and their introduction. A key starting point for transport policy is to promote the use of more environmentally friendly means of transport, in particular by making public transportation attractive and, if necessary, by making the use of individual motorized mobility less attractive. The taxi industry must face the challenges of automation by opening up to these developments and focusing on service orientation – to strengthen the drivers' main unique selling point compared to automated technology.

Assessing the impacts of the not-yet-existing generally involves great uncertainty. With the results of my work, however, I would like to argue that a user-oriented technology assessment can usefully complement the findings of classic methods of technology assessment and can iteratively inform the development process regarding technology and regulation.

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RELATED PUBLICATIONS

Some of the research presented in this work has been previously published, presented, and/or discussed with scientists in the fields of e-business, mobility and transportation, and human-computer interaction. The following list provides an overview of the material that was previously published as articles in conference proceedings or journals:

- Study 1 (Section 5): **Pakusch, C**.; Bossauer, P.; Shakoor, M.; Stevens, G. Using, Sharing, and Owning Smart Cars: A Future Scenario Analysis Taking General Socio-Technical Trends into Account (2016). International Conference on e-Business / International Joint Conference on e-Business and Telecommunications (ICETE 2016). Proceedings of the 13th International Joint Conference on e-Business and Telecommunications (ICETE 2016) ISBN 978-989-758-196-0. DOI: 10.5220/0005960900190030. https://www.scitepress.org/PublicationsDetail.aspx?ID=yvid7qI6rUo=&t=1
- Study 2 (Section 6): **Pakusch C.,** Stevens G., Schreiber D. (2020) How Millennials Will Use Autonomous Vehicles: An Interview Study. In: Cagáňová D., Horňáková N. (eds) Mobility Internet of Things 2018. Mobility IoT 2018. EAI/Springer Innovations in Communication and Computing. Springer, Cham. https://doi.org/10.1007/978-3-030-30911-4_33.
- Study 3 (Section 7): **Pakusch, C**.; Stevens, G.; Boden, A.; Bossauer, P. Unintended Effects of Autonomous Driving: A Study on Mobility Preferences in the Future. Sustainability 10(7): 2404. DOI: 10.3390/su10072404.
- Study 4 (Section 8): **Pakusch, C**., Stevens, G., & Bossauer, P., Weber, T. (2018). The Users' Perspective on Autonomous Driving-A Comparative Analysis of Partworth Utilities. International Conference on e-Business / International Joint Conference on e-Business and Telecommunications (ICETE 2018). Proceedings of the 15th International Joint Conference on e-Business and Telecommunications (ICETE 2018). July 26-28, 2018, Porto, Portugal, Vol 1. https://doi.org/10.5220/00. https://www.scitepress.org/PublicationsDetail.aspx?ID=4hwBxBaNna0=&t=1
- Study 5 (Section 9): **Pakusch C**.; Bossauer P. (2017). User Acceptance of Fully Autonomous Public Transport. International Conference on e-Business / International Joint Conference on e-Business and Telecommunications (ICETE 2017). In Proceedings of the 14th International Joint Conference on e-Business and Telecommunications - Volume 4: ICE-B, (ICETE 2017) ISBN 978-989-758-257-8, pages 52-60. DOI: 10.5220/0006472900520060. https://www.scitepress.org/PublicationsDetail.aspx?ID=3AsEkxF3iYQ=&t=1. Best Paper Award.

- Study 7 (Section 11): **Pakusch, C.**, Meurer, D., Tolmie, P., Stevens, G. (2020). Traditional Taxis vs. Automated Taxis – Does the Driver Matter for Millennials? Travel Behaviour and Society 21 (2020): 214–225. DOI: http://doi.org/10.1016/j.tbs.2020.06.009.
- Study 8 (Section 12): **Pakusch C**.; Bossauer P., Stevens, G. (2020). The Unintended Social Consequences of Driverless Mobility Services – How will Taxi Drivers and their Customers Be Affected? In Proceedings of the 7th International Conference on ICT for Sustainability (ICT4S2020). Association for Computing Machinery, New York, NY, USA, 98–106. DOI: https://doi.org/10.1145/3401335.3401346.

One article is at the time of submission of this thesis under consideration for publication in a journal:

- Study 6 (Section 10): **Pakusch, C**., Boden, A., Stein, M., Sauer, S., Stevens, G. (2020). "There Must Be a Taxi Driver" – Expectations and Attitudes of Professional Taxi Drivers Towards Autonomous Vehicles. Under Review after Resubmission at ACM Transactions on Computer-Human Interaction (TOCHI).

Other publications:

In addition to these previously presented works, there are other publications that were published during the work on this thesis and thus inspired and shaped the research carried out. For the matter of completeness, these studies will be listed below without presenting them in full. Papers in which the author of this thesis has first authorship are listed first:

- **Pakusch, C**., Stevens, G., & Bossauer, P. (2018). Shared Autonomous Vehicles: Potentials for a Sustainable Mobility and Risks of Unintended Effects. ICT4S2018. 5th International Conference on Information and Communication Technology for Sustainability. Birgit Penzenstadler, Steve Easterbrook, Colin Venters and Syed Ishtiaque Ahmed (editors). ICT4S2018. 5th International Conference on Information and Communication Technology for Sustainability, vol 52, pages 258--269.
- **Pakusch, C**.; Weber, T.; Stevens, G.; Bossauer, P. (2018). Akzeptanz autonomer Verkehrsmittel: Eine Analyse relativer Mehrwerte selbstfahrender Autos im Vergleich zu heutigen Verkehrsmitteln. Multikonferenz Wirtschaftsinformatik 2018. Proceedings of the Tagungsband. Wirtschaftsinformatik 2018, Data Driven X—Turning Data into Value, Lüneburg, Germany, 6–9 March 2018; pp. 938–949.
- **Pakusch, C.;** Neifer, T.; Bossauer, P.; Stevens, G. (2018). P2P-Carsharing. Motive, Ängste und Barrieren bei der Teilnahme – eine explorative Studie. Internationales Verkehrswesen (70) 4, 57-60.

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- **Pakusch, C.;** Bossauer, P.; Meurer, J.; Stevens, G. (2020). Walking the Tightrope: Designing Autonomous Vehicles for Comfort and Sustainability Presented at the workshop "Should I Stay or Should I Go? Automated Vehicles in the Age of Climate Change", April 25, 2020, Honolulu, HI, USA.
- Meurer, J. **Pakusch, C**., Randall, D. & Wulf, V. (2020). Thank you for Taking our Service: A Wizard of Oz Study on Passenger Experiences with Robo-Taxis. In *Proceedings of the 2020 ACM on Designing Interactive Systems Conference* (pp. 1365-1377).
- Bossauer, P., Neifer, T., Stevens, G., & **Pakusch, C.** (2020). Trust versus Privacy: Using Connected Car Data in Peer-to-Peer Carsharing. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (pp. 1-13).
- Stevens, G., Bossauer, P., Vonholdt, S., **Pakusch, C**. (2019). Using Time and Space Efficiently in Driverless Cars: Findings of a Co-Design Study. ACM CHI 2019. Full paper accepted for presentation and publication.
- Stevens, G., Meurer, J., **Pakusch, C**., & Bossauer, P. (2019). Investigating Car Futures from Different Angles. Mensch und Computer 2019-Workshopband.
- Meurer, J., Lawo, D., **Pakusch, C**., Tolmie, P., & Wulf, V. (2019). Opportunities for Sustainable Mobility: Re-thinking Eco-feedback from a Citizen's Perspective. In Proceedings of the 9th International Conference on Communities & Technologies-Transforming Communities (pp. 102-113). ACM.
- Bossauer, P., Neifer, T., **Pakusch, C.,** & Staskiewicz, P. (2019). Using Blockchain in Peer-to-Peer Carsharing to Build Trust in the Sharing Economy. WI 2019 Proceedings. 14th International Conference on Wirtschaftsinformatik, February 24-27, 2019, Siegen, Germany.
- Stevens, G., Bossauer, P., Jakobi, T., & **Pakusch, C**. (2018). Mehrseitiges Vertrauen bei IoT-basierten Reputationssystemen. Mensch und Computer 2018. In R. Dachselt, G. Weber (Ed..): Mensch und Computer 2018 – Workshopband, 02.–05. September 2018, Dresden. https://doi.org/10.18420/muc2018-ws08-0543.
- Stevens, G., Bossauer, P., Jakobi, T., & **Pakusch, C**. (2017). Second Dashboard: Information Demands in a Connected Car. Mensch und Computer 2017. Mensch und Computer 2017-Tagungsband.
- Wödl, S.; **Pakusch. C**.; Bossauer, P.; Stevens, G. Auswirkung vollautomatisierter PKWs auf die Verkehrsmittelwahl (2017). Internationales Verkehrswesen. (69) 3, 68-72.

- Stevens, G.; Meurer, J.; **Pakusch, C**.; Bossauer, P. (2016). From a Driver-centric towards a Service-centric lens on Self-Driving Cars. CHI 2016 Workshop: HCI and Autonomous Vehicles: Contextual Experience Informs Design. San José, USA. 6 pages

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LIST OF ABBREVIATIONS

AD	Autonomous Driving
APT	Automated Public Transportation
AV	Autonomous Vehicle
BTL	Bradley-Terry-Luce
BZP	Bundes-Zentralverband Personenverkehr – Taxi und Mietwagen
DDT	Dynamic Driving Task
FAD	Fully Autonomous Driving
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
PT	Public Transportation
SAV	Shared Autonomous Vehicle
TA	Technology Assessment
TNC	Transportation Network Company
UITP	International Association of Public Transport
USV	Utility Scale Values
UTO	Unattended Train Operation
VKT	Vehicle-Kilometer-Traveled

1 INTRODUCTION

The trend towards sharing instead of owning has established itself in various areas of life and the economy, which has led to the sharing economy. New, sometimes disruptive business models enable us to consume goods or services in a new way. The idea of bartering, lending, or sharing goods or services is not new [184,338]; however, the development of digital technologies has meant that people can offer, buy, or rent services and goods online in a matter of seconds [243]. In addition to the sharing of private accommodation (e.g., Airbnb), increasing digitalization has given a new boost to the sharing of vehicles in the form of carsharing, bikesharing, eScooter sharing, and the provision of transport services (Uber, mytaxi, etc.).

While the term "sharing economy" is still associated with sustainability, it is very difficult to judge whether the sharing economy with all its forms and business models is more sustainable than the conventional ownership-oriented economy [147,243,334,475]. Focusing on mobility as a specific application area, the impacts of new on-demand mobility options have been widely discussed [79,214,215,541]. Modern carsharing constitutes one of these on-demand mobility options. The aim of the carsharing concept is ostensibly to achieve positive sustainable effects by more efficiently using cars or by considering the use of carsharing vehicles in combination with public transport as an alternative to owning a car. Studies have shown that carsharing can indeed have positive effects: It can lead to carsharing users reducing total vehicular travel [107], while increasing travel by public transport, bicycle, carpool, or foot [335], and even to carsharing members selling a car, consequently reducing the number of total vehicles on the road [336]. Although the number of carsharing users in Germany is increasing [88], it remains a small percentage compared to the number of authorized drivers of a car who would theoretically be able to use carsharing. In 2018, for example, carsharing services in Germany still did not see a large proportion of use in comparison with the total population. While 46.5 million cars were registered in Germany in 2018, only 2.1 million – not necessarily regularly active – carsharing users were registered [88,385]. In addition to the lack of carsharing services outside large cities with well-developed public transport systems, carsharing also lacks flexibility and immediate availability compared to private cars, hindering mass adoption [463].

One development that could greatly increase the attractiveness of carsharing services is fully autonomous vehicles (AVs) [566], because they make it possible for carsharing vehicles to be requested by smartphone and drive to the customer independently, taking him or her to the destination, after which they are available for further journeys [177]. The driverless control of autonomous vehicles promises the elimination of parking and availability problems, so that the level of service and comfort of automated carsharing vehicles converges with that of private (automated) vehicles. Some experts therefore expect a substantial modal shift away from the private car towards the shared autonomous vehicle (SAV) [176,492]. Against the background of the opportunities, potentials, and changes resulting from this shift, the contribution that (shared) AVs could make to a more sustainable mobility has been the subject of controversial discussion for some time now. Much effort has recently been put into studies to best anticipate the impact of SAVs on individual mobility behavior, on transport as a whole, and on transport-induced emissions, as well as how SAVs will affect our social world. With regard to these pressing questions, this work is focused on possible future scenarios with autonomous vehicles and the potential impacts of SAVs, addressing two key questions:

- What are the ecological impacts of the expected concept of SAVs?
- What are the social impacts of the expected concept of SAVs?

Within this work, two specific aspects of environmental and social impacts are addressed: By focusing on mobility behavior changes induced by the introduction of SAVs, especially rebound effects, I contribute to the assessment of the ecological consequences of SAVs. Regarding the social consequences of SAVs, I contribute to the existing literature on autonomous driving by investigating how the role of professional taxi drivers will be affected by the advent of SAVs. Assessing the consequences of an innovative technology – such as autonomous driving, in this case – is the core task of technology assessment (TA) [220]. The results of my work are thus intended to inform politics, industry, society, and science about possible consequences of SAVs, so that they can be taken into account in decisions regarding the further development of SAVs, both with regard to technology and, especially, with regard to business models and regulations.

To introduce the topic of the potential impacts of SAVs, I briefly present the state of the art of carsharing as an application example of the sharing economy, of autonomous driving in general and of shared autonomous vehicles in particular (Section 2). After positioning my research methodically and deriving the concrete questions of the individual studies (Sections 3 and 4), I present the results of the studies in detail: To frame my research topic, I first performed a scenario analysis with my colleagues to identify possible futures with autonomous vehicles and to examine these in terms of their sustainability effects – that is, their economic, ecological, and social impacts (Section 5). This scenario analysis served as a starting point for identifying and formulating more specific research questions. To address the first aspect of ecological impacts of SAVs, I conducted four empirical studies tackling slightly different aspects that, in combination, should help answer the first key question. From the backdrop of travel mode choice theory [433], study 2 (qualitative, Section 6) and study 3 (quantitative, Section 7) focus on exploring how users[1] assess the concept of SAVs in comparison to classical means of transport, how they want to adapt it from today's perspective, how their mobility behavior could change in response, and what this means for development towards a more sustainable mobility. In order to find out what drives users' travel mode choices, conducting study 4 (Section 8), my colleagues and I investigated which specific characteristics of current and future means of transport offer added value in comparison to each other. With a view to the acceptance and adoption of autonomous public transport, we carried out study 5 (Section 9).

Regarding the second aspect, the social impact of SAVs, especially on taxi drivers, two qualitative interview studies and one quantitative study were conducted. Study 6 (Section 10) investigates the relevance of taxi drivers in the age of AVs from the perspective of professional drivers, in particular by examining how they perceive the risk of their job becoming obsolete and their added value, while study 7 (Section 11) examines whether millennium-aged taxi users actually see added value in the person of the taxi driver or whether they would prefer an unmanned SAV instead. In order to assess the importance of taxi customers who might potentially need human assistance in order to use taxi services, study 8 evaluated a statistic of current taxi use in Germany in terms of the proportion of taxi rides made by mobility impaired people (Section 12).

In Section 13, I discuss the outlined research question in light of the insights I have gained through my studies and their implications for the design of SAVs from an individual perspective, and from a societal perspective, taking affected stakeholders into account. Finally, in Section 14, I summarize the most important takeaways of my thesis and provide an outlook for future research.

[1] The *potential future users of AVs and SAVs* cannot yet be called *users*, to be exact. However, this term will be used in this work in favor of a simple reading flow.

2 STATE OF THE ART

Before I present my research questions, my research methodology, and the result of the studies, I first provide a brief introduction to the sharing economy research (2.1.1) with a special focus on sustainable development (2.1.2). As a concrete business model of the sharing economy in the field of mobility, I then present the concept of carsharing and briefly illustrate the current insights in research with regard to its sustainability impacts (section 2.1.3). With regard to the ecological impact of novel transportation modes, not only technological, but also behavioral issues must be taken into account. Against this background, I provide an overview of current mobility behavior in Germany before outlining the main principles of the travel mode choice theory, including possible rebound effects, in Section 2.2. In the next section, I introduce autonomous driving by first defining the terms, especially the degree of automation (section 2.3.1), and surveying of the development of autonomous driving to date and presenting the time horizons discussed for the market introduction of autonomous vehicles (Section 2.3.2). I then present the state of the art regarding the expected effects of autonomous vehicles, subdivided into economic, social, and ecological consequences (Section 2.3.3). As a special object of analysis, the concept of SAVs is introduced in greater detail (Section 2.4.1) and the findings from the previous literature with regard to possible sustainability effects are presented (Section 2.4.2).

2.1 Sharing Economy and Sustainability

2.1.1 Sharing Economy

Sharing, not owning: This is the basic idea of the sharing economy. Some proponents predict that the sharing economy has the potential to turn the world upside down [243,338]. The sharing of resources is not a new phenomenon: Things have been borrowed, passed on, or purchased in collaboration when doing so alone would have been too expensive for the individual [52]. In the past, this kind of exchange was limited to people who knew each other in person [189]. However, increasing digitalization and the Internet have greatly changed with whom we can interact. Markets have emerged in the form of digital platforms in which supply and demand meet, and their participants have the opportunity to reach many more people with whom to coordinate transactions. Digital platforms thus give us a wider reach that leads to people finding each other when they would never have found each other in the real world [184].

The sharing economy as we know it today has expanded beyond its original motivation [475]. While the initial aim was to share partially or completely unused resources with others or to make large assets accessible to as many people as possible by sharing costs [69], today, concern is centered more on profit-oriented business models [198]. While various authors have attempted to formulate a broad definition, there remains no universally agreed-upon definition of the term [475], as its diversity is great and business models are changing in a highly dynamic manner. For example, the classification of various examples in the sharing economy according to platform orientation (non-profit/for-profit) and type of provider (peer-to-peer/business-to-peer) as proposed by Schor [475] is no longer valid today, as platforms tend to open up to mixed forms. However, in recent publications and articles, we tend to see that authors mention flagship examples when discussing the sharing economy. The most mentioned examples are Airbnb, Uber, or Lyft [334,475].

The examples of sharing economy flagships Uber and Airbnb demonstrate this development towards profit orientation. The original idea behind Uber was to connect private car drivers with private individuals who were looking for a ride in the same direction to share travel costs. It was thus the driver who determined the route and the destination. Nowadays, Uber driving has become a part-time or full-time job for most drivers, who drive with the motivation of gaining (additional) income [110,205,432]. Customers determine a destination and request a ride, and Uber drivers carry out the ride for the customer with the intention of making a profit. The technology is not only an enabler of carrying out the transaction by supporting standardized processes for booking, settlement, and payment, but also enables the use of trust-building systems such as reputation systems that simplify the transaction between unknown peers. The same applies to Airbnb. Originally, the online platform was intended to give private individuals the opportunity to rent out unused rooms or properties for the short to long term, while tenants had the advantage of being able to stay in very personal accommodation with connections to locals at a reasonable price [184]. Participants in this industry have also recognized the profit potential, and investors are now buying apartments in popular urban locations to rent out these exclusively through Airbnb. What both platforms have in common is that today, the dominant motivation to participate is no longer to share costs and offer personal services but to make profit through professional business behavior [20,159,376,394].

Based on the commonalities of these two flagships, the following description of the sharing economy can be formulated: The sharing economy consists of internet-based, largely access-free, profit-oriented platforms and communities that act as intermediaries between at least two complementary market actors, mediating goods, services or sources of information with the help of standardized processes and transaction cost–reducing systems. The role of the buyer and the provider can be assumed simultaneously and sequentially by private individuals as well as by institutions that pursue predominantly egoistic economic goals and subordinate altruistic motives.

While with the advent of the sharing economy the consequences with regard to sustainability were predominantly discussed as positive, with advancing development and commercialization, fears grew that the sustainability effects of the sharing economy might be less positive than expected or even negative [189,334]. The sustainability of the sharing economy cannot, of course, be answered in general terms, as it covers many sectors of the economy and has a wide variety of characteristics [198]. In this work, I therefore consider only one field of application, in which the sharing economy has already developed strongly: the mobility sector – and in particular automated mobility on demand.

2.1.2 Sustainability

The World Commission on Environment and Development (WCED) defines sustainable development as a development which “meets the needs of the present generation without compromising the ability of future generations to meet their own needs” [82]. According to this frequently quoted definition, present generations have a special responsibility towards future generations [282]. The goal of sustainable development is to secure the livelihood of all people in the present and in the future. [157]. Whereas the concept of sustainability originally focused only on its ecological aspect [23,125,435], today, sustainability is predominantly understood as an integrated concept that encompasses the three dimensions of ecological, economic, and social sustainability and is always regarded as interacting-wise [82,169,548,549].[2] According to this consideration, in the long-term, sustainability can only be achieved if economic and social aspects are taken into account in addition to ecological aspects, as these three dimensions are not mutually exclusive, but rather interdependent [550].

Ecological sustainability refers to a way of life or economic activity that demands nature or the natural resources of life only to the extent that they can regenerate. With regard to ecologically sustainable management, the literature differentiates between the production-oriented approach and the consumption-oriented approach [118,374]. Production-oriented concepts pursue the goal of low resource consumption, which is to be achieved by a more efficient use of energy and raw materials in the production of goods or services [392,556]. The consumption-oriented approach, meanwhile, considers consumer behavior and in particular rebound effects [246,544]. These rebound effects occur when innovative technologies that have the potential to increase

[2] However, this three-pillar model is not accepted without criticism. Details can be found e.g. in [261,493].

the efficiency of resources are consumed in a way that leads to a reduction in possible gains expected from that innovation [61,78,466]. Rebound effects are triggered in particular by falling prices resulting from more efficient production, which lead to increased consumer demand.

Economically sustainable means that a society should not live beyond its means, because this inevitably leads to deficits in future generations. A company, an institution, or a person operates sustainably if the economy can be operated on a permanent basis. This is consequently not the case if, for example, resources such as raw materials or labor are exploited to an excessive extent in order to achieve high short-term profits.

A society is socially sustainable when there is intergenerational, intragenerational, and global distributive justice. In addition to combating poverty and securing human basic needs, this includes fair access to opportunities and education; the fair distribution of resources regardless of generation, status, and place; and gender equality. Social sustainability also includes the influence of companies on people and society. Companies act socially when they provide safe working conditions and a salary that covers the cost of living of their employees.

For many institutions and actors, the idea of sustainable development has now become a model for political, economic, and ecological action. In 2001, the German Federal Government appointed the German Council for Sustainable Development. With the sustainability strategy "Perspectives for Germany," adopted in April 2002, it defined three fields of action in which it considers activities to be particularly necessary: "Climate protection and energy policy," "Environment, nutrition, and health," and "Environmentally compatible mobility" [87]. Thus, the field of mobility is an important element of sustainable development, and for good reason: At present, transport is a major burden on the environment and a threat to human health [275,298]. At the same time, mobility is also a central prerequisite for the economic and social development of modern societies. Predicted continued strong growth in transport services and the associated environmental impacts of transport represent a challenge for actors at all levels. According to the understanding of sustainability as described above, society does not act in a sustainable way in the present and did not in the past, as can be demonstrated by the fact that people, planet, and profit are damaged by traffic and its impacts. This can be seen in air pollution, CO_2 emissions, and noise pollution caused by traffic; health problems of local residents; problems in inner cities caused by parked and moving cars; and sealing, soil damage, and fragmentation of the landscape by roads.

The current problems of motorized private transport increase the need to seek and develop alternative mobility concepts. In Germany, the total number of motor vehicles on January 1, 2019,

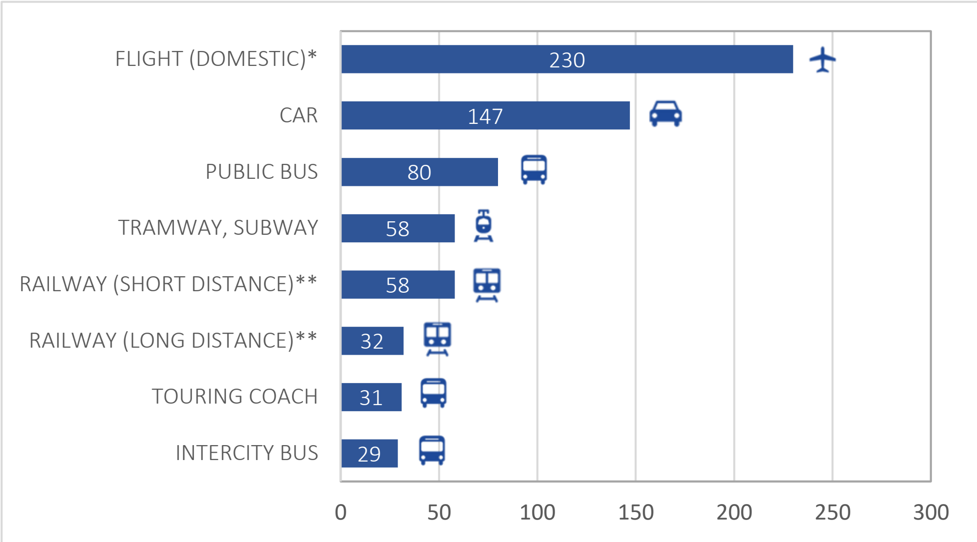

Figure 1: Greenhouse gas emissions in gram per passenger kilometer (Germany 2018) (Umweltbundesamt 2020).

was around 64.8 million (+1.6% compared with the previous year). Of these, passenger cars accounted for the largest share of vehicle classes, at around 47.1 million (+1.6% compared to the previous year) [292]. The percentage of motorization in Germany has thus steadily increased in recent decades, although air quality has improved steadily over the past few years due to strict emission regulations, sophisticated catalytic converter technology, and more environmentally friendly fuels.

The different means of transport contribute to varying degrees to environmental pollution. The German Environment Agency regularly publishes the average greenhouse gas emissions of individual passenger transport modes, as demonstrated in Figure 1 [546].

According to this, with 147 g/passenger kilometer, the car ranks second after the aircraft (230 g/ passenger kilometer) in terms of the most emissions per passenger-kilometer (1.5 persons per passenger car). Because public transport, cycling, and walking are significantly more climate and environmentally friendly than motorized private transport, the modal shift is one of the general objectives of transportation science and policies [174,558].

2.1.3 Potentials of New Mobility on Demand Concepts as Solutions for Sustainable Mobility

Against this background, the potentials and effects of alternative mobility concepts are discussed. Because mere technological innovations are likely not sufficient to reduce transport-related environmental pollution, socio-technical innovations are also increasingly being promoted by governments and communities [64]. One example of such a socio-technical innovation is modern carsharing. Due to the sharing economy approach, the shared use of vehicles should lead to a more efficient utilization of the resource and thus contribute to more sustainable mobility.

Cars were shared even before the age of digitization and the Internet. Often, this type of carsharing was informal, for example, in the neighborhood, often driven by social motivations (giving people access to a car that they could not afford) or environmental motivations [481,502]. Some initiatives have led to the formation of associations that have become increasingly professional, some of which were the forerunners of today's larger carsharing providers [315]. These carsharing providers rent out vehicles on a short-term basis to their institution members.[3] Nowadays, carsharing also makes use of the advantages of internet-based processing, as discussed in Section 2.1.1, and is currently offered in two forms. The first variant is station-bound carsharing, so that the starting point and destination of the journey are determined by the rental station. The advantage of this variant is that stations generally offer a collection of vehicles from which the user can choose the type best suited to the specific demands on the journey. Meanwhile, for some years, free-floating carsharing has been offered, allowing the vehicle to be picked up and parked freely within a given service area, thus offering increased flexibility to its users.

Research on carsharing has shown that this mode of travel can make an important contribution to the decline of private motorized transport, to strengthening multimodal transport concepts, and to reducing CO_2 emissions [112,336,372,381]. However, it remains uncertain whether this potential will actually be exploited and whether it will consequently make a positive contribution to environmental protection and more sustainable transport. For example, more than 2.1 million people in Germany are said to use carsharing (or at least are registered for such use), and some studies show that carsharing users have done away with cars and use more public transport and bicycles [335]. However, travel mode choices are very complex, and often, the question remains of whether the use of carsharing was actually the determinant factor [256]. For users, sustainability considerations play a subordinate role in the choice of travel mode [33]. Rather, economic (reducing mobility or vehicle costs) and situational-practical reasons (availability, convenience and flexibility) are decisive [315,467]. The question thus remains of whether people really done away with a car because of carsharing or were planning to do so anyway. Neither could it be finally clarified whether carsharing is used for those routes for which one would have alternatively used the bus or a bicycle, nor is there clarity as to whether the advent of carsharing has led

[3] The distinction between carsharing and classical car rental is becoming increasingly blurred. Currently, there are major differences in the length of the rental (short-term, i.e. by the minute vs. long-term, i.e. at least 24 hours), the need for institution membership, and the way the vehicle is handed over (digitally only and location-independent vs. personal handover by employees at the rental station).

some users to become car drivers in the first place. The latter would mean that the environmental balance of the users has deteriorated rather than improved as a result of carsharing. Similar questions arise if self-driving technology were to substantially change carsharing – making it even more convenient. In terms of its contribution to a sustainable mobility, who the users of automated carsharing will be and what behavioral changes will occur as a result of the advent of automated carsharing or SAVs is particular interesting.

Similar issues are also being discussed regarding the business model of transportation network companies (TNCs) such as Uber and Lyft. Like carsharing, digitization and networking made it possible to achieve better matching in the provision of travel services. Not only private car pools, but also profit-oriented ridesharing providers such as Uber or Lyft benefited from bringing together mobility demand and supply on digital platforms [240]. These digital intermediaries mediate rides between private car owners and customers in their primary and most popular business model, UberPOP (see 2.1.1). By combining the journeys of passengers who want to travel in the same direction, higher vehicle occupancy rates can be achieved and emissions reduced. Nowadays, however, most of these rides are customer-induced journeys that would not have taken place without the customer's request. The trip is then no longer shared between peers but is instead carried out on behalf of the customer for a fee. As a result, trips are not being saved. Some studies have already dealt with the use of Uber and its effects on transport in general and its impact on an individual's choice of travel mode choice. These studies show that the new TNCs are changing the mobility market. Since Uber has long struggled to establish itself in the market in many countries, most studies refer to the Anglo-American region, where they show that the turnover of traditional taxis in cities in which TNCs operate decreased; however, at the same time, this offer apparently addresses a new market. For example, an early study by the San Francisco Municipal Transportation Agency (SFMTA) found that in the first eighteen months after the introduction of Uber, the taxi industry experienced a 65% decline in revenues [462]. While in 2014, New Orleans still arranged about 2.9 million taxi rides, the number of rides decreased to about 2.8 million in 2015. At the same time, however, approximately 1.2 million trips were also arranged via TNCs, resulting in an increase of approximately 1.1 million trips in individual local public transport [117]. A similar effect was observed in Los Angeles. After Uber entered the market in 2012, the turnover of the taxi market there fell from approximately USD 46 million to approximately USD 40 million in 2014. In the same period, however, Uber drivers generated sales of approximately USD 60 million [146]. A study by Rayle et al. (2014) showed that ridesharing replaces not only taxi trips (39%) but also public transit (33%), walking (8%), and cycling (2%). Only 6% of all ridesharing trips would have been made with a privately owned car instead, and 8% of ridesharing trips would not have being made, which suggests that ridesharing causes a small but not insignificant increase in routes demanded [434]. Similar results were achieved by Lewis and Mackenzie in 2017, when they found that users who made the non-profit UberHOP service their main commuter mode were replacing public transport and, to a lesser extent, private cars [308]. These results are also confirmed by the studies of Mahmoudifard et al. [330] and Tirachini and del Rio [536], which showed that Uber mainly replaced public transport and the taxi.

Human-computer interaction (HCI) researchers and computer-supported cooperative work (CSCW) researchers have investigated the TNC drivers' motivations to participate [74,580], their working conditions [11,20,234], and the impact of platforms on drivers [11,305,327], and they analyzed optimization approaches [20,38]. Researchers such as [20,333] analyzed how digitally mediated TNC platforms coordinate and organize work, how they influence drivers, and how drivers react to their digital "principals". The impact of Uber's algorithm-controlled price system was the topic of research of Chen and Sheldon [111] and Cachon et al. [101], who investigated how surge pricing effects workers and consumers. Ma et al. [327] and Kim et al. [278] analyzed the drivers' stakes of earning, autonomy, and satisfaction. The results of the following studies are of particular interest for our study: How the advent of the TNC app Ola has changed the work practices of Indian auto rickshaw drivers was subject of Zade and O'Neill's research [589]. Regarding working conditions and workers' rights, Alkhatib et al. [11] noted that it is difficult for drivers to unite and assert their interests against the Uber corporation. Addressing uneven power between gig workers and platforms, some studies have analyzed workers' rights in more detail [359,537] and worked out how workers' rights could be strengthened [141,506]. Much work has been done on the pressure that rating systems put on ridesharing drivers [17,20,205,326,432], investigating how the strong pressure of the ratings influences the behavior of the drivers and the design of the service. With a look at the high service orientation and how the ridesharing drivers respond to the platforms' rating systems, for instance, Glöss et al. [205] and Arita et al. [20] outlined how important new tasks and skills such as empathy and emotional labor in general are. In the same line, Raval and Dourish [432] and Anderson [17] worked out how ridesharing drivers try to create a personalized and pleasurable experience for their passengers, with the pressure of the five-star rating system always in mind. Kameswaran et al. [270] analyzed how drivers and riders can benefit from interaction in the form of social capital and cultural capital. Rekhviashvili and Sgibnev [436] compared Uber with the traditional Marshrutkas (informal paratransit in some post-Soviet cities) and found that Uber's habits of not subjecting itself to regulations and exploiting workers and existing infrastructure are not a new phenomenon, but were already ubiquitous among the Marshrutkas.

Both business models – carsharing and TNCs – therefore make use of the same technologies and benefit equally from greater acceptance and wider adoption. With the advent of fully automated driverless vehicles, it can be expected that the business models will converge to a certain extent [400].

2.2 Mobility Behavior and Travel Mode Choice

On average, Germans travel 39 km a day. As in many other western countries, the car plays an important role in Germany. It is the dominant travel mode for three quarters of all passenger kilometers, as the comprehensive study "Mobility in Germany" recently showed again [385]. A further 19% of passenger kilometers are travelled by public transport such as buses and trams and 3% by bicycle and on foot. This modal split has remained relatively constant in recent years. While the share of cars in the total traffic volume has slightly decreased, the older population uses cars more intensively. However, among younger people and in cities, there is a slight increase in the use of public transport by bus and train and of bicycles. In metropolitan areas, less than 40% of journeys are made by car. The most frequent routes are to work or university (34%) and for leisure activities (28%). We also travel regularly for shopping (16%) and other activities (14%). New mobility services only take effect very slowly. The number of memberships with carsharing providers is increasing continuously, especially in cities. More than every tenth household is already a member. The members, however, use carsharing vehicles very rarely, with around two thirds of carsharing members using them less than once a month.

Travel mode choice theory aims to explain the factors determining the choice of transport means, seeking to determine and predict which travel modes are preferred to others and why [433]. In principle, the travel mode choice is a classic decision-making situation: The decision-maker has various alternatives from which he or she selects a travel mode that satisfies his or her need to travel from A to B on the basis of certain criteria. In this respect, the choice of travel mode is a decision that maximizes benefits in the sense of the rational choice theory [553]. The individuals have a certain goal (to reach a destination) and receive a benefit from the realization of that goal. In order to assess which of the available alternatives maximizes the benefit, the decision-maker considers the characteristics of the respective transport alternatives. The idea that the benefit is not anchored in the good itself, but in its respective attributes, is the subject of Lancaster's new theory of consumer demand [301]. According to McFadden's random utility theory, the total utility of a good consists of two components: a systematic utility component and a random component [341]. The systematic component depends on these attributes (which correspond to the rational choice theory and the new theory of consumer demand); observing the selections of decision makers, one can deduce the systematic utility component and the significance of the attributes. Accordingly, discrete choice experiments are carried out in transport research in order to draw conclusions about the significance of the various attributes by analyzing the actual choice [54,575]. However, the random component is not observable and can lead to unexpected, seemingly “irrational” selection results in the form of an error term [354]. As simplifying models, travel mode choice theory and random utility theory do not capture all aspects of the complex decision-making process in transport mode choice. They have in common that they focus on certain aspects and abstract strongly from the respective context. Nevertheless, they are suitable as a heuristic basis for the analyses in this work.

In transport research, it has been found that time and cost as economic factors in particular influence the utility assessment [158,173,174,267,565]. Thus, the lower the cost and time involved, the greater the benefit of a means of transport. Here, it is not always the objective values that are relevant, but often the perceived costs or the perceived travel time that count for the individuals [65,248]. In addition, other attributes such as travel comfort also play an important role [266,499,509]. There are different approaches in the literature as to whether other important characteristics such as flexibility, parking facilities, and transport mode changes should be grouped together [154] or assessed individually [499]. Research has shown that environmental factors play no relevant role in the choice of transport modes [501,504].

Table 1: Duration, costs, and CO2 emissions for short-distance and commute-distance trips with different travel modes

	Short distance (within Berlin)				Commute distance (city to city)	
	Walking	Bicycle	Public transport	Car (1 Person)	Public transport	Car (1 Person)
Distance	4.1 km	4.7 km	6.4 km	4.9 km	27.0 km	25.8 km
Cost	0 €	0.45 €	2.90 €	2.77 €	8.20 €	14.58 €
Time	51 min	18 min	25 min	17 min	66 min	29 min
CO_2-Emission	0,00 kg	0,00 kg	0.41 kg	0.93 kg	1.73kg	4.88 kg

	Short distance (greater rural area of Berlin)				Commute distance (rural to city)	
	Walking	Bicycle	Public transport	Car (1 Person)	Public transport	Car (1 Person)
Distance	3.8 km	3.8 km	5,9 km	3.8 km	28.1 km	25.4 km
cost	0 €	0.36 €	1.60 €	2.15 €	4.00 €	14,35
time	62 min	13 min	17 min	8 min	52 min	39 min
CO_2-emission	0,00 kg	0,00 kg	0.38 kg	0.72 kg	1.80 kg	4.80 kg

The different transportation modes thus offer specific advantages and disadvantages in terms of time and cost. Table 1 shows a calculation of the duration, costs and CO_2 emissions for a short-distance and a commute-distance trip based on data from [12,153,428].

The calculation for a specific short-distance door-to-door route within the city of Berlin and in the greater rural area of Berlin shows that the car is advantageous in terms of time (highlighted gray), while the bicycle route and the footpath represent the cheapest and most environmentally friendly connection. However, the car is only slightly faster than the bicycle for these short distance routes but emits by far the most CO_2 emissions. For commute-distance travel, the car is the best option in terms of time; however, the car is more expensive and has higher CO_2 emissions than public transport. The high costs and high emissions could, however, be reduced by taking additional passengers. Other factors not related to the travel mode, such as socio-demographic and socio-economic background variables like gender, age, family size, education and location, as well as the trip purpose and trip timing influence the travel mode choice too [54,160,245,424].

For a new route that an individual wants to travel, he or she could thus assess the possible transport alternatives in terms of time, cost, and comfort, considering the transport modes not in isolation, but rather setting the attributes in relation to each other.

As demonstrated, the time spent in a car is small compared to public transport and cycling [65], because the car can be used for the entire journey, and there is no need to change to other modes of transport. There is direct access to the car, there is no need to travel to it before driving. However, there may be delays in the event of a traffic jam or a search for a parking space. However, users regularly underestimate the time they spend in the car [248]. Although in principle all costs of car ownership (insurance, tax, repairs etc.) and use (fuel etc.) would have to be relevant for the travel mode decision, the costs relevant for the decision are usually only the variable costs [65,248]. The comfort of a car is also relatively high: It is always available, the driver does not have to share it with strangers, it is very flexible in use and one can easily transport things.

Public transport is often slower than the car due to routes to and from stops, waiting times at stops and changing times. In relation to the use-dependent costs of the car, public transport is often comparable or even more expensive. The situation is different if the individual has a public transport pass, which encourages more use of public transportation, making each trip cheaper compared to buying single tickets [269]. Comfort is less high compared to the car: Public transport is less flexible, the driver must share transport with strangers, one is more exposed to the weather, and it is more difficult to transport things [499]. However, passengers do not have to be able to drive or concentrate on the primary driving task but can do other things such as reading or sleeping.

The bicycle offers advantages over both alternatives in terms of cost, as it is very inexpensive to use. Except for cities with heavy traffic, it is slower than a car and public transportation. Like the car, it is always available and flexible in terms of times and routes, and finding a parking space is easier. However, things can only be transported to a limited extent and the comfort of the bicycle is more dependent on the weather and spatial structure (e.g., topography) than with a car and public transport.

However, these parameter assessments are not fixed and permanent, but can change if the properties themselves change. For example, if the costs of one of the means of transport falls or if the frequency of public transport increases, thereby reducing the time required, people reassess. A re-evaluation of the attributes of the transport modes also takes place if the attributes of existing transport modes change due to socio-technical innovations or if new transport modes with a new bundle of attributes are included in the travel mode choice. As a result, both the intensity of use of a given travel mode or the travel mode choice itself may change. Against the background of the current challenges mentioned above, such changes that contribute to more sustainable mobility are worthwhile. In this respect, it is important to assess the changes in mobility use, such as rebound effects triggered by socio-technical innovations. These rebound effects can be divided into three levels:

1) Classical rebound effects: Socio-technical innovations can increase the efficiency of existing transport modes, thereby reducing the resource consumption of transport modes. If the cost savings associated with the increase in efficiency are passed on to the users, they often have repercussions on the users' behavior [57,61]. An energy-efficient car causes lower fuel costs per kilometer driven. As a result, it can be observed that by car, journeys are more frequent, longer distances are travelled, and public transport or bicycles are used less. As a result, the technically possible efficiency gains are often not achieved in practice because the product is used more frequently or more intensively.

2) Time rebound effects: If an existing transport mode becomes faster due to innovation, then the user saves time as a result. Traffic statistics show that the time budget for transport is quite stable over time [257,350,363], which suggests that when a transport mode becomes faster, people are willing to travel longer distances or make additional journeys, reinvesting the time saved in mobility and thus not overall traveling less.

3) Modal shift effects: Socio-technical innovation can also constitute a completely new transport mode. Positive effects can be achieved when users switch from relatively less efficient alternatives to the new relatively more efficient alternative. This would be the case, for example,

if new electric scooters are used instead of a car. However, initial studies have shown that eScooters are more likely to be used for routes for which public transportation was previously used or which were walked [1]. In this sense, an innovative alternative can lead to undesirable migration effects and, consequently, to a greater strain on resources.

With the implementation of automated driving technology, new travel modes will be added to the mobility offer: private autonomous cars, SAVs, pooled SAVs, or automated public transport such as driverless shuttle buses [508]. The question then arises of what happens as a result of this socio-technical innovation at the consumption level. Users will have a wider choice of travel modes due to the new alternatives and will re-evaluate the benefits of the different travel modes – again in relation to each other. For example, it is conceivable that an individual may rate the use of time (as part of driving comfort) in a private autonomous car higher than in a conventional car or that he or she may see advantages in SAVs with regard to changes compared to public transport (driving comfort and driving time). If the overall benefit of one of the new transport modes exceeds the benefit of the previously favored transport mode, the individual will make a new decision, and his or her behavior may change as a result. These behavioral changes must be assessed from a sustainability perspective. If the change in behavior means that the new mode is used instead of a relatively less sustainable mode (e.g., pooled SAV instead of private car), the change is positive from a sustainability point of view; however, if the new mode will replace a relatively more sustainable mode (SAV instead of bicycle), then the change is negative from a sustainability point of view.

Before presenting the methods and studies that address these questions and assessments, the next sections first discuss the concepts of autonomous driving and SAVs and their anticipated effects.

2.3 Autonomous Driving

2.3.1 Definition and Taxonomy

To provide a taxonomy describing the full range of levels of driving automation in on-road motor vehicles, SAE International published the SAE International Standard J3016, which has been in force since January 2014 [458]. It defines six levels of driving automation, from level 0 (no automation) to level 5 (full autonomation). According to that taxonomy, the degree of automation relies on the roles of the (human) driver and the driving automation system in relation to each other (Table 2):[4]

Level 0 (no automation): The (human) driver performs the entire dynamic driving task and is thus exclusively responsible for detecting and responding to objects and events, even when enhanced by active safety systems.

Level 1 (driver assistance): Subtasks of the dynamic driving task can be taken over by the driving automation system at the driver's request and under limited geographic, roadway, environmental, traffic, speed, and/or temporal conditions. This can affect either the longitudinal (acceleration and deceleration) or the lateral (steering) vehicle motion control at any given time. The driver meanwhile supervises the driving automation system and decides when it is appropriate to switch the driving automation system on and off, thus constantly monitoring the vehicle and its environment and intervening to ensure the safe operation of the vehicle while needing to be able to take over the entire dynamic driving tasks at any time.

Level 2 (partial driving automation): At the driver's request, the driving automation system performs both longitudinal and lateral vehicle motion as a subtask of the dynamic driving task under limited conditions at one time. The driver meanwhile supervises the driving automation system, deciding when it is appropriate to switch the driving automation system on and off, thus constantly monitoring the vehicle and its environment and intervening to ensure the safe operation of the vehicle while being able to take over the entire dynamic driving tasks at any time.

Level 3 (conditional driving automation): The driving automation system performs the entire dynamic driving task under limited conditions. The driving automation system constantly monitors the vehicle and its environment, intervenes to ensure the safe operation of the vehicle, and requests that the driver intervene whenever there is a performance-related system failure or when limited conditions are to be exceeded. The driver decides when it is appropriate to switch the driving automation system on and off and supervises the driving automation system. In the event of a takeover request, the driver performs the dynamic driving task.

Level 4 (high driving automation): The driving automation system performs the entire dynamic driving task under limited conditions even in the event of a performance related system failure. Therefore, the driving automation system constantly monitors the vehicle and its environment, intervenes to ensure the safe operation of the vehicle, and performs a fallback into a minimal risk condition mode whenever there is a performance-related system failure or when

[4] For a detailed description of the taxonomy, including various interpretation examples and definitions of all terms used, see [458].

limited conditions are to be exceeded. The driver/dispatcher decides when it is appropriate to switch the driving automation system on and off and becomes a passenger when inside the vehicle but may become the driver after a requested disengagement of the driving automation system.

Table 2: Summary of levels of driving automation
(SAE International 2016, p. 17)

Level	Name	Narrative Definition	*Dynamic Driving Task (DDT)*		*DDT Fallback*	*Operational design domain (ODD)*
			Sustained lateral and longitudinal vehicle motion control	*Object and event detection and response (OEDR)*		
Driver performs part or all of the DDT						
0	No Driving Automation	The performance by the driver of the entire DDT, even when enhanced by active safety systems.	*Driver*	*Driver*	*Driver*	*n/a*
1	Driver Assistance	The sustained and 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.	*Driver and System*	*Driver*	*Driver*	*Limited*
2	Partial Driving Automation	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 OEDR subtask and supervises the driving automation system.	*System*	*Driver*	*Driver*	*Limited*
ADS ("System") performs the entire DDT (while engaged)						
3	Conditional Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT with the expectation that the DDT fallback-ready user is receptive to ADS-issued requests to intervene, as well as to DDT performance-relevant system failures in other vehicle systems, and will respond appropriately.	*System*	*System*	*Fallback-ready user (becomes the driver during fallback)*	*Limited*
4	High Driving Automation	The sustained and 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.	*System*	*System*	*System*	*Limited*
5	Full Driving Automation	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.	*System*	*System*	*System*	***Unlimited***

Level 5 (full driving automation): The driving automation system performs the entire dynamic driving task under all on-road conditions, even in the event of a performance-related system failure or when limited conditions are to be exceeded. Therefore, the driving automation system constantly monitors the vehicle and its environment, intervenes to ensure the safe operation of the vehicle, and performs a fallback into a minimal risk condition mode whenever there is a performance-related system failure or limited conditions are to be exceeded. The driver/dispatcher decides when it is appropriate to switch the driving automation system on and off and becomes a passenger when inside the vehicle but may become the driver after a requested disengagement of the driving automation system.

The fully automated execution of the dynamic driving task presupposes that the driving automation system acts on the basis of machine-autonomous behavior within a pre-defined behavioral framework [495]. Automated driving therefore requires programming of the driving automation system on the basis of statutory specifications. The behavioral decisions made in traffic will be based on algorithms that must include all conceivable events. In this context, there is great discourse regarding the ethical design of the algorithms for autonomous driving, which, however, will not be considered further in this thesis.

2.3.2 Development and Market Penetration of Automated Vehicles

Currently, two different development scenarios can be identified in the field of autonomous driving that are being derived in various scenario analyses [170,219,317]. On the one hand, in terms of an evolutionary strategy of development towards autonomous driving, traditional automobile manufacturers are continuously developing driver assistance systems, holding on to a ownership-based business model [68]. Driver assistance systems intervene semi-autonomously or autonomously in the longitudinal vehicle motion control (e.g., acceleration, cruise control or deceleration, emergency brake assist), the lateral vehicle motion control (e.g., intelligent parking assist system), and signaling devices of the vehicle (e.g., tire pressure monitoring system) or warn the driver shortly before or during critical situations by means of suitable man–machine interfaces (e.g., driver drowsiness detection). The aim of these systems is to increase safety and efficiency as well as driving comfort. As early as 40 years ago, the first driver assistance systems were established to support the driver in longitudinal vehicle motion control (e.g., cruise control). By linking existing longitudinal and lateral assistance systems to form a system network, such as the traffic jam assistant or automated valet parking, the criteria for semi-automated driving are already being met today. In traffic jams, the car automatically follows its vehicle in front, starting off and accelerating as well as braking and steering within its own lane. With automated valet parking, the driver leaves the car, which then drives into the parking garage without any further human intervention and maneuvers into a free parking space [32,319]. These examples show that numerous components for autonomous driving are already available and that further functions can be implemented through intelligent cooperation between existing assistance systems. The further development towards highly or fully automated driving requires a corresponding network between vehicles and infrastructure, which enables the necessary data exchange [483]. In a few years, the first vehicles will be equipped with appropriate sensors and information processing, so that specific application scenarios can be realized. Experts initially expect automated driving functions for motorway and traffic jams. In the distant future, driving across country and in the city will increasingly be supported [317,337].

By contrast, tech companies outside the automotive industry in particular are pursuing a revolutionary scenario, aiming for the development of fully automated or at least highly automated vehicles that will radically change people's mobility behavior. In this respect, the technology companies (i.e., Google, Uber) pushing into the automotive market often pursue disruptive business models that differ fundamentally from the usual business models of automobile manufacturers [24]. While the classic automobile manufacturers advertise the purchase and contribution of highly or fully automated vehicles in the sense of the evolutionary scenario [503], the TNC Uber in the United States and the startup nuTonomy in Singapore, for example, are testing autonomous taxis with the aim of replacing owner-centered mobility with demand-oriented, usage-based point-to-point mobility. In both development scenarios, however, the path to high and full automation is not only a technological challenge, but also requires national and international adaptation of the legal framework.

Estimates as to when highly automated and fully automated vehicles will come onto the market and when they will make up the majority of cars on the roads vary considerably. Automobile manufacturers and other producers of driverless vehicles are announcing the imminent market introduction of either autonomous vehicles or SAVs. All major car manufacturers collaborate with companies that have specialized in AV technology such as Waymo, Uber, Agro AI, and Bosch. Honda, Toyota, and Renault-Nissan want to offer Level 4 autonomous vehicles that can maneuver fully autonomously on motorways from 2020 [250,570]. Ford and Volvo plan in 2021 to introduce Level 4 driveress vehicles to the market which are allowed to drive in predefined areas [49,53]. Hyundai aims to release affordable autonomous vehicles that can be driven on motorways from 2020 and on urban roads from 2030 [144]. Daimler is planning to introduce Level 4 and Level 5 vehicles in the early 2020s [131]. BMW considers it possible to produce Level 5 autonomous vehicles as early as 2021 [425]. Tesla has announced that all vehicles produced from 2016 onwards will be equipped with AD Technology. [531].

However, mobility experts believe that the spread of driverless vehicles will be rather slow. This is due to pending changes in legislation and infrastructure as well as the relatively long lifecycle of private vehicles [347,382]. With regard to privately owned autonomous vehicles, Litman [317] predicts that in the 2040s, driverless vehicles will represent approximately 50% of vehicle sales, 30% of vehicles, and 40% of all vehicle travel and that it will take until the 2050s for most vehicles to be capable of automated driving. A recent Boston Consulting Group and World Economic Forum survey among 25 urban policymakers revealed that those experts expect the first SAV fleet to be operating in cities by 2025. They further expect that as a result of such SAV fleets, cities will have banned traditional car ownership by 2025 or 2030 [302]. According to Barclays analyst Brian Johnson's analysis, car sales will drop by up to 40% over the next 25 years due to the use of driverless vehicles, as a large proportion of journeys will be covered by SAVs [264].

2.3.3 Impacts of Autonomous Driving

Autonomous driving has the potential to have a transformative effect on society, with driverless vehicles fundamentally changing people's mobility behavior. However, the development holds both opportunities and risks with regard to the creation of more sustainable mobility. The effects of autonomous driving are controversial among experts and scientists. The sustainability perspective described above includes economic, ecological, and social consequences. Figure 2 shows the different impacts and assigns them to these three areas. However, this list of sustainability-related impacts is not exhaustive. Further, the direction of the change (e.g., emissions rise vs. emissions fall) is deliberately not indicated, as different consequences are to be expected depending on assumptions and interdependencies, as becomes clear in the various studies.

2.3.3.1 Economic Impacts

The advent of driverless vehicles will facilitate carsharing and create new business opportunities for automotive manufacturers, particularly for conventional auteurs that decide to enter this innovative market [533]. In addition, new competitors from the technology sector will aim to seize opportunities and establish themselves as mobility providers, in particular with the use of disruptive business models. Traditional insurance companies will also revise their business models if the

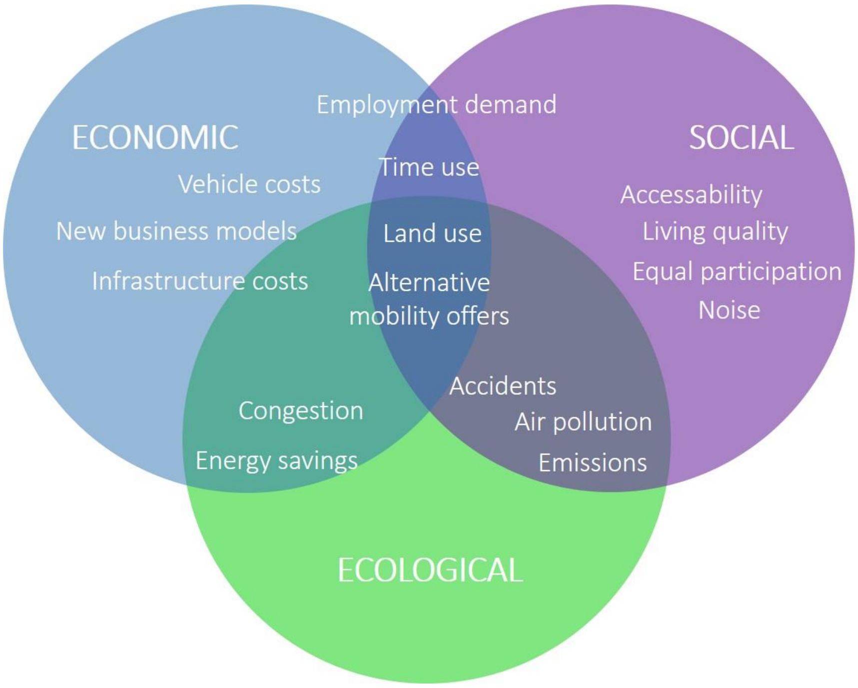

Figure 2: Possible economic, social, and ecological impacts of autonomous driving

number of human-induced accidents decreases [391,477,583]. As automated vehicles and infrastructure will be digitally connected in order to coordinate, new forms of big data will be created, the innovative use of which can become the subject of new business models creating value for stakeholders [533].

Different types of cost savings are being discussed as positive effects of AVs. Efficient driving and platooning could lead to energy savings and consequently to reduced costs [79,571]. Roadway costs could drop as a result of increased road capacity as the need for wide lanes and intersection stops might decrease [18,317]. In addition, parking costs would decrease if autonomous vehicles drop off passengers and find parking spaces autonomously [542]. If autonomous vehicles made a positive contribution in terms of emissions, air pollution, and noise, thus leading to a better quality of life and better health, illness costs would decrease as well [414]. From a company's perspective, vehicle automation can also lead to savings in personnel costs as a result of reduced employment demands for paid drivers, that is, for taxis, public transport, or delivery services [203,415].

However, vehicle automation may induce higher costs as well. Autonomous vehicle technology itself is expected to be relatively expensive during the introduction phase. In their HIS Automotive study, Juliussen and Carlson [268] projected that AV technology will have a price premium of USD 7,000–10,000. In order to achieve a mass adoption of driverless cars, they conclude that autonomous vehicle technology costs would have to be reduced to USD 1,000. A study by Daziano et al. [138] revealed that a large number of people are unwilling to pay any surplus for vehicle automation technology; however, the average household is willing to pay about USD 4,900 for full automation. The development and expansion of the required roadway infrastructure will cost a significant amount of money.

2.3.3.2 Social Impacts

Autonomous driving will increase social sustainability, as it allows for a socially more equitable and self-determined access to and use of mobility [63]. For example, driverless vehicles can be used by people who are not allowed or not able to drive today, such as children or people with physical or other disabilities [18,219,584]. Autonomous vehicles could also continue to provide access to mobility for elderly people whose ability to drive is diminishing [343,584]. People who cannot afford to have their own car could use SAVs that offer comparable comfort on a demand-oriented basis. As a result, equal access to flexible mobility will be strengthened. By giving these no-drivers autonomy in their mobility, others will no longer have to chauffeur them [18,317]. By transferring the driving task to the system, the driver will be relieved of the driving task and can use the time for other activities such as resting, reading, sleeping, or working [534]. In rural areas, in which attractive local public transport cannot be offered due to insufficient population density, autonomous driving can increase mobility and the provision of goods and services [390]. The most relevant contribution of autonomous driving in social terms is its potential contribution to increase road safety [414]. Today, 88.4% of accidents involving personal injury are due to human error, while only 0.9% are due to technical defects on the vehicle [498]. Experts expect autonomous driving to lead to a significant reduction in traffic accidents, since the transfer of the driving task from a human driver to a driving automation system promises a significant reduction in the number of accidents and their severity [176,356,415].

Others, however, consider it possible that more accidents could occur during the transition period, when both conventional and autonomous cars coexist on the roads [533]. Another negative consequence that has widely been discussed by experts are the effects of autonomous driving on the labor market, as the transition will put thousands of jobs of professional drivers at risk [46,63,521]. These include taxi drivers, public transport drivers, truck drivers, and delivery staff [14,46,310,512,521,571], as well as other jobs related to car construction, car driving, car repair, car ownership, car insurance, and traffic accidents [218,223]. In the United States, one in nine workers is employed in occupations that could be affected by the introduction of automated vehicles [46]. Occupations in which driving vehicles for the transport of passengers and goods is a major activity are most likely to be replaced by autonomous vehicles. This particularly includes jobs in the transport and warehousing industries. In 2015, 3.8 million people were employed in these occupations. These workers were predominantly male, older, less educated, and paid less than the typical worker [46]. However, not all driving-related jobs will disappear completely with the advent of autonomous driving; many jobs will need to be redefined [10,116,328,365].

2.3.3.3 Ecological Impacts

Autonomous driving could have a positive effect on the environment. By exchanging data, vehicles are expected to be able to coordinate driving speed, braking behavior, and distances between other vehicles, thus avoiding unnecessary braking and starting. Connected driving can further reduce or avoid stop-and-go traffic and congestion density and frequency [79,176,492]. By networking vehicles and infrastructure, the flow of traffic could be optimized, and with self-driving vehicles implementing energy-saving driving strategies such as anticipatory driving, automated driving could thus become more energy efficient [440, for a detailed review on energy demand see 522]. This could reduce emissions, air pollution, and noise [214,215,317]. "Platooning," that is, driving several vehicles behind each other at a very short distance, could increase the capacity of the existing infrastructure [79,571]. As accidents become rare, vehicles can be built smaller and with less safety equipment. The vehicle's lighter weight is also expected to contribute to a decrease in energy consumption [566]. The number of vehicles is expected to decrease with the advent of automation: Due to the autonomous relocation of vehicles, 18.3% of households have the potential to reduce vehicle ownership without changing their travel patterns [592]. The reduction will be significantly larger with autonomous vehicles not being privately owned, but shared, allowing for more efficient vehicle utilization [113,318,320]. Consequently, the number of vehicles could be reduced by up to 95% [62,93,95,176,179,492]. Due to reduced space requirements, there is a chance of reducing the area required for flowing traffic. In addition, the land consumption of automobiles will be further reduced if autonomous driving increases the spread of mobility services. Because fewer people might own a car in such a scenario, the need for parking space is reduced. Several studies simulating driverless taxi fleets have concluded that parking demand can be reduced by up to 94% [151,185,591], so that these areas can be used differently in terms of urban development.

While such ecological, economic, and social advantages of AVs are discussed often, some studies also attempt to assess negative consequences. A main concern is the various types of rebound effects that can occur as a result of resource saving [465,490,572]. Experts conclude that the desired effect on the environment can be mitigated by increased car use. Some researchers have tried to determine how mobility demand will change with the introduction of autonomous vehicles. Conducting a scenario analysis, Gruel and Stanford (2016) concluded that a future with private or shared AVs might result in increased vehicle-km traveled (VKT), leading to a potential increase in energy consumption and emissions [219]. Other studies model future transportation [62,541] and assume that the widespread use of autonomous vehicles will increase the number of trips, resulting in 3–27% additional journeys [356]. There are various reasons that trip demand might increase [134]. First, additional journeys or increases in VKT could be caused by the present non-drivers who will be enabled to make use of individual motorized mobility through automated vehicles [114,566]. Harper et al. [237] calculated a 14% increase in annual VKT for the US population aged 19 and older as a result of the additional travels of elderly people, non-drivers, and people with medical conditions. Second, lower trip costs could result in increased user demand for individual and motorized travels [95,179]. Simulation studies have shown that autonomous vehicles and SAVs could be offered at reasonable costs, attracting new demand: Burns et al. [95] calculates that SAV trips are 31% cheaper than trips by private car, depending on the fleet size and capacity utilization, and others found that SAV cost might be less than a third of what a traditional taxi charges nowadays [176,177,179,492]. Third, people will have better use of trip time [79] and will thus be willing to spend more time in the car and travel longer distances [257,350,363].

Automakers currently focus on designing autonomous vehicles for new forms of passenger experiences. In order to respond to the need of future drivers or passengers to use in-car-time meaningfully, that is, for working, relaxing, education, or entertaining, car manufacturers can consider various interior design elements such as retractable steering wheels [383,442,538,562,563], revolving chairs [345,383,442,562,563], movable objects [562], extendable shelves [345,383,442,563], ambient light [442,538], interactive surfaces [26,345,346,562], living room [26], and multi-purpose environments [563], as an analysis of Stevens et al. [503] revealed. Fourth, vehicles are expected to maneuver unoccupied [317,541] for reasons of relocation or valet parking [62,134,179]. Zhang et al. [592] calculated that unoccupied vehicles may lead to an increase in VKT of 13%. Some studies discuss possible mobility shifts away from eco-friendly mass transportation or alternatives such as walking, cycling towards more comfortable SAVs [296,358,541].

Thus, while various positive effects are to be expected due to the introduction of autonomous vehicles, there is general agreement that negative consequences can also be expected. At this stage of the analysis, however, it is not yet possible to predict what kind of effects will be dominant due to the many uncertainties and imponderables [223].

2.3.3.4 The Interaction of the Three Dimensions of Sustainability

Although the various impacts of autonomous driving are often discussed under one of the three sustainability pillars, an exclusive classification is not possible in many cases. In almost every aspect, impacts are likely not only for one dimension, but for two or all three dimensions. Take, for example, the aspect of demand for labor. For mobility service providers, autonomous driving means large cost savings when professional drivers are no longer needed, and a relatively large portion of personnel costs can thus be saved. Business opportunities can thus become much more efficient (economic aspect). At the same time, of course, there is the important social question on the side of jobs that could be eliminated in the mobility industries (social aspect). The change in transport cannot be attributed exclusively to the environmental dimension either; if there are fewer traffic problems, the costs associated with transport will also fall (economic aspect), and the lower emissions and reduced noise will increase the quality of life of local residents, and environmental health risks will be reduced (social aspect). This speaks in favor of a joint and against a solitary view of the three dimensions of sustainability – at least for the sustainability analysis of autonomous vehicles.

2.4 Shared Autonomous Vehicles

2.4.1 Automated Mobility on Demand

Three forms of autonomous driving are conceivable and are currently in different development and test stages: autonomous public transport, private autonomous vehicles, and shared autonomous vehicles [415]. The first two variants represent further developments of established means of transport. Autonomous driving in the form of autonomous buses, autonomous trains, or automated shuttle buses enriches public transportation. There are already a number of semi-autonomous and fully autonomous trains and metro lines, some of which have been in real operation for years, for example, in Spain [540], China [127], Dubai [431], and many more countries [545]. Autonomous shuttle buses are also being tested in real operation, for example, in France [426], Michigan [532], Switzerland [423], Germany [172,230,377], and Sweden [162,444]. Offering private automated vehicles is primarily the focus of the classic automobile manufacturers [68], which aim to adhere to their business model and sell the automated vehicles to their customers. As before, manufacturers are focusing on the driver [346,383,442,448] and aim to maintain the emotional bond between driver and car. Meanwhile, there is the concept of SAVs, which is the most disruptive of the three and which represents not only a technical innovation (automation), but also a social innovation (sharing). As such, it represents a passenger-centric concept [504].

Shared autonomous vehicles are thus understood as vehicles with automation levels 5 that can be hailed via an app, drive to the passenger to pick him or her up, and chauffeur him or her to the desired destination [177]. Discussions focus both on the exclusive use of such a service as known from conventional taxis – also referred to as robo taxis [9,564] or automated taxis [310,571] – or the simultaneous shared use of such a service – in the latter case referred to as an SAV with dynamic ridesharing [296] or pooled SAV [42,287,508]. The concept of SAVs without ridesharing is considered particularly competitive with conventional ownership and public transportation, because it combines the advantages of these two alternatives [353]. Thus, SAVs are expected to offer the travel experience of private vehicles including a door-to-door service, but at a low cost and without the burden of financial investment and ownership of private vehicles. Shared autonomous vehicles are currently in the testing phase. Uber has been testing robo taxis in Pittsburgh since 2016 and in San Francisco since 2017 [361]. Waymo, the Google autonomous driving project, has been testing robo taxis in Arizona since 2016. All three variants are thus currently being further developed, but experts consider SAVs to be the ones that will help autonomous driving achieve a breakthrough [375]. They believe that the sharing concept will prevail for two reasons: first, because it relieves the burden on users, since they do not have to invest in an asset but rather receive mobility as a subscription or pay for it according their use, and second, because, according to initial research, shared use seems to be the only way in which autonomous vehicles can contribute to a more sustainable and decarbonized mobility [68,177,588].

The shared use of vehicles is of course not a novelty. Already in the 1980s, interest groups came together to share a car. Since then, carsharing has gained in popularity and users as a result of digitalization. However, it remains a niche existence (see Section 2.1.3). If autonomous driving could be realized, this would have a strong impact on the various traffic concepts, with the carsharing concept particularly benefiting from automation. Carsharing users would no longer have to go to the vehicle and park it at one of the stations after use but could order the vehicle at a location of their choice, so that no additional routes would be necessary. Against the background of the different mobility services being harmonized as a result of automation, the concepts of carsharing, taxis, and ridesharing are converging to a large extent. Furthermore, an automated carsharing (/taxi/ridesharing) vehicle would offer the same level of comfort as a private car. For this reason, some experts expect that in the age of automated vehicles, cars will no longer be owned but rather shared and used according to individuals' needs. Against this backdrop, the experts expect a significant decline in the total number of vehicles as well as a reduction in emissions and traffic problems. On the other hand, rebound effects are also conceivable here: While automated carsharing is just as comfortable as an automated private car, it is much more comfortable than public transportation or cycling. If the use of an SAV is affordable at the same time, it could thus be particularly attractive for users of bicycles and public transportation and lead to an increase in individual traffic and the associated problems.

2.4.2 Effects of Shared Autonomous Vehicles

Experts forecast considerable potential for SAVs in terms of economic and ecological sustainability [47,396]. As with AVs in general, they expect SAVs to operate more efficiently than traditional vehicles [79,176,492], reducing resource consumption and environmental impact [440]. Intelligent algorithms and vehicle networking thereby enable SAV operators to easily reposition their vehicles to meet customer demand efficiently. As a result, experts expect positive effects with the advent of automated mobility on demand [179,215], mainly due to its potential to reduce the number of vehicles by up to 95% [62,93,95,176,179,492].

2.4.2.1 Theoretical and Quantitative Studies on Shared Autonomous Vehicles

To achieve such results, several simulation studies for the modeling of SAV fleets have recently been performed. In those studies, the authors have sought to forecast the effects of SAVs on travel, cost, or environment compared to forecasts on the use of privately-owned vehicles. For their analyses, they use agent-based modelling and queuing and network and simulation models to estimate transport system performance. For the simulations, trips are either based on the real internal trips of a region [95,492] or are generated throughout a grid-based urban area to mimic realistic travel profiles [177,367]. Burns et al. [95] simulated an SAV fleet for a medium-sized city such as Ann Arbor (285,000), for a small city such as the planned Babcock Ranch (50,000), and for the high-density area of Manhattan (1.6 million). They found that the average SAV cost per mile is 31% less than the average cost of a privately-owned vehicle and calculated that all trips could be executed with a fleet of only 15% of the number of privately-owned vehicles. In contrast to Burns et al. [95] , Fagnant and Kockelman [176] did not replace 100% of the formerly human-driven (city-internal) trips, but only a small proportion of 3.5%. In other work, Fagnant et al. [179] replaced only 1.3% of the trips. Both those papers concluded that each SAV can replace, respectively, around eleven or nine conventional vehicles with a reasonable level of waiting times (one minute or less), while VKT may increase by 10% or 8%, respectively, due to repositioning vehicles. Burghout et al. [93] produced similar results in their simulation of a SAV fleet, concluding that it is possible to replace private car commuter trips in a metropolitan area with self-driving on-demand taxis using less than 5% of the passenger vehicles currently in operation and less than 5%

of current parking places. They also found that a taxi fleet could only relieve the environment and congestion if users were willing to adopt ridesharing. A larger region such as Singapore would need a substantially greater number of vehicles to replace all traffic. Spieser et al. [492] simulated SAV transportation for Singapore and calculated that an effective fleet needs to have one-third of today's private vehicles. Owczarzak and Żak [396] developed eight different concepts of passengers' public transportation solutions based on autonomous driving and compared them with traditional forms of passenger transportation, simulating a trip and evaluating each means of transportation in terms of demand variants using a previously defined criteria catalog. Their results show that either the variant *autonomous vehicle only* or the variant *combination of buses and autonomous vehicle* serves best as an urban transportation solution.

Studies such as that by Burns et al. [95] additionally explored future costs of SAV rides – an aspect that is of great importance to users in their choice of means of transport. In their simulations, they show that SAV trips could actually be cheaper than trips by private car or taxi, with costs per mile of $0.41 depending on the fleet size and capacity utilization. These average costs per mile represent a savings of 31% compared to privately owned cars. Fagnant and Kockelman [176] achieved similarly positive results. In contrast to the previous calculations, Fagnant and Kockelman [177] and Fagnant et al. [179] assumed travel fares of $0.62 per trip-kilometer, less than a third of what is charged for a traditional taxi nowadays. They also assumed that the operating costs of SAVs will be higher in the early phases of SAVs and that these costs will only fall in the long term due to efficiency advantages.

As assumptions must be made and conditions for the modeling defined, these simulations cannot represent the true picture of future SAV use but can at least offer a broad, new understanding of the travel, cost, and environmental implications. In addition, these studies show that total distance traveled by all vehicles will increase [179,492]. The authors also generally agree that such sharing concepts offer great economic and ecological potential. If those societal potentials are to be tapped into, the factors of user acceptance and user experience in SAV use should be examined more closely. Such an examination would allow the factors that must be taken into account at an early stage of development in the design process to be determined.

2.4.2.2 User-Oriented Empirical Studies of Shared Autonomous Vehicles

As outlined, SAV simulations are based on data concerning current traffic flows and the resulting forecasts for future traffic flows [492]. In this respect, traffic simulations are often extrapolations of the current situation. It is difficult to estimate future changes in the behavior of road users. While behavioral changes due to, for example, bans or commandments can be relatively easily mapped in simulations, behavioral changes due to personal motives or attitudes are difficult to predict and for researchers to insert into analyses. Therefore, it is important to investigate the personal attitudes of potential users of automated mobility on demand. Recently, some – predominantly quantitative – studies have been published analyzing the user's perspective on the concept of SAVs, in particular with regard to their attitudes towards SAVs in general, their willingness to pay for the use of SAVs as well as intentions and purposes of use. As these works represent the most important part of the state of research and preliminary work, the results are summarized in Table 3 and presented in more detail below.

Haboucha et al. [227] performed an online stated choice experiment using two samples, one from Israel and the other from North America. Participants, most of whom were currently using private cars for their commutes with no one else in the vehicle (82.4%), were asked to choose a regular private vehicle, a private AV, or an SAV for their current commute. Among their choice sets, the authors varied the mode attributes of purchase cost (for next regular private vehicle or private autonomous vehicle), variable operating cost, and parking cost and found that a great majority of 76% preferred a privately owned vehicle, either a regular car (44%) or a private AV (32%), while only 24% preferred an SAV. Furthermore, even if the offer of SAVs were completely free of charge, a maximum of 75% of respondents would choose this option.

Krueger et al. [296] included the option of dynamic ridesharing into their stated choice survey to identify the characteristics and modality styles of users who are likely to adopt SAVs. They allowed their study participants to choose one mode out of three options – SAV without dynamic ridesharing, SAV with dynamic ridesharing, and their current mode option – for a trip that they had previously individually specified, while varying the service attributes of travel cost, travel time, and waiting time. Results showed that most respondents stick to their current option. Concerning the travel behavior impacts of SAVs, they found that car drivers and public transportation users were relatively more likely to choose the SAV option without dynamic ridesharing, whereas selecting the option SAV with dynamic ridesharing was more likely for car passengers.

Moreno et al. [367] combined an online stated preference survey and an agent-based traffic simulation in order to predict the impact of SAVs on vehicle-km traveled (VKT) and average trip duration. When asking how they would consider using automated vehicles, 41.5% of the respondents indicated that they were willing to use autonomous vehicles as SAVs, while 58.5% were not willing to use them as SAVs. Based on this assumed actual use of autonomous vehicles and SAVs, the authors generated commute trips and homebased other trips for a synthetic population and simulated urban traffic with a varying SAV fleet size. The simulation revealed an increase in VKT of 8% due to empty runs when the SAV fleet is relatively small, but this drops when the SAV fleet gains size. However, it should be noted that the underlying sample shows relatively strong biases in terms of gender, age, and car ownership compared to the actual population.

Stoiber et al. [508] conducted an online choice experiment with 709 Swiss participants to test what autonomous vehicle mode users are likely to choose for a typical trip in an AV's future, either privately owned AVs, pooled-use SAVs, or autonomous public transportation shuttles in combination with trains. Their results showed that 61% of respondents opted for either a pooled-use SAV or the autonomous shuttle/train combination, while 39% of the respondents preferred the privately-owned AV option or were indecisive. They further tested different push and pull instruments, considering changes in comfort, cost, or time that ought to incite mode shifts towards the pooled-use SAV or autonomous shuttle/train combination with regard to short- and long-term mobility decisions. They found that instruments increasing the attractiveness of pooled modes were more effective when they combined pull measures on comfort, cost, and time and when they were introduced along with push measures away from privately owned AVs.

Using a stated choice experiment, Winter et al. [577] asked 732 Dutch respondents to choose among SAVs, free-floating carsharing, private vehicles, and public transportation, taking into account how specific attributes such as travel time, waiting time, the time to walk to and from the vehicle or bus stop, parking cost, and trip cost vary among these alternative modes. Analyzing the participants' choice of mode in terms of their innovativeness when trying out new mobility trends, the findings revealed that early adopters of mobility trends showed a clear preference for SAVs over all other modes, while both normal and late adopters showed a clear aversion to this mode.

Similarly to that study, Ashkrof et al. [22] conducted an online stated choice experiment among 663 Dutch respondents taking different travel distances and different travel purposes into account. They limited their choice sets to conventional cars, public transportation, and an automated driving transport service. As the respondents rate the conventional car most negatively for short-distance commuting trips and rate public transportation as having the highest disutility of travel time for long distance commuting trips but the lowest disutility of travel time for short distance and long distance leisure trips, overall results suggest that the combination of different travel distances and purposes can significantly influence travelers' preferences.

In their online survey with 556 residents of metropolitan Austin (Texas), Zmud and Sener [395] applied the car acceptance model to predict the intention to use AVs and to analyze how different adopter groups can be characterized [593]. Among their respondents, the majority was interested in owning an autonomous vehicle (59%), while 41% were interested in SAVs. To gain a deeper understanding of the impact on the respondents' travel behavior, the authors conducted 44 qualitative interviews with participants from the latter group. Most of these respondents

(61%) indicated that with the option of SAVs, they would not change the number of vehicles in their household, while 23% would reduce and 16% would increase the number of vehicles in the household. While the overall number of vehicles (of that sample) might therefore drop, VKT will tend to rise, as 25% reported that their VKT would increase, 66% reported that their VKT would stay the same, and 9% reported that their VKT would decrease.

Kolarova et al. [287] used an online stated choice experiment survey to analyze possible changes in perceived value of time in conventional and automated travel modes and in user's travel behavior. With a first stated preference model, they allowed the participants to choose their preferred mode of transport among the current modes of transport for an individually defined trip, before in a second stated preference model they reduced the model selection by the option of the conventional car and extended it by the options of the privately owned AVs, SAVs and pooled AVs. The results showed that time spent in an automated vehicle was perceived less negatively than in a conventional car and was perceived as similar to the value of time in public transportation. Thus, from a value of time perspective, (shared/pooled) AVs could attract public transportation users, and on the other hand, the (pooled) SAV option could also be interesting for car drivers.

The stated choice survey of Becker and Axhausen [43] aimed at predicting the use of automated vehicles by providing highly differentiated scenarios and mode options to their participants. Allowing the participants to choose a preferred mode of transport out of the modes conventional car, bike, traditional public transport, SAVs, pooled AV, and an SAV feeder service for public transportation under varying circumstances, their results revealed that 25 out of 53 participants would decrease the number of cars in the household when SAVs and pooled autonomous vehicles are available, with the price not being the relevant determinant of that decision.

Menon et al. [344] investigated whether the presence of SAVs leads to a reduction in household-owned vehicles. Using an online questionnaire to address two study populations (university members and members of American Automobile Association), they found that 25.9% of respondents were likely or extreme likely to relinquish one vehicle in their household, whereas 54.2% of respondents were unlikely or extremely unlikely to relinquish one vehicle in their household. The willingness to relinquish one vehicle partly depends on various factors, such as gender, but varies considerably between single- and multivehicle households. Younger and well-educated users are more likely to relinquish a vehicle.

So, user-oriented stated choice studies on the selection of different means of transport show that a large proportion opt for the means of transport they are currently used to or a similar variant: Even in the age of autonomous driving, most users prefer private vehicles – either non-automated or automated. However, results vary significantly among the studies, with individual studies indicating a majority for SAVs. Such differences are likely due to the specific studies' framing or other participant-dependent or country-dependent specialties. SAVs will attract early adopters of mobility trends; however, users' preferences will depend on travel distances and purposes. Some studies revealed that SAVs may lead to a slight decrease in the overall number of vehicles, while there might be a slight increase in VKT. Overall, the analysis of related literature shows that quantitative studies outweigh qualitative studies. Particularly with regard to possible changes in user behavior that could be triggered by the emergence of SAV as a new mobility alternative, those affected are relatively uninvolved in the research themselves, especially in the form of qualitative methods.

Table 3: Summary of the literature review on empirical studies on SAV impacts

REFERENCE	METHOD	LOCATION	NO. RESPONDENTS	RESULTS				
				Modal Choice	Impact on Vehicle Ownership	Impact on vehicle kilometers traveled	User Profile	Other attitudes towards AVs
Ashkrof et al. (2019)	Online stated choice survey	Netherlands	663	--	--	--	People aged 18 to 40 are more willing to use the conventional car; working people and men are more likely to favor SAVs for long-distance trips	Regarding perceived in-vehicle travel time PT is perceived best, SAVs rank second before the car
Becker & Axhausen (2017).	Online stated choice survey		62	SAV was dominant in 8 out of 91 trips (3 compared to car, 5 compared to PT), PAV was dominant in 20 trips (8 compared to car, 12 compared to PT)	25 out of 53 households that own cars would decrease the number of cars in the household	--	--	--
Haboucha et al. (2017)	Online stated choice survey	Israel, USA, and Canada	721	76% preferred a privately owned vehicle, either a regular car (44%) or a PAV (32%), 24% prefer SAVs	--	Tendency to increase VKT	In Israel, males are more likely than females to favor SAVs; people with higher education favor AVs	--
Kolarova et al. (2018)	Online stated choice survey	Germany	485	--	--	--	Gender and age were not found to influence preferences toward AD	People perceived in-vehicle time PT less negative than in a car; and time spent travelling in an AV more similar to public transportation than in a conventional car
Krueger et al. (2016)	Online stated choice survey	Adelaide, Brisbane, Melbourne, Perth, Sydney, Australia	435	15.7% of participants chose the alternative SAV without DRS; 12.7% chose SAV with DRS, 71.5% chose their current travel mode	--	..	Individuals aged 24–29 are more likely to select the option SAV with DRS; multi-modal travelers are more likely to select one of the SAV options	--

REFERENCE	METHOD	LOCATION	NO. RESPONDENTS	RESULTS				
				Modal Choice	Impact on Vehicle Ownership	Impact on vehicle kilometers traveled	User Profile	Other attitudes towards AVs
Menon et al. (2019)	Online Survey	Tampa, St. Petersburg, Sarasota-Manatee, Florida, USA	1214	--	25.9% were (extremely) likely to relinquish one vehicle in their household; 54.2% were (extremely) unlikely to relinquish one vehicle in their household	--	Females were more likely to relinquish a vehicle in a single-vehicle household; millennials and graduate degree holders were more likely to relinquish a vehicle	--
Moreno et al. (2018)	Online stated choice survey / agent-based traffic simulation	Greater Munich metropolitan area, Germany	106	41.5% willing to use AVs as SAVs, 58.5% not willing to use them as SAVs	--	Increase in VKT of 8%	Male individuals younger than 35 years owning a conventional car were the most likely to use SAVs	
Stoiber et al. (2019)	Online survey	Switzerland	709	61% chose a pooled-use SAV or the autonomous shuttle/train combination, 39% preferred the privately-owned AV option or were indecisive	--	--	--	--
Winter et al. (2017)	Online stated choice survey	Amsterdam, The Hague, Rotterdam and Utrecht, Netherlands	732	Normal and late adopters showed a strong aversion towards SAV, early adopters selected AVs over all other presented modes	--	--	--	--
Zmud & Sener (2017).	Online survey / qualitative interviews	Austin (Texas),	556 / 44	Quantitative: 59% were interested in owning an AV, 41% were interested in shared AVs (results online survey)	Qualitative: 23% would reduce and 16% would increase the number of vehicles in the household, 61% would not change the number of vehicles	Qualitative: 25% reported their VKT would increase, 9% report VKT would decrease, 66% report VKT would stay the same	Males and higher incomes are more likely to use; households with children are less likely to indicate intent to use (51%) than households without children (45%)	--

3 ASSESSING THE IMPACT OF TECHNOLOGIES – INVOLVING STAKEHOLDERS IN SHARED AUTONOMOUS VEHICLE RESEARCH

Facing all these uncertainties that might come along with the disruptive potential of autonomous vehicles and SAVs, researchers recently called for the possible effects of autonomous driving to be investigated today, even if, in view of the many imponderables, few reliable conclusions can be drawn about possible technological consequences [232]. Given that autonomous driving is expected to provide greater safety, convenience, and equal mobility access while also posing economic, ecological, and societal risks, Grunwald (2016) considers an "early, comprehensive analysis and evaluation of the possible risks of autonomous driving [...] an indispensable part of a responsible research and innovation process" [223]. The Institute for Technology Assessment and Systems Analysis (ITAS) of the Karlsruhe Institute of Technology thus raised the question: "Automated Driving – Blessing or curse for a sustainable mobility?" [181].

Technical applications can never be regarded and evaluated in isolation in terms of their functionality. Apart from their primary purpose, technical applications are embedded in societal processes [443], always bringing along intended or unintended effects on their economic, natural and social environment [41,457]. There is always a social dimension that comes along with technology, as well as, by nature, a moral facet inherent in technology development [222].

Technology essentially means progress, because in many cases, it has clearly positive consequences. In the past, technology has made a significant contribution to combating diseases, protecting against natural hazards, and increasing human prosperity [222]. It has transformed how people live and work in positive ways. But there have always been undesirable side-effects of technology, which have not always been trivial [221]. Technical devices such as computers have facilitated many activities of our everyday lives, but at the same time, all these devices require energy, which comes from natural resources and results in the massive emission of pollution into the environment. Social media enable us to connect with each other regardless of time and place. However, social media has also spawned cyberbullying, fake news, and copyright and privacy infringements [28,231].

Within the interdisciplinary research field of technology assessment, researchers attempt to derive and identify possible scenarios of opportunities and risks. Thus, technology assessment is not a discipline in its own right, but rather a problem-oriented research approach across the various disciplines in which it can be applied [60]. Furthermore, technology assessment does not describe a specific method but is rather a collective term for different systematic procedures that are suitable for the scientific investigation of the conditions and consequences of technology as well as their social evaluation [221]. While technology assessment provides knowledge, direction, or methods on how to identify and cope with undesirable effects, it is not capable of solving the problems themselves. Rather, the aim of technology assessment is to provide (political) decision-makers with input for the decisions that accompany the further development and implementation of new technologies. As new technologies, such as autonomous driving, develop, representatives from politics, industry, society, and science must address questions such as which technical systems are socially desirable, where are the ethical limits of technology, and under what circumstances and up to what limits are technical risks reasonable [221]. While technology assessment can inform politicians of whether and in what way the further development of new technologies should be continued and whether and which regulations should be introduced in order to control the consequences of the technology [60], technology assessment can form a basis for (participative) technology design for industry and science. Technology assessment should not act as a hindrance to technology, but should, in the form of a constructive technology assessment, constructively accompany the development of new technology [220,362].

This is how the contribution of this thesis is to be understood. It is indeed the purpose of this work to critically examine the possible consequences of SAVs with regard to changing mobility behavior and the consequences of possible job losses. This should not, however, serve to demonize this technology in general, but rather to reflect back early indications to scientists, developers, and politicians in order to create new forms of mobility that take people's needs into account and are not overly burdensome to the environment. Within the subject area of SAVs, we are investigating a technology that does not yet exist on public roads, but which is heavily discussed, also due to incidents such as the deadly accident caused by a supervised automated Uber car in 2018 [568]. As such, I conduct a technology-induced technology assessment rather than a problem-induced technology assessment [322,555], which is by nature innovative rather than reactive, as it accompanies the entire process of technical developments through to market diffusion in a constructive manner [450,488].

Autonomous driving is a new technology that holds the potential to have far-reaching consequences. As outlined in Section 2.2, travel mode choices are very complex. Any change affecting the travel mode choice can lead to major changes in traveler behavior. In the complex field of travel mode choice, many aspects that play a role in the selection process are interdependent. A change at one point can result in all variables reacting to it (e.g., rising car cost leading to a decrease in car use while all other means of transport are being used more). Therefore, it is extremely important to consider these interactions in the case of a change, such as the introduction of AVs and SAVs. Mobility in its entirety represents a concrete subject area in which the individual travel modes can satisfy the needs of travel with each offering a different quality and therefore competing with each other. At the same time, however, other subject areas such as living and working also have a significant influence on mobility. Against this background, an isolated consideration of user decisions is not sufficient; rather, a dynamic-systemic approach is required in order to consider the interactions. In view of this complexity, I use different research methods to address the research questions (Section 4), as also proposed by technology assessment.

To be able to assess the technology consequences, I triangulated various methods and instruments in the studies presented within this thesis. To this end, I followed the general advice of the mixed-method methodology [524,525,529]. Using various methods to study a phenomenon from different angles provides a differentiated picture that is here meant to contribute to a "responsible research and innovation process" [223]. Technology assessment makes use of different methods that all try to forecast the effects of an innovative technology. To gain knowledge in a rather unknown field, technology assessors make use of expert interviews or Delphi studies, the results of which are then often incorporated into more specific analyses. These often focus on the expertise and experience of representatives in the respective field and try to forecast future technology developments and their effects [219,552]. In order to gain future knowledge, trend extrapolations, modelling, simulations, and scenario techniques are carried out for technology assessment. From an economic perspective, the results of cost-benefit analyses and decision analyses are of interest. In the research field of autonomous driving, many of these methods have already been applied with regard to the effects of autonomous driving. As outlined in Sections 2.3 and 2.4, studies such as those of Begg [47], Pettigrew et al. [415], and Trommer et al. [541] make use of expert interviews and Delphi studies. Furthermore, many scenario studies [219,356] and simulations have been carried out to forecast the effects of autonomous driving on, for example, transport [179,320,492], vehicle ownership [177,592], and parking in cities [591], and a risk analysis regarding societal consequences has been conducted [139,223].

While these methods are well-established and used regularly in technology assessment, they have in common that they reflect the results of analyses involving experts and scientists [219], while the expertise and opinions of other stakeholders can only be surmised. Therefore, following the logics of participatory technology assessment, I would like to go a step further in exploring the research question and integrate affected stakeholders such as users and professionals into the assessment of the consequences of SAVs. To do so, I make use of classical qualitative and quantitative methods used in social sciences. Although I thereby somewhat leave the classic set of technology assessment methods behind, the involvement of those affected opens up new perspectives on the research field, where the views of experts and scientists reach their limits. By doing so and having in mind that technology assessment methods are understood as "systematic methods used to scientifically investigate the conditions for and the consequences of technology and technicising and to denote their societal evaluation” [220], I argue that the systematic investigation of stakeholders’ expectations and possible reactions also falls under the technology assessment in a broader sense.

4 RESEARCH OUTLINE

4.1 Research Questions

Guided by the overall question of whether SAVs will contribute to a more sustainable mobility, I performed several empirical studies. Forecasts are always speculative, as they depend on several explicit and implicit assumptions. This is particularly true for technical and social developments that depend on a number of contingent factors and events that are difficult to anticipate. Furthermore, forecasts can themselves have an influence on future developments, which means that the initially predicted future does not occur as a result. Scenarios on the future climate can, for example, influence political action to the effect that the scenarios do not come true. The quality of research into possible futures is therefore not measured by whether it correctly predicts future developments, but rather by the fact that it provides insights to inform today's decisions about shaping the future [449].

Hence, to uncover the field of possible futures, together with my colleagues, I took a systematic look at fundamental issues regarding possible futures with AVs. Driven by the question how a future with autonomous driving might look, we conducted a scenario analysis, applying the scenario-axes technique [283], the results of which are presented in **Study 1** (Section 5). Building different future scenarios depending on further progress of the socio-technological megatrends of sharing and digitalization allowed us to draw four different pictures of possible futures. Depending on how high the probability (in the Bayesian sense [263] of probability as an expression of [un]certainty) is that each of these trends will continue, different scenarios with different implications for a future with autonomous driving arise. By identifying relevant driving forces for the two mega trends, we drew conclusions as to which of these scenarios appear to be the most realistic. For these scenarios, we discussed the respective consequences in terms of the possible social, societal, and economical effects of these scenarios. The results of this scenario analysis represent a landscape of possible effects of autonomous driving, on the basis of which we identified more specific research questions that are intended to contribute to answering the overall question.

As outlined, I address two dimensions of sustainability – the ecological dimension and the social dimension – in order to further enrich the picture of possible SAV impacts. As outlined in Section 2.1.2, sustainability assessments are highly complex, as different dimensions that are interwoven and thus strongly interact with each other must be taken into account. This makes it necessary to focus on more specific assessments that cannot fully answer that question at hand, but that by reflecting different aspects and sub questions may contribute to doing so. The issue of the ecological impacts of the expected concept of SAVs is focused on in Studies 2, 3, 4, and 5, which apply different methods that, when triangulated, are meant to provide a rich picture that contributes to answering the first key question.

The ecological consequences of transportation are on the one hand dependent on the travel means' attributes, such as its energy consumption or durability, and on the other hand on the means and intensity of its usage [519]. Driven by a user-oriented approach, I concentrated on behavioral changes induced by introducing a new means of transport such as SAVs (Section 2.2) that can lead to an overall decrease or increase in greenhouse gas emissions and other positive or negative consequences. Tackling the issue of behavioral changes, I therefore raised the research question "*How will users respond to the advent of SAVs in terms of changes in their mobility behavior?"* This question is focused on in **Study 2** using a qualitative approach. As it is difficult (for a user and a researcher) to answer that question right away given that this travel mode is not yet usable for the ordinary user, I tried to approach an answer in different ways. First, I aimed to understand the basic attitude of users towards this innovative business model, which combines both the innovative components of self-drive technology and the innovative components of sharing. Furthermore, I was interested in what purposes users can imagine for SAVs. Exploring what kind of trips users consider suitable to be conducted by SAVs helped to assess what part of their overall trips might be executed by SAVs in the future and whether SAVs may lead to additional journeys. Combining these insights with information about their current mobility behavior enabled us to analyze what means of transport they will substitute for SAVs.

Travel mode choices are complex but, following neo-classical utility theories [301], highly driven by user preferences towards the respective travel mode [210]. Identifying user preferences towards transportation means can thus help anticipate actual travel behavior to some extent. Analyzing user preferences can thus serve as a means of anticipating future travel mode choices, including the potential new automated travel modes. Furthermore, by analyzing both current and future travel mode preferences, insights can be gained regarding potential modal shifts and possible rebound effects. In **Study 3**, I therefore addressed the research question "*How do user preferences change with the advent of autonomous mobility concepts?"* Conducting a stated preference survey, this study also served to validate the qualitative findings of Study 2.

While stated preference analyses reveal overall attitude towards a transportation mode, nothing can be said about why users have this particular preference. As outlined in Section 2.2, the decision for a good reflects the utility assessment of the good's attributes according to the random utility theory. Thus, analyzing users' assessments of the attributes of different means of transport can serve as a means to better understand how users come to their respective preference/travel mode choice. Furthermore, gaining knowledge about the users' specific assessments of different mode features reveals implications for strengthening sustainable forms of mobility.

Hence, we aimed to analyze how the decision in favor of or against a travel mode relates to the relative overall benefit and what relative partworth utilities automated travel modes offer. **Study 4** also served as a compliment to Study 3, and we thus opted for a quantitative approach, conducting a user survey online.

Since motorized private transport causes considerable air pollution and traffic problems, transport policy aims to shift traffic to the more environmentally friendly public transportation. There are many indications that automating the car will make individual transport even more attractive, which will make the desired modal shift even more challenging. In order to become more attractive, public transportation services would also have to become more attractive. Here, too, automation could contribute. This raises the question of whether a combination of automated driving and public transport is a flexible and efficient transport solution that can also make public transport attractive to former non-customers. We addressed this question in **Study 5**, investigating the experience with and the intention to use automated public transportation. To this end, we performed a quantitative online survey.

With regard to the second key question on the social impacts of the expected concept of SAVs, I conducted two qualitative studies (Studies 6 and 7) and one quantitative study (Study 8), all of which complement each other. As outlined in the introduction of this work, I focus on the impact that fully autonomous vehicles will have on labor in the mobility sector. While many professional drivers, such as public transportation drivers, truck drivers, and delivery staff are expected to be negatively affected by fully autonomous driving (Section 2.3.3), I focus on taxi drivers, as SAVs are considered to be a substitution for traditional taxis [177,317].

Some experts expect the profession of taxi drivers to become obsolete as a consequence [46,63,134,571]. Since most of these experts claim in a rather undifferentiated manner that there will not be any professional drivers in the age of autonomous driving, there is a lack of investigation into whether indeed all professional drivers will become obsolete or whether there are reasons for the job of a human taxi driver to still exist in the age of SAVs. Furthermore, these expectations stem from researchers or other mobility experts, while the taxi drivers themselves have not been heard in this context. This leads to the questions of *how taxi drivers assess the potentials for the automation of their profession by SAVs* and *what contextual factors shape the adaptation of the profession to increasing automation and how these factors can inform the design of new technologies.* We took up these questions in **Study 6**, in which we extended the discourse by including the perspective of professional taxi drivers. Since nobody knows the profession of a taxi driver as well as the taxi driver him- or herself, we expect him or her to be able to explain to what extent the human taxi driver might be superior to a fully automated taxi in the future. To gain insight into the subjective and social worlds of drivers, we chose a qualitative approach.

As discussed in Section 2.4.2.2, many studies have recently investigated the a priori user acceptance of SAVs. As those who will finally decide whether to take a human driven taxi or an SAV, the users are of particular interest to investigate regarding their preferences and attitudes. The mentioned studies, however, do not explicitly tackle the question of whether users will favor SAVs over traditional human driven taxis. To address this gap and in order to further enrich the discourse by including the stakeholder group of actual taxi users, we focused on the research questions *how important users think it is to have a human driver in their transportation services* and *whether they will consequently prefer autonomous taxis over traditional taxis* in **Study 7**. There are many reasons why taxi customers might prefer one of the alternative taxi services (traditional human-driven taxi vs. SAV) over the others. While the cost of using the service surely is one critical reason, the quality of the service itself is another that must be considered (Section 2.1.3). In order to learn what today's taxi customers value about taxis as they are today and what they do not and to what extent SAVs would be suitable to meet their needs regarding costs and comfort, we made use of a qualitative research design focusing on millennial-aged users.

While these qualitative studies provide information about the breadth of personal attitudes of those affected, they cannot provide an exact indication of the quantitative significance that the group of potentially support-needy customers actually has. Quantifying this group might reveal on the one hand the potential for assisting taxi drivers, who might also have a right to exist in times of autonomous vehicles, and on the other hand, the potential for the design of SAV concepts focusing on mobility impaired people. **Study 8** therefore addresses the questions of *what share of the taxi business is accounted for by taxi rides with mobility-impaired customers* and *how the needs of mobility-impaired people can be considered in times of autonomous driving?* A survey on taxi use conducted in Germany in 2014 [258] serves as the basis for a quantitative secondary analysis.

4.2 Methodology

To address the outlined research questions, I applied a mixed-methods approach, which ought to provide a differentiated picture regarding the ecological and social impacts of SAVs. By triangulating different methods, the strengths of one method should compensate for the weaknesses of the other with the aim of achieving a higher validity [104]. I first analyzed existing literature to identify findings that have already been published in this context. The findings of the literature review were presented in the state of the art section (Sections 2.3 and 2.4) and have been incorporated into the respective studies of this thesis. Specific literature analyses have further been conducted for each study respectively (see Sections 5–12). Based on these first insights, we made use of the scenario-axes technique [283], one of many scenario techniques, in order to gain an deeper understanding about possible futures in the area of autonomous cars. The development of scenarios was meant to provide qualitative information on the expected effects and to identify opportunities and risks for different futures at different levels (entrepreneurial, individual, societal).

With regard to the subsequent studies, we concentrated on the scenario in which automated vehicles are provided on demand (SAVs). In order to investigate basic aspects regarding the attitude towards and the possible future use of autonomous mobility concepts, we first chose a qualitative approach, in which we conducted personal problem-centered semi-structured interviews with potential users (Studies 2 and 7) and professional drivers (Study 6). Qualitative methods are often used when the research object is new or to explore the field of research and develop hypotheses [201]. As such, the interview method is often used to capture initial findings and the breadth of relevant aspects about a research object. Results from qualitative methods could precede quantitative methods to clarify the direction of the investigation and can serve to form the basis for the design of a quantitative questionnaire [427,452]. Since autonomous driving and SAVs represent a new research topic, and the state of knowledge of non-experts is very diverse, making use of such a qualitative approach presents a reasonable procedure. The main strength of qualitative interviews is their ability to capture subjective experiences and interpret needs and attitudes. With regard to autonomous cars, these topics are still changing and are quite diffuse. By choosing this method, we aimed to bring the participants' subject-related understanding and their subjective opinions, views, impressions, and experiences to the fore [251]. Furthermore, at this stage of the investigation, I wanted to take advantage of the high degree of openness and flexibility of qualitative interviews, which allow the researcher to react to the answers of the interviewees, to consider their level of knowledge, and to adapt the further questions accordingly in order to achieve a smooth conversation flow [152,427]. All interviews were recorded, fully transcribed, and analyzed independently by me and at least one other researcher. We followed a thematic analysis procedure based on Braun and Clarke [73]. Thematic analysis is a method for identifying, analyzing and creating topics from datasets and is not bound to any theoretical framework [72]. Coding the transcribed interviews, we followed a deductive semantic approach.

While qualitative methods primarily aim to capture subjectivity and a wide range of responses, their disadvantage is that their results cannot be generalized in a statistical sense. Rossman and Wilson [452] therefore argue that combining qualitative and quantitative research methods within one research project can be a sensible approach. Quantitative techniques are suitable to confirm the results originally obtained from qualitative methods [216]. Once we had obtained initial results from the qualitative studies, we intended to examine how attitudes relate to the broad mass of users. To receive large scale information about the user's preferences towards future automated mobility concepts and their perception of the different attributes of the travel modes, we conducted quantitative surveys via the Internet (Studies 3, 4, and 5) and conducted a quantitative secondary analysis surveying taxi use in Germany in 2014 [505] (Study 8). With quantitative methods, the questions to the participants are determined before the survey is carried out, so the method offers a high degree of standardization. As a result, it is no longer possible for a researcher to respond individually to the survey participants. Using quantitative surveys, we collected numerical data, which we then analyzed statistically in order to gain new insights (Studies 3 and 4) or test hypotheses (Study 5) [452]. With the help of suitable mathematical-statistical methods, we reduced complex information to its essential characteristics, which helped contribute to answering the main research questions [373].

5 STUDY 1: USING, SHARING, AND OWNING SMART CARS – A FUTURE SCENARIO ANALYSIS TAKING GENERAL SOCIO-TECHNICAL TRENDS INTO ACCOUNT

The megatrends towards both a digital and a usership economy have changed entire markets in the past and will continue to do so over the next decades. In this work, we outline what this change means for possible futures of the mobility sector, taking the combination of trends in both economies into account. Using a systematic, scenario-based trend analysis, we draft four general future scenarios and adapt the two most relevant scenarios to the automotive sector. Our findings show that combing the trends from both economies provides new insights that have often been neglected in literature because of an isolated view on digital technology only. However, service concepts such as self-driving car sharing or self-driving taxis have a great impact at various levels including microeconomic (e.g., service and product design, business models) and macroeconomic (e.g., with regard to ecological, economical, and social impacts). We give a brief outline of these issues and show which business models could be successful in the most likely future scenarios, before we frame strategic implications for today's automobile manufacturers.

5.1 Introduction

What are possible futures of car mobility in Europe 2030-50 and what are the implications at the consumer, business, and societal levels?

In various respects, modern Western societies are mobile societies characterized by highly individualized lifestyles. This mobility is facilitated by transport systems and mobility, with the car as the main means of transport. However, the picture is changing as monomodal, private-car based mobility neither meets the challenges of today's mobility complexity nor satisfies the needs of individualized lifestyles and the demands of sustainable societies. In contrast, multi-optional offers where users can combine appropriate mobility forms that suit their respective situations seem to be better suited. Computer-based and app-based travel information systems make it easier to plan and perform these multimodal trips. First signs are already visible; in car-focused nations such as Germany the importance of public transport and non-motorized transport slightly increased in recent years [306].

New mobility concepts such as fully autonomous driving are appearing on the horizon. Self-driving cars, in particular, do not present just an incremental innovation in safety and fuel-efficiency. They present a completely new mode of transportation that has the potential of a disruptive innovation [355]. They enable completely new mobility services, which affects the choice and use of available transportation options.

The research field of self-driving is fairly new. Most of the work focusses on technological, legal, political, and ethical issues. Only a few papers investigate the design of mobility services and usership models and their impact on everyday mobility (cf. Section 2). This blind spot is partly caused by the fact that automated driving is currently not yet reality and its effects are not yet empirically observable. Investigations into a self-driving-based mobility are therefore, to some extent, uncertain and speculative. However, to actively shape the future, we have to envision possible effects of this trend. Mobility researchers, traffic planners, and business men should take the opportunity to re-think mobility from scratch and develop urban concepts and business models that go beyond switching from private traditional cars to private autonomous cars.

We study possible future development paths by using scenario-based analysis. Supplementing existing scenario studies [e.g. 170,316,355], we take a closer look at the general social megatrends of digitalization and usership rather than ownership. We outline how these two megatrends affect the future of car mobility. In particular, we believe that combining both trends constitutes the disruptive quality that impacts the consumer, business, and social levels. Although our analysis shows that it is a megatrend, usership is unlikely to become the dominant consumption mode. Business models and policy instruments should therefore be designed for the situation that owning and using smart cars will co-exist for a long period.

5.2 Related Studies

In the last years, the smart car research field has witnessed a boost in work covering topics such as driver assistance systems, connected cars or autonomous, self-driving, or driverless vehicles. Several studies have focused on particular technological issues while others pinpoint to ethical issues and the user acceptance of self-driving cars. Based on these insights, some studies looking at the future have been published recently. They draft scenarios that show how automated vehicles might change future mobility; work that we continue here.

One cluster of future studies focusses on policy instruments and their impact on the penetration rate and speed of adoption. For instance, Milakis et al. [355] discuss different development paths in the Netherlands with regard to the speed at which automated vehicles are accepted. They assume that technological development and policy directions are the most relevant driving forces. In their scenario, fully automated cars are most likely to be launched between 2025 and 2045, penetrating the market rapidly after their introduction. Litman [316] also factors policy instruments into his discussion of various paths with regard to market penetration and diffusion of other technological innovations. For his most realistic scenario, he concludes that it will take 10-30 years from market launch until the automated vehicle dominates car sales. In a similar vein, Nieuwenhuijsen [380] outlines a simulation model that also considers policy instruments such as knowledge sharing, collaborative projects, and public and private technology funding. His model shows that these instruments lead to faster technological progress and hence to a faster market penetration. Yun et al. [587] ascertain that decreasing governmental regulation and an increasing business model level will facilitate market growth. Their findings are based on a simulation that shows how different technology paths and business models impact the market development of automated vehicles under varying circumstances.

A second cluster of studies focusses on human factors and their impact on business strategies. For instance, Bartl [35] shows that strategic planning should consider vehicle design and ownership as relevant dimensions that shape car futures. The first dimension ranges from conventional to reinvented design, depending on the level of automation. The second dimension is characterized by two poles: owning versus sharing. Similarly, Epprecht et al. [170] use expert interviews to identify automated driving and sharing as two visionary forces in the automotive industry. Conducting a scenario analysis, they pinpoint that the user acceptance of car-sharing and usership models will be a key question in the future. In particular, they see current consumer attitudes as a vital barrier to the success of innovative technologies.

This barrier has led to a third cluster of user acceptance studies recently gaining more attention. With regard to autonomous cars in general, a recent study by Payre et al. [410] reveals that a large majority of the population have a positive attitude and can imagine buying and/or using them. The literature further shows that acceptance depends on several other parameters. For instance, acceptance increases when users are allowed to take control [175]. Other factors are age and gender, individual personality, pre-experience with partly autonomous cars, characteristics of the innovation, the driving environment, and the manufacturer's reputation [386,445]. At the same time, other studies report that people are concerned about self-driving vehicles [253]. These concerns seems to be cultural and country dependent as well as gender dependent: females seem to be more concerned than males [473].

However, most studies focus on autonomous cars in general but neglect ownership as a relevant category. In particular, the surveys do not differentiate between ownership and usership models but focus on private cars only – whether explicitly or implicitly. Only a few investigations look at self-driving mobility services, e.g., self-driving taxis, in detail [e.g. 96,238]. Furthermore, empirical studies can only provide a snapshot of the status quo; they fail to consider the long-term process of changing norms and attitudes, changes that affect user acceptance in the long run.

In summary, the literature shows that technological development paths cannot be studied in isolation because they are shaped by various socio-technical factors. These factors include ethical and legal issues as well as economic and design issues. All in all, it is the consumer who will determine what kind of mobility will dominate, and ownership would thus appear to be a category that future mobility studies should take into account. User acceptance can be investigated in empirical studies but only for current users; researchers are unable to consider temporal changes in user attitudes. We therefore want to answer two research questions in this work:

(RQ1) *What are the pre- and post-conditions of the broader socio-technical trends of digitalization and usership?*

(RQ2) *How do these trends impact future car mobility models?*

5.3 Methodology

To answer our research questions, we conduct a scenario analysis. This methodology is an approved instrument for identifying and structuring changes, drivers, and consequences within unknown, uncertain, and changing environments [329,441]. Various scenario analysis techniques exist. In this paper we adapt the scenario-axes technique [520]. This variant covers the four activities: scanning, monitoring, forecasting, and assessing in order to outline possible futures.

We applied these steps as follows: First, we outlined the framing question (at the beginning of this paper), which was shaped by the current car mobility discourse in research, politics, and the mass media. We reviewed general future studies and found that the two megatrends of digitalization and usership economies are often mentioned in literature [56,366]. Hence, we analyzed these megatrends in more detail by placing them into a broader context of general trends in societies without applying them to a specific industry at this point of the analysis. We then identified the pre-conditions that have driven the two trends so far, taking relevant literature into account. Post-conditions under which the trends are going to proceed were also investigated. The assumptions behind these post-conditions were subsequently evaluated with regard to their uncertainty and their impact on the trend. This evaluation process was adapted from the concept of expert assessments. To increase the evaluation's intersubjectivity, three authors independently rated the impact of the assumption. In most cases, the evaluations coincided with little deviation. When there was a higher deviation, the authors discussed their opinions and came to a consolidated conclusion. Based on the results of this evaluation, the two most critical and thus decisive driving forces were derived by selecting the most uncertain assumptions with the highest impact to the trend [520], also taking into consideration other important assumptions. These critical uncertainties serve as the axes for the scenario matrix that classifies the four scenarios. By taking into consideration the assumptions made for the trends and fitting them into the context of the particular scenario, coherent scenario descriptions were developed. Finally, we evaluated the scenarios' probabilities, by using the method we applied in evaluating the post-conditions, selected the most likely scenarios, and interpreted them in terms of car mobility futures. Based on the scenarios implications for the industry were derived on a consumer, business, and social level.

5.4 Trends

5.4.1 Digitalization

Pre-Conditions

Digitalization describes the socio-technological trend of the *ubiquitous computing* of all areas of life in which people are part of digital ecosystems using smart objects that are mutually connected without loss of information or function [576].

The main driver of this trend is the exponential growth of IT-technology, which can be seen, for instance, in the doubling of the computing power every 18 months (Moore's Law), in the doubling of data transfer rates every six months (Gilder's Law) or in the value of computer networks being proportional to the square of the number of users and machines (Metcalfe's Law) [303]. This development is supplemented by widespread utilization, general user acceptance, and everyday usage of social web and digital services. Today it is common to have a smart phone and a Facebook account, to buy goods online, or to use location-based services such as Yelp or Foursquare. With the development towards an Internet of Things [25], various systems are becoming increasingly integrated, with social webs, semantic webs, and sensor webs constituting dynamic, cyber-physical systems. Material goods are enriched by digital solutions and becoming cyber-physical. Embedded systems are an integral part of products and services, leading to new or expanded feature sets. These changes are the result of the progress in artificial intelligence (AI) and semantic technologies, which have allowed goods to become smarter and more autonomous.

Digitalization has already changed entire industries within the consumer market. It has led to a whole industries being rapidly transformed, with products and services completely or partly been substituted by digitized ones [518]. Examples can be found in the music industry [254], the photography industry [321], and the newspaper industry [271].

Post-Conditions

For this trend to proceed, it is important to assume continuing **technological advancement**. Technological progress cannot be expected to stagnate. Government **investments** in and subsidization of Internet and mobile infrastructure build a base for further networking and for developing the artificial intelligence of things. In all probability, governments are going to implement **regulations** to improve Internet security and personal privacy and thereby reduce cybercrime and terrorism to a minimum. Further they will define requirements for secure information systems and clarify liability questions within autonomous systems. They will also continue to outline competition regulations and improve the funding of open standards, making connection of devices and system integration easier.

People's trust in digitalized environments will continue to grow, and they are prepared to **connect** their goods and use smart functions in many areas of their everyday life. It can be safely assumed that, as long as the data is not too sensitive, people will be ready to supply private data to benefit from the convenience these goods provide. The generation connected, or so-called **generation c** [193], born after 1990, has grown up or will grow up in a primarily digital world. Their familiarity with technology and reliance on mobile communications and their desire to remain in contact with large networks, either private or business ones, will change how everyone works and how they consume.

5.4.2 Usership

Pre-Conditions

Usership [380] describes the socio-cultural trend of sharing or using goods on demand rather owning them [51]. In the literature, these two trends of sharing and using on demand are often described independently [331,474]. In this paper, we consider usership to cover both the using and the sharing concepts.

There are different drivers for this trend. First, in the past, ownership had a strong symbolic function, following the dictum "You are what you own" [50]. But in times of mass-consumption and rising urbanization, owing has lost its means of distinction. As a result, the attitude has shifted in recent years towards alternative forms of property and consumption [229]. Second, increasing environmental awareness is driving usership. Here, sharing resources is not tainted by an image of poverty; it now has a positive green image [70,229,535]. Moreover, sustainable consumption serves as a new means of distinction [489].

Third, the Internet is often seen as enabler for collaborative consumption services [516] as it reduces tremendously the searching and transaction cost of sharing goods and helps to reduce physical interaction. Web 2.0 created yet more forms of sharing [52] since the sharing platforms allow suppliers to reach a broader audience and consumers to have access to a broader range of products and services at minimal costs. The trend towards usership is most evident in the case of immaterial goods such as music, films, or software, where owning has increasingly become the exception rather than the rule [129].

Post-Conditions

Generally, new sharing and service concepts are well known, but they currently play a minor role in people's everyday life. However, it can be assumed that they will become a general commodity.

In particular, the young generation (generation c) is changing its consumer habits [244]. The general assumption is that consumer **awareness of sustainability** issues will continue to expand. This assumption is supported by an increasing consumer demand for sustainable goods and food. Further, international agreements such as the United Nations Climate Change Conference 2015 agreed to a strict set of goals limiting global warming. Hence, it is reasonable that sustainable transport modes will be widely promoted by governments in the future. A general abundance of goods and generation c, which embraces the shared economy-thought, may allow a **shift in consumer attitude** from ownership for status reasons to usership to develop. The growing population in conjunction with limited resources will inevitably result in higher **costs** for consumers. Hence there will be a need to forgo individual ownership. The question is in which categories of goods the shift will take place next.

It can further be assumed that the transaction costs of service and sharing economies will decrease because of an increasing **urbanization** [547]. The higher density of people in urban will make sharing easier to realize because more potential users will be able to collaborate in sharing. Additionally, it will become necessary to share goods in some sectors with limited (mineral) resources e.g., rare earth elements used in the production, but also with limited physical resources such as housing, streets, or parking places. Under the assumption that the governments will set clear **regulations** concerning privacy issues as well as clear regulations, e.g., for liability standards, occupational safety and taxation, consumers are more likely to be more open to using and sharing, and will thus strengthen the trend. Due to their contribution to sustainability, governments will presumably promote and subsidize collaborative consumption.

5.4.3 Impact Evaluation

The evaluation process has already been discussed in more detail in Section 5.3. From the evaluation, we were able to identify five driving forces (see Table 4). Each is assumed to be critical, with either a direct or an indirect effect on how the trends continue and/or intensify.

To assess the level of impact, we considered the post-condition of each factor and how it shapes future developments. To assess the critical uncertainties, we stated how confident we are that each particular condition will come true. By combining both indicators, we could define the critical conditions/uncertainties (Total in Table 4). For the digitalization trend, we conclude that the actual development path of the Internet of Things **connecting** cyber-physical systems [25] is crucial and builds the first critical uncertainty. For the usership trend, we conclude that the acceptance of usership models is primarily dependent on a change in **consumers' attitudes**. Usership will only become a dominant economic model in society if ownership becomes less important for consumers.

Table 4: Evaluation of post-conditions

POST-CONDITION		POTENTIAL IMPACT	UNCERTAINTY	TOTAL
Digitalization	Technology	7	2	9
	Regulations	5	4	9
	Investments	8,5	3	11,5
	Connection	8,5	6	**14,5**
	Gen-C Attitude	7	2	9
Usership	Sustainability	4,5	4,5	9
	Consumer Attitude	9,5	7,5	**17**
	Costs	7,5	1,5	9
	Urbanization	7	3	10
	Regulation	6	5	11
	Costs	7,5	1,5	9
	Urbanization	7	3	10
	Regulation	6	5	11
	Costs	7,5	1,5	9
	Urbanization	7	3	10
	Regulation	6	5	11

5.5 Scenarios

Our scenario development reflects that these two trends play the most vital role in how the future will develop; *connected smart systems* and *usership attitudes* therefore build the axes of the scenario graph. The combination of these two different driving forces with their reasonable possibilities leads to the following set of four scenarios (see Figure 3).

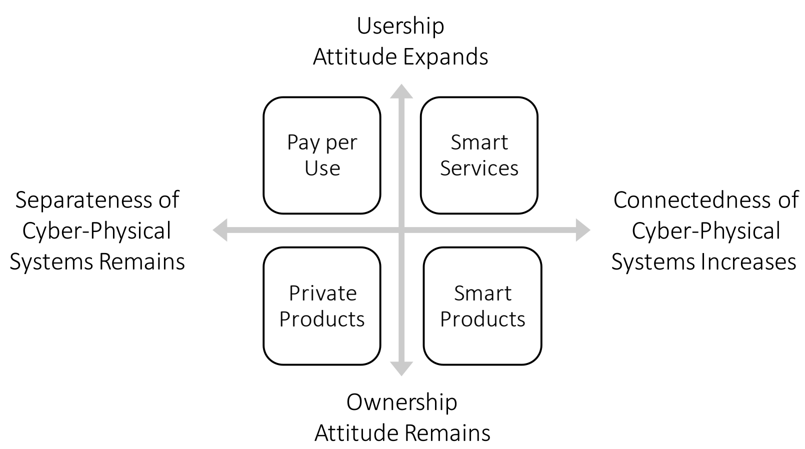

Figure 3: Scenario matrix

5.5.1 Private Products

In a private products scenario, people prefer ownership over usership for goods that are not highly digitally connected. Status symbols are still essential for individuals, even if the goods that provide this status have changed. The importance of expressing one's individuality through those goods results from increased costs caused by a rising population in conjunction with limited resources. The growing urbanization and a slow but steadily growing awareness of sustainability needs also contribute to higher costs. At the same time, only a few of these goods are integrated, although technological progress has made a broader networking of things possible. But since the high complexity of this market does not allow the government to provide rigorous openness, security, and privacy standards and since data abuse and cybercrime occur, people are not ready to hand over personal and sensitive data.

5.5.2 Pay per Use

In this scenario, people have a usership attitude. They use and share things instead of buying and owning them. The attitude is supported by people recognizing and accepting the need to reduce waste and environmental pollution. This consumer behavior is also encouraged by the government: the government has set strict climate protection goals and promoted the usership economy by increasing the price of ownership, formulating minimum requirements for shared goods and services, and developing strict data protection laws. Indeed, a high connection and integration of the shared goods and services is possible from a technological point of view, but techniques reach their limits when it comes to ethical questions that a machine is not able to answer. Since people additionally have data protection concerns, society often rejects further connection such as smart services and smart goods.

5.5.3 Smart Products

In the smart product scenario, the vision of an Internet of Things [25] where all things are smart and connected has become real. This scenario promises great technological progress, a platform for digital innovations, and high security and privacy standards. People set great value on sustainable assets. However, as in the private products scenario, people prefer owning rather than sharing goods, with a preference for high-tech products as status symbols. In the private domain, more and more appliances and devices are communicating and that is leading to a smart environment. In particular, smart technologies are used when they make domestic life more convenient. People are ready to trust technology within their ownership. However, they are still skeptical towards digital, connected services where personal data are collected and externally used by commercial and public service providers. Smart connections are only tolerated if they increase comfort and do not affect the power of disposition and the privacy of personal data.

5.5.4 Smart Services

As in the previous scenario, the technological vision of an Internet of Things has become real. But here the social vision of service and sharing economies has also become real. Consumer attitude shifts from an ownership to a usership approach. Status-based thinking has been replaced by a pragmatic approach of benefit-based thinking. Reduced power of disposition and control is tolerated if it increases quality and stability of the overall service system and is compensated by other incentives (e.g., service discounts, service upgrading, etc.). Therefore, the consumer agrees to disclosing personal data if it does not just improve the provider's resource planning but has a personal benefit, too. Improved efficiency means that smart services also answer the challenges of continued resource limits and sustainability demands. Resource efficiency is not simply an option; it is a necessity for society to prosper and advance. Development is facilitated by an increased urbanization, where more potential sharers are available and sharing becomes easier and the pressure to share increases. Sharing is supported by the government applying share-focused policies e.g., investing in share-infrastructure in urban areas, taking measures to increase sharing, and imposing regulations and standards for privacy and security. These improved sharing conditions are internalized by consumers, thus strengthening their usership and sharing attitude. This change in attitude also leads to a greater desire to stay connected through networks, enabled by technology breakthroughs and government subsidies in investments in high-speed broadband networks. The high privacy standards give society greater trust in new technologies. Digital interactions and collaborations replace major parts of society's face-to-face interactions.

5.5.5 Scenario Evaluation

We consider the general scenarios smart products and smart services to be the most likely scenarios. Likelihoods of the scenarios were evaluated by assessing them for the two dimensions separately and multiplying them for the individual cells. This step reduces the complexity but neglects possible interactions between both dimensions.

There are good reasons for assuming an increase in the socio-technological trend, displayed on the horizontal axis, e.g., by the connection, integration, and collaboration the value of the Internet of Things growths squared for all members (Metcalfe's Law). However, several counterforces might hinder or delay this trend. With the further connection of things, the complexity grows exponentially, too. Therefore, we consider that high connectedness is more realistic (assessed with 70% probability) than digital separateness (assessed with 30% probability).

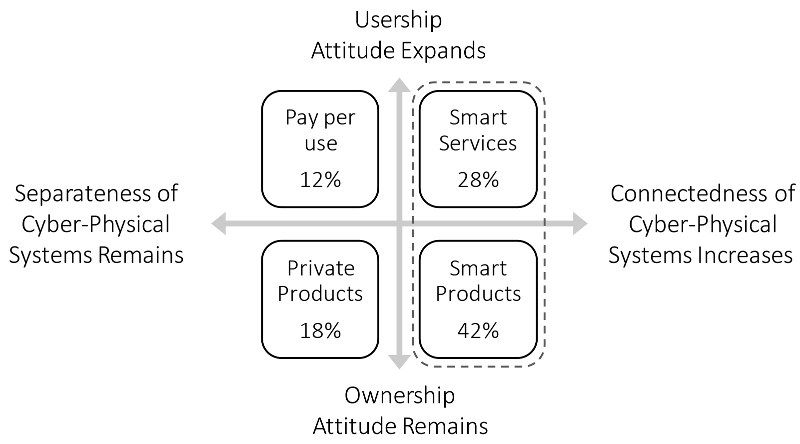

Figure 4: Scenario matrix assessment

For the vertical axis (usership attitude) both directions are conceivable. On the one hand, a future is possible where the material-oriented attitude remains because of two main reasons: first, usership does not provide the same level of comfort, reliability, or control as owning goods and second, identification with goods still matters. On the other hand, usership economies generally have better resource efficiency. This improved efficiency especially holds in the case of smart services. A complete disappearance of ownership, however, does not seem to be realistic. We therefore assessed an expansion of the usership attitude with 40% probability and the ownership attitude remaining the dominant model as being 60% probable

Based on these assessments, we consider the scenarios *smart products* (42%) and *smart services* (28%) to be the ones that are most likely to occur in the future. In contrast, non-digital private products (12%) and pay-per-use services (18%) will be less important in the future (see Figure 4).

5.6 Car Futures

In this section, we apply these general considerations to the mobility sector, in particular what this means for possible car futures. We focus on the smart products and the smart services scenarios as the two scenarios with the highest probabilities. As both have similar probabilities, we also believe that the future of the car is given by a mixture of both scenarios. Hence, we also outline what a co-existence of both could look like in the future.

5.6.1 Smart Private Cars

In terms of mobility, the smart products scenario means that in the future private cars still play a major role in people's individual mobility. However, future private cars are smart equipped with innovative technological features. The cars are able to maneuver automatically within cities and on highways. They support drivers and provide new driving experiences in various ways. Overall, this scenario describes **an evolutionary development path**, where smart cars are mainly characterized by additional features. The general concepts do not differ significantly from those nowadays. Still, there are subtle but important differences in detail. For better or worse, in this scenario, owners decide individually when to make use of the new smart features and when not to.

On the consumer level, needs will change and requirements will be imposed on smart cars [316]. We can distinguish between the pragmatic values and the hedonic values a (smart) car has for a consumer [239]. The business models need to satisfy the following demands of car buyers. The most important pragmatic value propositions attributed to car mobility are autonomy, independency, and flexibility [352], all of which inherently apply in this ownership-oriented scenario. A special case is linked to those who cannot drive because of cognitive or physical constraints, such as older or disabled people. For this user group, smart cars are a promise of liberty [316,352]. Comfort is an important reason for choosing cars as a preferred mode of transportation, too [484]. In this scenario, smart cars aim to gain a comparative advantage by increasing the perceived comfort. Many smart car features fall into this category: the highway pilot, valet parking, or traffic jam assistant [18,316,339,355].

Reduced crashes and increased safety is another advantage often mentioned in literature [316,355]. From a consumer perspective, however, safety is less important than the subjective feeling of safety [48]. Cooperative concepts that delegate control to an external authority (such as Cooperative Adaptive Cruise Control) might be perceived as less secure and, as a result, be less accepted by smart car owners [380]. Drivers must be able to switch to (semi-) autonomous driving. On the one hand switching it off ensures to meet the drivers' goals of autonomy, perceived control, and perceived safety. On the other hand, switching to (semi-) autonomous driving relieves of driving activities that are perceived as annoying and wasteful. In addition to reduced stress while driving [316], the value of time [224] increases and smart cars offer new work opportunities during travel.

Features such as intelligent traffic-aware routing and adaptive cruise control are a further category that improve driving efficiency [40,167,316,355,517]. Here too, such features are only accepted if they do not reduce driver autonomy; they must be perceived as a support not as a burden [136]. For instance, cooperative concepts such as routing vehicles into platoons [55] must be optional. It is questionable whether a driver will use this option, thus perhaps also saving a small amount of energy, if the platoon speed is perceived as too low (or too high in the case of insecure people).

In this scenario, the hedonic value of cars having a symbolic function for their owners remains. They are a means of distinction [71], expressing an innovative attitude, a social status, or membership of a peer-group or (sub-)culture. Other common hedonic values attributed to cars and driving are fun [445] and sensation seeking [386]. Here, an incentive for owning cars is being able to tune them and steer them. Smart cars do not necessarily preclude these options. At best, they provide new opportunities for enjoyment and sensation seeking, e.g., enabling more sports driving, even for novice drivers, and providing software updates that improve the car e.g., by making it more powerful.

On the business level, car manufacturers must face up to new legal restrictions and questions of liability. For instance, they need to build up competencies in cyber-security by attracting talents from outside the traditional automotive industry [194] and clarify the issue of liability in the case of an accident [339]. In addition to traditional competitors, car manufactures have to compete with new market entrants from the IT and communication industry. In particular, safety and intelligence features will benefit from digital car-to-car and car-to-infrastructure communication. IT companies might therefore have a comparative advantage, and major shifts in the market share might occur. However, in this scenario, lock-in and network effects are smaller than those in the IT sector. In particular, there are too many individual demands and preferences for them all to be satisfied by just one brand. This implies that the private smart car market is not a "winner-takes-all" one [99]. New niche markets and market segments will also emerge. For instance, smart cars enter the new market segment of providing independent mobility for non- or handicapped drivers. Cars in this segment reduce the need for motorists to chauffeur non-driving family members and friends or, for those being driven to use conventional public transit or ridesharing services [316,352]. Another topic relates to brands and the satisfaction of the symbolic value of owning a car. Here, high-tech IT companies as well as premium car manufacturers could benefit from strategic alliances to create brand's promises of highly innovative and appealing cars with a high comfort level, a high fun factor, and/or a high symbolic value [339].

On the societal level, the main problems presently caused by private car traffic compound in this scenario. Since people are in need of a car, the number of personal cars is going to increase. Especially in some regional areas, the growing population and urbanization have led to congestion, parking chaos, and increasing air pollution. The current parking problems remain and reach new dimensions. For the individual, valet parking features make parking less stressful. However, as each person wants to have a parking place nearby, parking spaces must be increasingly provided in the cities. Alternatively, to improve the availability, smart parking might be realized by driving around the block autonomously until the driver is back from a (short) stop. Automobile manufacturers have to face and address these problems by taking the rising challenges into consideration. Possible solutions can be the development of self-parking cars, finding free lots or navigating to centralized parking areas, or space-saving cars such as foldable cars [514]. Car manufacturers also need to launch enhanced ecofriendly cars, either by improving propulsion technologies using renewable energy or through advanced efficiency.

However, autonomous private cars can address other problems. Driving safety is improved whenever the car takes over control during critical traffic situations. Governmental legislation might even require cars to activate driving assistance systems to ensure safe driving and that the laws are obeyed. At the same time, automobile manufacturers face new customer groups such as disabled or older people, or maybe even children. These people are now able to use their private autonomous cars independently.

5.6.2 Smart Car Services

In terms of mobility, the smart services scenario means that, in future, private cars play no or only a minor part in the daily routine. It shares with the previous scenario that cars are smart and able to maneuver automatically. The aim, however, is not to support drivers but to support passengers who use the new smart mobility services. Therefore, the business models of automobile manufacturer will change distinctly. Car manufacturers have to go through a **revolutionary process** and realign their business models.

On the consumer level, individual pragmatic needs differ from the previous scenario only in degree. Perceived safety and perceived flexibility are still important for consumers, in particular having the freedom to go anywhere at any time. The significant difference, however, is the attitude concerning how the need is satisfied. Instead of owning a car, consumers chose the mobility service optimal for the situation [474]. As a result, the long-term-oriented mobility decision of buying a car shifts to a short-term-oriented mobility decision and choosing mobility services in line with the situation. Therefore lock-in effects can be reduced in the use of a car so that the transport choices are more volatile. In particular, pragmatic values and hedonic values do not refer to the smart car itself anymore, referring instead to a smart service system. From the consumer perspective, the most important pragmatic service qualities are availability and reliability. In addition, the service must be easy to use without great planning [474] e.g., easy to book and pay for via Smartphones. For disabled and older people, the accessibility of the service system plays a crucial role, for instance, that smart cars can be used with a wheel-chair, luggage can be easily stowed, or assistance is offered – either by service staff or service robots.

As the hedonic value of driving fun [445] decreases in this scenario, the pragmatic demand for travel time enrichment [225] increases. Hence cars might be equipped as mobile offices or offer special entertainment features or opportunities for relaxation.

In this scenario, consumers become more price conscious when the smart cars rely on a pay-per-use model. For private cars these costs are much less transparent as many costs such as acquisition, repairs, and insurance are indirect. Therefore, they weigh up the cost and benefits of service features with regard to the particular situation. Like today – where people usually take buses and only take taxis in exceptional situations – a consumer might accept ridesharing-like smart car services when they are significantly cheaper and only use taxi-like services as an exception. In addition to the practical cost-benefit analysis, selecting these service systems also has a symbolic significance. For instance, using ridesharing-type services expresses a green value system. However, the use of taxi-like and exclusive transport services might serve as status symbol [474].

On the business level, the business models aim to satisfy the outlined demands of mobility service users. Producing and selling cars to private customers will no longer be the prevailing business activity. Instead one promising business model lies in becoming a mobility supplier, offering mobility as an on-demand service. Besides the production of the cars, their prior business activity will shift towards data management and analysis to provide unconditional and convenient mobility.

Car manufacturers who act as mobility suppliers must face new competitors. Since there is no steering wheel and no driver inside the car, there is no longer a difference between self-driving taxis and self-driving car sharing. Companies aim for high occupancy rides and as few empty trips as possible. As an add-on to the general self-driving-technology, the cars are smart in terms of relocating, parking, and optimizing routes based on a customer-relationship database. Although the customers do not own these cars, the cars must satisfy the consistent user needs of being available whenever a user wants to take one and having no recognizable difference in disposability. Using big data from the customer-relationship database helps the companies to predict user demands and routes and automatically plan the operations. The cars must also provide comfort, privacy, and security. These requirements are relatively easy to cover, under the assumption that full security is technologically realizable, and that the car is used by one person alone or by a group of people who know each other. Autonomous ridesharing is, of course, also possible: customers use a car service and share their ride with another – probably to them strange – customer. When the database recognizes that two customers want to take (nearly) the same route, the system could suggest sharing the vehicle and offer a discount. This special offer fulfills the economic, ecological, and social needs of those people who think "green" and are convinced sharers.

To meet the situation-dependent user demands, car manufacturers and the mobility suppliers can organize their fleets. They can provide vehicles equipped as offices, vans, convertibles, and small city cars with a different number of seats. Fleets must be large enough to guarantee availability and reliability. Additionally, they can offer different service models such as pay-per-use prices or flat rates.

Another important point of the autonomous mobility services scenario is the trend towards intermodal services that are almost hidden for the customers. Customers chose a route from one destination to another and pay for one ticket per travel. With intermodal services, the transition between the different mobility modes is almost seamless, such as taking the train for a long-distance journey and then using a car for the last mile, all with the one ticket. These intermodal mobility services can be offered by individual companies, by holding organizations, or through cooperations between different mobility organizations. The trend towards mobility as a service can lead to an expansion of business models within existing companies. For example, short-range public transportation companies could widen their range of mobility services into different mobility modes and therefore offer intermodal or multimodal mobility services.

On the societal level, this scenario brings numerous changes – challenges as well as opportunities. First, traditional car manufacturers are affected as smart mobility services enable a dramatic reduction in vehicles [492]. Second, existing mobility providers, including taxis and other driving services, are threatened by innovative mobility services as they lead to a reduction in driving staff. Jobs will be lost since fully automated vehicles no longer need a driver. These challenges can already be seen in the discussion about permitting UBER [199]. Even though other forms of employment will arise through the new business models, the redundancy of taxi drivers is unavoidable. Furthermore, automated cars on demand will raise the level of equality in the mobility sector. Disabled people, older people, and other individuals who are not able to drive independently will be more mobile [410]. Additionally, personal parking spaces can be saved and open possibilities for new concepts in using urban areas. In this scenario, platooning is easy to implement since people do not insist on their own speed. This leads to additional savings in fuel and infrastructure and overall to an improved utilization of the car and the roads. So, sustainability is expected to rise in terms of **economic** and **ecological sustainability**. At the same time, rebound effects can occur. If using the self-driving-service is easily affordable, reliable, and comfortable and people can even do other things during their ride, the total amount of rides could increase significantly [316]. Negative ecological and economic effects could arise when empty runnings prevail as a result of relocating and optimizing routes and parking. It is also possible that consumers will mainly use autonomous car services instead of sustainable mobility modes such as bicycles or public transport.

5.6.3 Co-existence of Private Cars and Services

The scenarios surely draft very extreme pictures of the future following strictly one development path – either ownership or usership. We are convinced that there will be a mixture of self-driving private cars and self-driving services. The likelihoods we defined for the different scenarios could also be interpreted as market segments. In the long run, mall different variants will appear. This mixture will cause even greater challenges since all variants must be coordinated. Independent of the challenges, we assume that there are also positive outcomes of the mixture of autonomous private cars and mobility services. Each scenario has advantages for specific cases.

The co-existence of private cars and mobility services reduces both the number of cars within urban areas and the traffic density. This improved traffic situation will lead to private cars still being used for business. Especially in the beginning of autonomous mobility services, it is important to offer the customer both scenarios. The incremental integration of mobility services means that the customers can gather experiences, which, in turn, could raise the acceptance of the mobility services. But still it is important that the customers have a choice of mobility modes. A roll-out concept for autonomous mobility services could be incrementally integrating these services within the taxi or short-range transit sector.

5.7 Conclusions

Smart and self-driving cars seem to be the next major leap the automotive industry is trying to achieve. Digitalization challenges the automotive industry to rethink or even change their business models to meet the customer's demands. With regard to this, other studies outline digitalization's challenges (e.g., technological, ethical, and legal) and effects (e.g., on mobility practices, safety, sustainability, and service markets). Our analysis confirms to a large extent the findings of earlier scenario analyses concerning assumed trends, pre-conditions, and possible future scenarios. In this paper, we have demonstrated that future car scenarios should not be studied in isolation but should consider general socio-technical megatrends associated with digital connected systems and innovative usership models. This general view then gives an orientation, informs decision makers, and enables them to re-evaluate the status quo of the trends by continuously checking the critical assumptions. For the digitalization trend to proceed, it is crucial that the digital connection of goods is ubiquitous, which basically depends on society's readiness. For a usership-orientated society to prevail over an ownership-oriented society, consumer attitude must shift. Depending on whether the critical conditions are realized or not, different scenarios occur, with two of them being most likely and suited to meet the needs of individualized lifestyles and the demands of sustainable societies.

With regard to the business development, we have outlined that owner- and usership-oriented smart car scenarios are most likely and can realistically co-exist in the medium to long term. Both constitute different markets with specific characteristics that business models have to consider. For the private market, our analysis shows that smart cars should not just satisfy pragmatic mobility needs but must also address hedonic and symbolic values such as freedom, driving fun, or providing a status symbol. Here the automotive industry is running along an evolutionary development path characterized by mainly technological advancements. For the service market, our analysis shows that hedonic qualities are less important. Instead the competitive position is based on the guarantee of a high service level with regard to availability, flexibility, comfort, usability, and attractive pricing. This combination leads to a revolutionary development with a major impact on traditional business models. But it is questionable if car manufacturers acknowledge theses disruptive changes. Experience shows that traditional technology companies tend to stick to their top seller and react too late [321].

Concerning scope and limitation, it has to be mentioned that the future scenario analysis is inherently characterized by uncertainty. Unanticipated disruptive phenomena cannot be forecasted. A maximum objectivity was aimed at, but a bias cannot be entirely excluded as conditions and probabilities have been evaluated intersubjectively by the authors. Also, the results of this study are only representative for Western societies. Future research should validate the findings by using supplementing methods such as expert interviews, consumer surveys, appropriation studies or different experimental design to identify acceptance and key success factors of innovative business models for the different mobility scenarios.

6 STUDY 2: HOW MILLENNIALS WILL USE AUTONOMOUS VEHICLES: AN INTERVIEW STUDY

Hardly any other innovation has the potential to change our traffic systems as profoundly and dramatically as autonomous vehicles. In this context, the potentials of Shared Autonomous Vehicles (SAV) are discussed controversially. In the age of cities struggling with growing emissions and congestion problems, some experts predict SAV to reduce private car use and to have an overall positive effect on transportation and traffic. Others fear an increase in vehicle miles travelled due to the high convenience SAV will offer. To address this concern more thoroughly we analyzed users' perceptions and attitudes towards SAV by conducting 25 qualitative interviews focusing on the questions if and under what circumstances users would adopt SAV and how SAV would affect a user's mobility behavior. Results show that participants especially tend to use SAV instead of traditional taxis and local public transport.

6.1 Introduction

The use of fully autonomous vehicles (AV) will have a disruptive effect on the transport market, as it will fundamentally change current patterns of use, ownership and business models. With the advent of fully autonomous driving, new business models are also emerging, because the self-driving vehicle can be put on the road in a variety of forms: as a private car, taxi, bus, carsharing vehicle, or a shared taxi [557]. Some experts and researchers predict a positive effect on vehicle ownership and existing growing emissions and congestion problems [177,179]. In particular, the combination of self-driving technology and mobility as a service-concepts are being discussed in this context. The result of this combination could be 'Shared Autonomous Vehicles' (SAV) [177,296,344,400]: fully automated vehicles that consumers do not own privately but use flexibly according to their needs and thus share with others. Since SAV will navigate, collect and carry passengers autonomously, these innovative services could overcome many disadvantages of traditional taxis and carsharing such as high labor costs or the distance users have to overcome to reach a carsharing vehicle [403]. The success of such mobility concepts, however, depends on user acceptance and its impact on users' mobility behavior.

So far, these are only visions of the future based on a technology that is not yet ready for series production. However, developments are progressing rapidly, with all the major players in the automotive industry and the tech giants in the process of advancing their own developments. This makes it even more important for the transport industry to actively address the possibilities and consequences of AV. This does not only apply to the producers and future operators of SAV, who have an interest in their vehicles being used intensively, but also to the public transport (PT) sector, for which the advent of AV can also be associated with changes and possible risks. Consequently, it is necessary for the industry to address these developments at an early stage, to position accordingly, take advantage of opportunities and counteract risks.

To better understand attitudes and potential effects of the advent of SAV on the mobility behavior of millennial-aged users, we conducted qualitative interviews with a qualitative sample of 25 users. Our findings thus contribute to the ongoing discourse about (S)AV by shedding light on expected adoption and use behavior. The results show that first, millennials tend to prefer a driverless taxi over a traditional taxi when the cost of a driverless taxi is correspondingly lower and second, that an offer of SAV might have a strong impact on users' mobility behavior; in particular, it will be easier to convince current PT users to adopt SAV than to convince car owners to do so.

The overall structure of the paper takes the form of six chapters, including this introductory chapter. Chapter Two begins by laying out the theoretical background and looks at how (S)AV and their effects are being discussed in scientific literature. The third chapter is concerned with the methodology used for this study. The fourth section presents the findings of the research, focusing on the two key themes. Chapter 5 analyses the results of interviews discussing the meaning of the results for the transportation sector. After presenting limitations of our study, the final chapter gives a brief summary and critique of the findings.

6.2 Related Work: Shared Autonomous Vehicles

Fully autonomous driving is understood as the autonomous, targeted driving of a vehicle in real traffic without the driver's intervention. An international standard for full automation has been defined to ensure a consistent taxonomy and understanding for On-Road Motor Vehicle Automated Driving Systems [458]. According to that J3016 standard, six levels of automation can be distinguished for road traffic depending on the level of driver intervention and attention required: no automation (0), driver assistance (1), partial automation (2), conditional automation (3), high automation (4) and the final stage of full automation (5). Thus, the vehicle is fully automated when the system dynamically and fully autonomously performs all aspects of the driving tasks under all roadway and environmental conditions without the need for a human driver. In this paper, we refer to the highest level of automation, in line with other studies about AV [296,402,410]. We think of vehicles as capturing the driving environment through sensors, communicating between cars and infrastructure independently and navigating without human intervention. Companies such as Audi, NVIDIA and NuTonomy have recently announced that these types of driverless cars will be available on the market from 2020 [290,437,451].

Vehicle automation does not only open up new possibilities for private mobility but also enables new ways of using sharing-based transportation concepts. In that discourse, different terms for these concepts are being used such as Robo-Taxis, autonomous taxis, autonomous carsharing; in the scientific literature, the term Shared Autonomous Vehicles (SAV) has become established [177,179,296,400]. Much of the current literature on SAV pays attention to the adoption of SAV and their impact on transportation systems. Research has recently focused on two different approaches: model-theoretic simulations of SAV fleets on a macro level and empirical user studies.

Simulation studies predict that SAV have the potential to reduce the number of private vehicles by more than 90% [62,91,176,179]. Burns et al. [95] simulate an SAV fleet for a small sized, medium sized as well as metropolitan cities. They investigate that the average SAV cost per mile is 31 percent less than the average cost of a privately-owned vehicle and calculate that all trips could be executed with a fleet of only 15% of the number of privately owned vehicles. Fagnant and Kockelman [176] and Fagnant et al. (2015) conclude that each SAV can replace around eleven/nine conventional vehicles with reasonable wait times of one minute or less [179]. Burghout et al. [93] have similar results in their simulation of an SAV fleet. They conclude that it is possible to replace private car commuter trips in a metropolitan area with self-driving on-demand taxis needing less than 5% of the passenger vehicles currently in operation and of the parking places. Spieser et al. [492] simulate an SAV transportation for Singapore and calculate that an effective fleet needs to have one third of today's private vehicles. The authors generally agree that such sharing concepts offer great economic and ecological potential.

Besides technological, economical or ethical oriented studies on autonomous driving [296,386,387,389,410], there is a growing number of user acceptance studies. However, most of those studies focus on autonomous cars in general while neglecting the question of ownership as a relevant category. De Winter et al. [142], for instance, conducted a survey finding only 50% of the respondents had heard of Google's Driverless Car, 74% of the respondents stated that fully automated driving will reach a 50% market share by 2050. Kyriakidis et al. [300] investigated the public opinion on automated driving showing that over 70% of the respondents agreed that manual driving is enjoyable but around 50% also agreed that fully automated driving would be enjoyable. With regard to autonomous cars in general, a study by Payre et al. [410] reveals that a large majority of the population have a positive attitude and can imagine buying and/or using them. Factors such as age and gender, individual personality, pre-experience with partly autonomous cars, characteristics of the innovation, the driving environment, and the manufacturer's reputation affect the users' acceptance [396,445]. Only a few studies have explicitly addressed the willingness to adopt SAV. When asking if people would adopt self-driving technology and in what form, Howard and Dai [253] found that people's willingness to use self-driving cars as taxis was not high, with wealthier people being willing to use a self-driving taxi more often than those with lower income. The study however showed that self-driving taxis still seem more popular than traditional taxis. Krueger et al. [296] identify a young age and multimodal travel patterns to be typical characteristics of potential SAV users. Results of their stated choice analysis showed that service attributes including the given travel time, waiting time and travel cost are significant determinants of SAV use and dynamic ridesharing acceptance. In a recent study by Moreno et al. [367], 41.5% of the respondents stated they were willing to use AV as SAV. Menon et al. [344] empirically investigated the willingness of people to relinquish one of their household vehicles if SAV are available. They found that for single-vehicle households, it is the male, well-educated millennials (born in the 1980s and 1990s) who would most likely give up their private vehicle in favor of SAV. The results of Pakusch et al. [403] show that privately owned cars – whether traditional or fully autonomous – will continue to be preferred over shared vehicles in the future.

While quantitative studies to simulate SAV use and hypothetical considerations regarding the influence of AV on mobility behavior have been performed, qualitative studies are lacking. Qualitative methods offer an effective way of shedding light on underlying reasons and aspects why users come to a decision. We therefore contribute to the field of user research in the context of AV by qualitatively unveiling the user's perceptions and attitudes towards SAV and by analyzing potential changes in mobility behavior.

6.3 Methodology

To address our research question on how millennials will respond to the advent of SAV regarding changes in their mobility behavior, we conducted 25 problem-centered narrative interviews [578]. As a well-established method in empirical social research, qualitative interviews are particularly suitable for exploring the more unknown research fields and the subjective perspectives of users [464]. In our study we focused on the so-called millennials, those born after 1982. A user group that is particularly interesting to consider when exploring attitudes towards technological innovations. To recruit participants, we used a combination of qualitative sampling [126] and snowball sampling [59]. We did not make any demands on previous knowledge of AV; the interviewees took part in the interviews on a voluntary basis and without being compensated. The participants consisted of 8 women and 17 men aged 20 to 34 years. All participants held a driver license and 19 of them owned a private car. While 15 respondents lived in rural areas and 10 in urban areas, all participants had access to PT and none of them had physical impairments necessitating car use (Table 5). With those mobility patterns they pretty good represent millennials in Germany.

The interview guidelines contained the following topics: We started by asking participants about their current mobility practices and their attitudes to established means of transport. In the course of the conversation, we confronted the participants with the concept of AV and asked them what they had already heard about this topic. Using a press release of a planned Uber-SAV fleet as an envision stimulus [554], we introduced the topic of SAV to the interviewees, discussing their opinion on AV and SAV as well as the impact of such a service on their mobility behavior. Interviews lasted between 20 and 45 minutes. All interviews were conducted face-to-face, were audio-recorded, fully transcribed and analyzed independently by three authors. The analysis method uses elements of grounded theory [204] and the technique of qualitative content analysis [73]. To organize the data material, deductive and inductive categorization were built with the help of the analysis tool MAXQDA. The formation of the category system was based on the semi-structured interview guideline, following the logic of a deductive category application. The code system was additionally expanded and inductively differentiated by the coders. To do this, we discussed and matched identified categories through an iterative process to ensure consensus and to follow the principle of intersubjective replicability.

Table 5: Socio-demographic data of study participants

ID	GENDER	AGE	JOB	PLACE OF RESIDENCE	DRIVING LICENSE	OWNING A CAR	MAIN TRAVEL MODE
01	male	27	Student	urban	Yes	No	PT*
02	male	22	Student	rural	Yes	Yes	Car
03	female	23	Medical Assistant	rural	Yes	Yes	Car
04	male	23	Marketing Manager	rural	Yes	Yes	Car
05	male	28	Cutting Machine Operator	rural	Yes	Yes	Car
06	female	26	Geriatric Nurse	rural	Yes	Yes	Car
07	male	34	Engineer	urban	Yes	Yes	Car
08	male	22	Student	rural	Yes	Yes	Car
09	female	22	Student	rural	Yes	Yes	Car
10	male	21	Student	rural	Yes	Yes	Car
11	female	26	Automobile Sales Person	rural	Yes	Yes	Car
12	male	26	Student	urban	Yes	No	PT
13	female	34	Architect	urban	Yes	Yes	Car
14	male	26	Student	urban	Yes	Yes	Car
15	male	21	Student	rural	Yes	No	PT
16	male	21	Student	rural	Yes	Yes	Car
17	male	22	Industr. Mgmt. Assistant	rural	Yes	Yes	Car
18	female	20	Apprentice	rural	Yes	Yes	Car
19	male	24	Student	urban	Yes	No	PT
20	male	22	Assistant Tax Consultant	rural	Yes	Yes	Car
21	female	20	Student	urban	Yes	No	PT
22	male	22	Student	urban	Yes	Yes	Car
23	female	25	Student	urban	Yes	No	PT
24	male	30	Nurse	rural	Yes	Yes	Car
25	male	22	Student	urban	Yes	No	PT

*PT = Public Transport

6.4 Findings

First, we give an overview of the situations in which users can imagine using an SAV before we show how users generally think about the question whether to use a traditional taxi or a driverless automated taxi. In the third section, we address the central question of the extent to which the advent of SAV could affect the mobility behavior of users.

6.4.1 Use Scenarios

Respondents described various reasons and purposes they would use SAV for. In the course of the interviews, we specifically asked them in which situations or for what journeys they would use SAV. In addition, they also casually mentioned routes in the conversations to illustrate other comments. The most frequently mentioned routes include the shorter, every day, and familiar routes to work or home, grocery shopping, going to the train station or the airport or to transport larger things.

> *I'd use it, so if the price is right, I'd use it to shop, go to work, travel longer distances and visit someone, for example, to drive to the airport or something like that. (P1)*

As P1’s commentary shows for other participants as well, the price plays an important role for the participants. Costs are repeatedly addressed directly or casually as a side condition. Our millennials state they will only use SAV if they had a significant financial advantage over alternative traditional means of transport. Many car users point out that the costs of an SAV must not exceed the cost of a car and should be as expensive or cheaper than a traditional taxi. Only for some persons social interaction with the taxi driver outweigh advantages of SAV when costs are left out of the equation:

> *…under no circumstances should it be more expensive than a taxi, then you would, of course, prefer the usual taxi. (P18)*

The way in which P18 talks about the conditions for using SAV is quite undifferentiated. For her it is clear that only a lower cost would make her prefer a driverless taxi to a traditional taxi. This means that apart from the cost, the traditional taxi generally has advantages over an SAV.

Furthermore, those people who mainly use private cars often refer to the costs of using a car. They state they will only make use of SAV if the offer will be cheaper than a private car:

> *And if [autonomous] carsharing is cheaper than owning your own car, this is the only relevant reason to use [autonomous] carsharing. (P2)*

Also, P2 speaks of the costs as *"the only relevant reason to use"* SAV. Just like him, the car-using participants feel their own car to be superior to SAV in all other characteristics. Particularly the permanent availability, the high degree of flexibility and the comfort are mentioned as special advantages of the own vehicle, which is always ready in front of the door. In summary, it can therefore be said that most respondents are not willing to spend more on the use of SAV than on their current means of transport. In the eyes of most respondents, SAV do not offer a relative advantage over the previously preferred means of transport, which would justify a higher price. Only 4 of the 25 people interviewed were willing to accept a surcharge. Two of them, people who do not currently have an own car and use PT, found higher cost than the current cost of PT reasonable. In a direct comparison of PT and SAV, they see a clear relative advantage:

> *…if I have the opportunity, then I would be ready to pay a little more than the normal bus and train fares for it. After all, there is still a lot of added value to it. […] The idea is great because you have the advantages of a car and at the same time the advantages of public transport. Time is not completely lost, because you can use it in a different way than when you drive. (P23)*

P23 describes that for her, the concept of a SAV combines the advantages of an own car (speed, flexibility, availability, spontaneous use, comfort) with the advantages of PT and thus brings together the best of both variants. As an advantage of PT, she mentions the use of time during the journey. While an SAV is considered to be disadvantageous compared to a car – with the exception of better use of time – the advantages of such a concept clearly exceed those of PT.

To get back to the potential trip purposes, which have been mentioned, it is worth noting that participants so far use their main travel modes for such everyday journeys like grocery shopping or going to work or home. The fact that they can imagine making these journeys with SAV, and not only using them for special occasions, indicates that SAV has some potential to replace their current main travel modes and become a routine travel mode.

In addition to the daily routes, the participants mentioned those situations in which they would currently prefer to take a traditional taxi or would like to take a traditional taxi but are not willing to bear the current taxi costs. Participants describe those situations as situations when they are not able to drive or do not feel fit to drive. In this context, participants often mentioned that SAV could be used well if one was at a party, had drunk alcohol, was exhausted from work, or in an emergency situation as an ambulance.

> *You can go to a party by car and drive back home with the same car being as drunk as you like. (P1)*

...if you have had a long day and are very tired, then you should not drive by yourself any more, then it's of course good if the car takes over the driving for you. (P25)

Even on routes where users do not feel any pleasure or may even feel stressed by driving, they would prefer to be driven by SAV instead of driving themselves. In addition, the millennials mentioned long and monotonous journeys such as on a motorway or when stuck in a traffic jam as suitable to be carried out by SAV. They see advantages in the fact that they can use the time in the car sensibly and can pursue other activities than driving.

Some participants feel particularly stressed during trips in foreign cities or areas. For those on unknown routes, in very confusing cities and areas where one does not know how to get home, the participants would like to have their control delivered to the SAV computer and then be transported.

I personally don't like driving in big cities so much, where the roads have multiple lanes (...) you get nervous quickly and don't know where you have to go, and it would be quite good if you could rely on the fact that you don't have to drive yourself. (P18)

6.4.2 Scenario: Traditional Taxi vs. Fully Autonomous Taxi

Our millennials use taxis only very rarely. They recognize the benefits that taxis offer. They appreciate the high comfort and being able to rely on the drivers' knowledge of the area. In addition, those who are PT users appreciate the fact that, compared to buses, taxis do not have long waiting times and that users are picked up at the desired location. Participants who live in urban areas where PT no longer runs regularly at night and on weekends use taxis as an alternative to PT. However, all millennials describe the taxi as a very expensive means of transport that is only used in exceptional cases.

I only order a taxi now, if there is no other way out, if I can't be taken along by someone else either. (P7)

The high costs of taxis are repeatedly mentioned as the reason why this comfortable means of transport is not used more frequently. The comments in the context of taxi usage show again how very cost-sensitive the millennials are when it comes to travel mode choices.

We asked the participants to imagine the following scenario: they were guests at a party, had some drinks and now want to go home. We then asked them to choose between two means of transport: either they could take a traditional taxi, or they could take a fully autonomous taxi that is 30% cheaper than the traditional taxi. Only five people decided to take the traditional one:

So now, I'd choose the traditional taxi, because I trust people more than the computer when it comes to driving, even if I would have this 30% cost saving. (P17)

Just as P17, those five participants who opted for this variant mentioned safety as a reason. They trust in the familiar variant and do not want to rely on driverless services. As long as there are still taxi drivers, some say, this means that autonomous driving has not yet fully established itself due to safety aspects.

When AV are being discussed in general, many respondents describe job losses as a negative consequence of the increasing automation of the mobility industry. They assess this factor ambivalently: On the one hand, they see it as an economic advantage for the operating taxi companies as they have lower labor costs but, on the other hand, they see the job losses as a clear disadvantage. As soon as the concrete decision situation is at stake, this social aspect takes a back seat. In the present case, the advantage of lower costs clearly outweighed the disadvantage of job losses. This advantage lead to the other 20 people opting for the less expensive driverless taxi:

As a student, I think I would definitely take the cheaper autonomous driving service. Simply because it's cheaper then and yes, the costs, that's what I'm all about. (P22)

With the addition *"As a student,"* P22 points to his current situation, which is characterized by the fact that he does not have a large income and therefore keeps his expenses for transportation as low as possible. At the same time, this restriction suggests that his decision is only valid for this phase of his life and may change later if the budget no longer determines his decisions as much as it does now.

For the voters of the traditional taxi, safety was the most important argument for the classic taxi. At the same time, three respondents also named safety as the reason for choosing the SAV:

...because I don't always know with the taxi drivers whether they are still roadworthy themselves. Autonomous cars might also be more likely to follow the traffic rules than taxi drivers; driving with less risk. Well, I guess [traditional] taxis aren't very safe. (P14)

For these participants it is not the potential advantages of the SAV that are decisive, but the disadvantages of the current taxi services, which are characterized in part by poor driver behavior.

6.4.3 Impact on Mobility Behavior

If SAV were available at a high service level and at comparatively low cost as some simulation studies suggest, this availability would have a huge impact on respondents' mobility behavior.

Some interviewees thought that, in this case, they did not need their own car and would abandon the private car or would not even acquire one at all. As a reason for this decision, the respondents cited that using SAV would be cheaper than owning and maintaining a private car, and they did not see any disadvantages with a high-service-level SAV compared to their own car.

> *If things go well and the car is really quickly available, and you don't have long waiting times, I could imagine selling my own car. (P17)*

However, 11 people did not want to give up their own car, 3 of them would still want to drive mainly with their own car but 4 of them can imagine driving less with their private car. People who do not want to do without their own car appreciate the private car being located directly in front of their house so that the car can be used very flexibly in the shortest possible time and without prior booking. In addition, some respondents said that they would miss the driving pleasure if they could not control SAV themselves.

> *I still wouldn't want to do without my own car because you sometimes still need it to be able to drive right in front of your door, sometimes it has to be right in front of your front door so that you can start driving straight away… (P22)*
> *I would probably leave my own car at home more often and fall back on it [SAV]. (P11)*

The SAV offer would not only affect car ownership and use but also change the use of other modes of transport. Ten people would reduce or even stop using PT to the benefit of SAV. This change was attributed, above all, to the time savings that would result from using SAV compared to PT. In addition, they would also appreciate the greater flexibility and speed of the new service, as well as the advantage of not having to get to or from the bus stop or station.

> *So, I think that if it saves some time and is also financially affordable, I might say I use less public transport. I don't think I'd give up my own car for that. (P8)*

Four people stated that they would use SAV like a traditional taxi. One person said she would walk less. Two respondents indicated that they would undertake additional journeys, thus increasing their overall demand for mobility. Only four people were convinced that they would not change their mobility behavior at all.

6.5 Discussion

The analysis of the interviews shows that millennials are open to the use of SAV. While it turned out that SAV will mainly compete with traditional taxis and PT, we also noticed that millennials are very cost-sensitive in their choice of means of transport. The costs represent the condition that is mentioned as a prerequisite for use in all aspects. Accordingly, most users choose an autonomous taxi when choosing between traditional taxis and cheaper autonomous taxis. The social aspect that the profession of a taxi driver could become obsolete with the advent of autonomous vehicles does not play a role for the millennials in the concrete decision situation. In this respect, it is important to address the consequences of autonomous driving at an early stage, since the profession of professional drivers could at least be altered, if not become superfluous. That is why taxi drivers and taxi organizations, in particular, should draw up a plan as to what kind of right of existence they still have in future and what services and added value they can offer their passengers that go beyond driving.

Further, the analysis suggests that it will generally be easier to convince current PT users to use SAV. Given benefits such as a lower travel time, less transfers, less people to share the vehicle with compared to a bus or train as well as easier ways of transporting goods support this assumption and stand in line with empirical studies, that show how users consider characteristics of private cars, PT and SAV in comparison to each other [404]. If SAV journeys characterized by a very high level of comfort were financially affordable – as some studies suggest they will be [62,91,176,179] – users would prefer to use SAV as a means of transport and might be willing to travel longer distances as they can make good use of the time in the SAV [134]. In contrast, private car users will be harder to convince and to forego private car ownership in favor of SAV. Longer travel times due to detours, less flexibility as well as the users' fear to lose control and driving pleasure reduce the likelihood that drivers will renounce their car. These results are consistent with the expectations of other non-empirical studies [296]. If this would be the case – always remembering that we argue highly speculative – SAV will result in an increase of road traffic and vehicle-km. Consequently, the efficient PT services will be used less, while the use of private vehicles will increase. Thus, contrary to the predicted and desired effects of SAV to alleviate traffic problems, especially in cities, SAV would contribute to a strengthening of those problems. These implications are of importance for state and environmental policy, PT operators and planning authorities. The companies that want to offer SAV on the market are interested in achieving the greatest possible success with SAV and generating profits. Accordingly, they will design and offer SAV in such a way that they are as attractive as possible for potential users. In this case, the operators' objectives do not coincide with environmental policy objectives. While the future SAV operators will be interested in an extensive use, it is in the interest of environmental policy to reduce vehicle miles traveled by emission-intensive means of transport. The policy must intervene here by influencing the operators of SAV. To counter this effect, it may therefore be necessary to regulate the SAV market from the very first moment. In addition, environmentally friendly means of transport must be further strengthened, and more effort must be put into making PT more attractive so that in future they are competitive not only against private (autonomous) vehicles but also against SAV.

With its qualitative character, our study does not provide reliable, representative forecasts. Based on the analysis, we suggest to quantitatively survey the questions whether millennials will prefer autonomous taxis to traditional taxis and whether PT users are more likely to adopt SAV than car users are.

6.6 Limitations

There are two major limitations to the interpretation of the results. First, the sample is small and focusses on a young average age. Since the study was conducted in Germany, the sample certainly has some specific characteristics that should be considered when looking at the results. Nevertheless, this study provides important insights into user's subjective perceptions of SAV. Second, studies such as those relating to future technologies that are not yet on the market generally pose problems: respondents must imagine something that does not yet exist, which they have not yet dealt with, and which they have not yet been able to test. This lack of knowledge and experience inevitably leads to the respondents being influenced by the interviewers' formulations and specifications. On the other hand, without such a priori studies, it would not be possible to anticipate the consequences of the introduction of new technologies.

6.7 Conclusion

Autonomous vehicles have the potential to address many of today's traffic problems. Experts predict that vehicle ownership will decrease, and cities will be able to provide efficient mobility with up to 90% fewer vehicles. However, the advent of autonomous vehicles could also have negative consequences: the jobs of professional drivers could become obsolete and low-cost SAV could compete with more environmentally friendly modes of transport such as PT. Our analysis shows that the fear of such negative consequences is justified.

Within our study, we have focused on millennials, the generation that grows up with smart technologies and is expected to be the first users of autonomous vehicles. In semi-structured interviews, we confronted 25 millennial-aged people with the concept of SAV to get insights into their subjective perceptions about SAV and to anticipate how the advent of SAV might change their mobility behavior as a result. If SAV can actually deliver on their promises and forecasts, they will have a major impact on people's mobility behavior. The study results suggest that it will generally be easier to convince current PT users to use SAV than to convince private car users to do so, and that ecological and social aspects play a very subordinate role in the mobility decisions of young people. This aspect has already been observed in earlier studies on travel mode choice

[123,188,196,396]. This study shows how important it is to deal with the effects of new mobility services at an early stage. It is nevertheless necessary to validate these qualitative results in future research to inform transport planners and policymakers. If these forecasts should be confirmed, the policymakers will have to intervene to prevent a worsening of the existing traffic problems. Furthermore, these results show how important it is to put effort into making environmentally friendlier means of transport such as PT more attractive and to expand their infrastructure so that they can compete with new forms of mobility services such as SAV in the future.

7 STUDY 3: UNINTENDED EFFECTS OF AUTONOMOUS DRIVING: A STUDY ON MOBILITY PREFERENCES IN THE FUTURE

Innovations in the mobility industry such as automated and connected cars could significantly reduce congestion and emissions by allowing the traffic to flow more freely and reducing the number of vehicles according to some researchers. However, the effectiveness of these sustainable product and service innovations is often limited by unexpected changes in consumption: some researchers thus hypothesize that the higher comfort and improved quality of time in driverless cars could lead to an increase in demand for driving with autonomous vehicles. So far, there is a lack of empirical evidence supporting either one or other of these hypotheses. To analyze the influence of autonomous driving on mobility behavior and to uncover user preferences, which serve as indicators for future travel mode choices, we conducted an online survey with a paired comparison of current and future travel modes with 302 participants in Germany. The results do not confirm the hypothesis that ownership will become an outdated model in the future. Instead they suggest that private cars, whether conventional or fully automated, will remain the preferred travel mode. At the same time, carsharing will benefit from full automation more than private cars. However, the findings indicate that the growth of carsharing will mainly be at the expense of public transport, showing that more emphasis should be placed in making public transport more attractive if sustainable mobility is to be developed.

7.1 Introduction

Mobility is an important prerequisite for social, cultural, and economic development and for social participation. It is also becoming affordable for an ever-increasing number of people worldwide. Motorized private transport has become the most important and most frequently used mode of transport, and forecasts indicate that this will continue to be the case in the future [195,260]. However, the high growth in population and the urbanization trend have led to an increasing volume of traffic worldwide, causing problems in both urban and rural areas. These developments, limited resources, and environmental and climate protection issues challenge transport systems internationally in many areas, calling for the development of sustainable mobility [211,294] to create smart and sustainable cities [249].

The growing interconnectedness of mobility is expected to make an important contribution here: Smart vehicles and an intelligent infrastructure can continue to make transport not only more efficient, safer, but also more environmentally friendly. To create a future competitive advantage, the sustainable integration of ICT into the value chain is one of the central challenges for the automotive industry. A radical development away from traditional towards connected and autonomous driving (AD) can already be observed. Various authors assume that the technological innovations in this area will make an important contribution to sustainable mobility: Intelligent traffic management systems and vehicle platooning (traveling close together at high speed), so the expectation, will lead to energy saving, congestion avoidance, as well as traffic flow becoming more efficient and driving behavior more ecological [396,492]. Another expectation is that AD can make the breakthrough for post-ownership mobility [492], with on-demand services such as shared autonomous vehicles (SAV) becoming the dominant travel mode [62,296].

However, the history of innovation has shown that it is insufficient to consider the effects of technological efficiency improvements in isolation. Repeatedly, technological progress has fallen short of expectation as user behavior is not considered in relevant research, and direct and indirect rebound effects, such as consumption shifting towards less emission-friendly travel modes, are being neglected [61,409,573]. In this regard, we see the danger that the current discourse on AD primarily underlines the potential benefits of an isolated technological perspective and neglects possible negative aspects due to acceptance problems and rebound effects. However, dealing with possible ecological downsides requires a better understanding of the effects of new forms of mobility on mobility behavior and of where supplementary measures may be needed to avoid these negative effects.

This paper contributes to the current discourse on AD from a more critical stance, taking user behavior as the focus. We conducted an empirical study to include the user in research on choice of travel mode that takes future forms of travel into consideration, as researchers have requested [356]. Using a paired comparison, we analyze user preferences in order to anticipate changes in mobility behavior, not by using monomodal analysis, as has so far been the case [410], but by using multimodal analysis that puts different travel modes into relation.

The rest of the paper is structured as follows: First we outline the prospective positive and negative effects of SAV before we derive the changes that will take place through automation based on the Travel Mode Choice theory. Then we briefly present our methodology and the results of our study. The latter starts with a general analysis of the travel mode choice of the participants before going into further detail by providing insights into the preference changes of the participants and group-specific results. These results are then critically discussed in Section 7.6. Finally, we present limiting factors and derive implications for future research and conclusions.

7.2 Environmental Impacts of Autonomous Driving

In the last few years, enormous effort has been put into enabling AD. SAE International defines six levels of automation for road traffic: no automation (0), driver assistance (1), partial automation (2), conditional automation (3), high automation (4) and the last stage of full automation (5)

[459]. In our study, we always refer to Level 5: full automation. Completely autonomous driving robots that have no manual driving mode are expected to be available from 2030 onwards. Optimistic forecasts assume that highly and fully automated vehicles will reach a market share of 11 to 42 percent in 2035 [541].

This rapid progress in the digitalization of the car raises the question of how to assess this development from a sustainability perspective. However, it is important to note that the technology itself is neither eco-friendly nor the opposite. This always depends on its impact on transportation e.g., on traffic system performance or on travel behavior. We therefore outline the expected impacts as discussed in the literature.

7.2.1 Positive Environmental Effects

7.2.1.1 Positive Impacts on Traffic System Performance

AV could operate more efficiently than traditional vehicles [79,176,492], and thus could reduce resource consumption and the environmental impact [440]. AD would allow vehicle emissions to be reduced by up to 94% [214]. Connected driving can reduce or avoid stop-and-go traffic and congestion [176,492]. So-called platooning can be used to improve traffic safety, optimize traffic flow, and reduce CO_2 emissions since vehicles can exchange data and coordinate driving speed, braking characteristics, and distances between vehicles [79,571]. Thus, energy consumption could be reduced [79]. As accidents can be avoided by using autonomous and connected cars, vehicles require lower safety mechanisms such as airbags and steel constructions than today and would therefore weigh less [18,47]. This means that the engine performance can be reduced, which would in turn lead to lower energy consumption and lower emissions and consequently to environmental pollution being considerably reduced.

7.2.1.2 Positive Impacts on Travel Mode Choice

Many researchers expect a great shift away from private cars towards on-demand mobility services [179,215] and expect positive effects, some of which are already being achieved with today’s carsharing [507]. Full automation could considerably increase the market share of individual public transport such as taxis and carsharing since the advantages of these business models can be realized to a new extent through autonomous vehicles (AV). Fully autonomous carsharing fleets would enable a high degree of spontaneity and flexibility because there would no longer be any set arrival and departure times, thus allowing direct competition with private cars [492]. Some studies simulate different scenarios with SAV fleets, calculating the number of vehicles needed to ensure efficient mobility with short waiting times and high quality at low costs. They show that SAV could potentially reduce the number of vehicles by between 31% to 95% [62,93,95,176,179,492].

7.2.2 Rebound Effects as Negative Environmental Effects

While the literature mainly discusses ecological, economic, and social advantages of AV, some studies also attempt to assess negative consequences. A main concern are the various types of rebound effects that can occur as a result of resource saving [465,490,572]. In the mobility sector, for example, increases in car efficiency can lead to increased vehicle mileage, a more energy-intensive driving style or even to the purchase of a larger or an additional car [45]. Direct rebound models assume that the savings in resources (in terms of costs or time) which result from the increase in efficiency can lead to an increase in demand for the same product [85]. As a result, the maximum possible resource saving through increased efficiency is not achieved; the direct rebound effect reduces, negates, or even exceeds the benefits of improved technological efficiency [57]. Related empirical studies have analyzed direct rebound effects in energy consumption in the company context [163,574] or in various consumer fields such as electricity [57], residential heating [128,281,407], residential cooling [165], or residential lighting [455,471]. For instance, studies investigating the rebound effect of fuel prices on vehicle miles traveled found that direct rebound effects regularly occur, varying between 10–30% [100,217].

For those studies on direct rebound effects, goods are considered in isolation. However, several studies show that technological innovations could also lead to indirect rebound effects [573]. They arise when the time and money saved by the innovation lead to an increased consumption of other goods and services (income and substitution effects). For example, the cost saving from more energy-efficient lighting may be put towards an overseas holiday [115]. It is different in the case of consumption shifting: when the innovation makes it attractive to satisfy a need through a substitutable product or service. For example, HD television, although initially expensive, may lead to cost savings since cinema visits could be replaced by private video nights.

If indirect rebound effects are included in the analysis, an even larger part of the efficiency saving may be negated [470]. Hence, more advanced models try to consider both the choice of consumer goods and the changes in consumer behavior. Choice of consumer goods is dependent not only on the efficiency but also on the consumer's preferences and life situation. When choosing their mode of travel, users can choose between different modes to meet their mobility needs. Studies therefore need to take into account indirect rebound effects that are caused by the changes in travel mode choice due to the innovation of automating vehicles.

So far, no econometric analyses have been carried out to measure rebound effects in the form of behavioral changes in the context of travel mode choice and AD. However, researchers are attempting to determine how mobility demand will change with the introduction of AV. Studies such as [62,541] conclude that the widespread use of AV will increase the number of trips resulting in 3% to 27% additional journeys [356]. There are various reasons for a possibly increased trip demand [134], the most important of which are outlined below.

7.2.2.1 Negative Impacts of Increased Travel Demand

As SAV trip costs might be substantially lower than today's taxi costs [95,179], user demand could rise when trips that, at the moment, have marginal net benefits will become more attractive. As a result, direct rebound effects can occur if the financial saving makes it possible or even attractive for users to take more trips in the AV. In addition, when the time spent in an AV can be better or more efficiently used, people may be willing to undertake more and longer trips [79]. Such time rebound effects can be caused not only by better use of time but also by the more efficient flow of traffic. Studies have shown that the users' mobility time budgets, i.e., the amount of time they are willing to spend on travel, has been stable over time. Hence, if a faster mobility option becomes available, users will accept longer journeys as the overall journey time will not place extra demands on their mobility time budget [280].

7.2.2.2 Negative Impacts of Empty Runs

A whole new class of travel will occur with AV maneuvering of unoccupied vehicles [317,541] as an unintended effect of changes in the user's behavior. AV can pick up their users, park, and carry out courier journeys autonomously. These empty runs are not a direct result of users' demand and are therefore attributable to indirect effects. The additional journeys will occur regardless of whether the AV are private or shared. With an increase in demand for SAV, there will be 8% to 17% more vehicle miles traveled for relocation of vehicles or arrival and departure reasons [62,134,179]. Even more pessimistic scenarios discuss the possibility that cars will no longer be parked in large cities due to a lack of or only expensive parking spaces but instead will drive around the block until they are next requested or park in distant car parks outside the expensive city locations [400].

7.2.2.3 Negative Impacts of Unintended Shifts in Mode Choice

Most of the simulation models mentioned above are based on the untested assumption that SAV are especially attractive for car owners, neglecting the fact that they could also unintendedly impact the mobility behavior of other, currently non-car, users. Some studies discuss possible mobility shifts away from eco-friendly mass transportation towards more comfortable SAV [541]. Krueger et al. [296], for example, pinpoint that people might prefer inexpensive and convenient mobility on-demand services over previous alternatives such as walking, cycling, or public transport (PT). They fear that PT could become neglected. So far—to our knowledge—these hypotheses have only been argumentatively derived and not empirically tested. We therefore used the travel mode choice theory to systematically check whether these fears are justified and examine these hypotheses empirically, concentrating on possible mode shifts as a special form of indirect rebound effects.

7.3 Theory and Research in Travel Mode Choice

7.3.1 Theory of Travel Mode Choice and Random Utility

Travel mode choice theories aim to predict which transportation mode will be used by understanding why people prefer one mode over another [433]. In general, people have various alternatives for managing mobility, and they choose one of the modes that meets their mobility needs, maximizing personal benefits. However, users are not able to keep track of all information important for a rational choice [265,486]. The user's subjective perception therefore does not necessarily have to correspond with objective reality. A mode's benefits only influence mode choice if they are perceived and valued by the users. If, for example, people believe that it would be more expensive to go by bus than by car, then, even if this belief is not based on facts, they will avoid the bus.

In decision making, the absolute level of utility of a product or a service is less relevant than the differences in utility [539]: A travel mode is used not because of its utility in absolute terms but because its utility is relatively seen better when compared to other alternatives. In the case of adopting new alternative travel modes, these modes must therefore offer a relative advantage over the travel modes previously used. Thus, travel mode choice theories are influenced by the random utility theory. This theory assumes that the use of alternatives is a latent construct that exists (if at all) in the minds of individuals. According to this theory, people do not compare various goods in general; they compare the (partworth) utility that they provide [301]. In this context, transportation research has identified several travel mode characteristics that affect individual travel mode choice [433]. The following factors are usually mentioned as the most relevant [296,396,499]:

- *Travel time* is the total time required to cover a distance from A to B. Depending on the travel mode, travel time includes not only the actual time spent travelling but also various activities such as finding a parking space, walking times from an origin to the access point, transfer times, or waiting times at stops.

- *Travel costs* include all costs for the use of a travel mode. For users, it is often only variable costs or perceived costs that are relevant [196].
- *Comfort* includes all the features that make a ride pleasant for the user. Thus, comfort consists of several sub-attributes such as the quality of seats, probability of sitting, possibility to transport goods, the passenger's privacy, level of crowdedness, and quality of time due to efficient time utilization.
- *Flexibility* refers to the possibility to use the travel mode at your own discretion and adapt it to your own needs.
- *Availability* of the travel modes is given if it is accessible to a user and ready for operation when *the user wants or needs it.*
- *Reliability* refers to the extent to which a travel mode carries out a trip as intended or scheduled.
- Safety describes the condition that gives the passenger the feeling of confidence that a travel mode will take him or her safely to a destination.

In the discourse of AD, the criteria of driving ability, control, and driving fun are repeatedly discussed [253,399,400]. AD opens the possibility of being mobile even when people are temporarily or permanently unable to drive. Many users and researchers see this aspect as an advantage of AD [410]. In contrast, acceptance studies show that users fear loss of control and driving fun when thinking of AD [253]. With a view to encouraging sustainable mobility, studies found environment-related attitudes hardly affect mobility behavior and mode choice in everyday life [188,396].

Taking these factors into account, we evaluate autonomous travel modes and derive first hypotheses on travel mode choice. As the direct inclusion of users has been overlooked in research on partworth utilities of autonomous travel modes, we base our estimates regarding these on general insights from literature.

7.3.2 Changes in Private Car Characteristics

Some studies try to anticipate what consequences the automation of vehicles will have and how users will experience these consequences. Experts predict some attributes such as travel time, comfort, and time utilization will be improved by automating cars. Travel time is expected to decrease as connected cars can anticipate and avoid congestion and drive in platoons [356,396]. Driving comfort and convenience are going to increase as travel time can be better used, e.g., for working, relaxing, or socializing, and the car is going to chauffeur its owner and park itself [95,541,571]. Other characteristics such as transportation of goods, personal independence, availability, and flexibility will not change significantly [579] as AV can be used to the same extent to transport goods and because users still have access to their property at all times.

In a recently published study, we present first insights into how users assess the characteristics of AV compared to conventional cars and PT [406]. This study reveals that autonomous cars provide greater driving comfort and greater time saving than traditional cars. Autonomous travel modes offer not only the personal space and comfort of a private car but also the advantages of PT, namely, not having to drive oneself. The use of time while driving a traditional car is currently limited to passive activities such as listening to the radio or making telephone calls. As the driving task is eliminated, self-driving technology makes it possible to make better use of the time spent in the car [130]. This possibility counteracts one of the advantages of PT because the driver becomes a passenger [399]. In terms of driving pleasure and control, users see an advantage in the traditional car compared to the autonomous car [168,386].

Surprisingly, users expect the reliability, availability, and flexibility of an autonomous car to be less than that of a traditional car, presumably due to the novelty of the technology, the inexperience of the users with the technology, and lack of confidence in this new technology. Users have repeatedly expressed concerns that the technology could fail [300,473], which may be one reason for the conviction that AV would have less reliability and availability.

In terms of costs, users also see disadvantages in private autonomous cars as they expect higher purchase costs due to the self-driving technology as well as higher operating costs due to the additional technology, which may cause new faults and require more maintenance [168,253].

Our previous study [406] confirms the assumptions that users today perceive autonomous cars as having more disadvantages than advantages. For this reason, we conclude that

H1: *Users will prefer the traditional car over the fully autonomous car.*

7.3.3 Changes in Carsharing Characteristics

Carsharing will benefit from automation in various respects. Travel time will shorten compared to today's carsharing since the user will not have to walk or use PT to get to the pick-up point. The pure riding time will therefore be similar to that of a (fully automated) private car, apart from the ordering and waiting time. Additionally, automatic relocation of SAV and automatic pick-up will improve availability and therefore also flexibility, leveraging personal independence [62,179]. Model simulations assume that data-driven control, automatic relocation, and automatic retrieval will greatly increase the availability, especially compared to today's carsharing, so that the user will on average have to wait less than one minute [179]. Still, if the vehicle has to reach the passenger's location, from the moment a user is ready to drive and places an order for autonomous carsharing, a waiting time can occur until the journey actual starts. In addition, users do not yet fully anticipate this progress in SAV transport planning so that perceived availability is still less than for a privately owned car since it cannot be guaranteed that an SAV is always ready to depart [579].

Hauling goods will generally become easier as passengers will be picked up at their origin and do not need to carry goods to the pick-up point. As in autonomous private cars, time usage, comfort, and overall convenience will increase, too. Simulations show that SAV travel costs could be greatly reduced compared to today's costs of carsharing or taxis [179,215]. However, since most users are not familiar with these simulations and many users are uncertain about the costs of carsharing anyway, this predicted cost reduction is probably of no relevance to them.

Attitudes towards safety, reliability, loss of control, and driving pleasure that apply to the private AV also apply to SAV [406]. However, we think that the loss of control and driving fun plays a lesser role than with a private car, as carsharing users might be less emotionally connected to the car. As there seem to be more advantages than disadvantages to carsharing due to automation, we conclude that

H2: *Users will prefer autonomous carsharing (SAV) over traditional carsharing.*

In line with our state-of-the-art review, we conclude that new modes based on AD (such as private AV or SAV) could in the future increase the alternatives in travel modes. The question therefore arises as to which travel mode users prefer and how this choice will change mobility behavior overall. Although there are many acceptance studies on AD, these studies generally consider the autonomous car in isolation. To our knowledge, travel mode choice analyses have not so far included the new modes, nor have these modes been evaluated in comparison with existing modes of transport.

7.4 Methodology

To investigate the impact of full automation on travel mode choice, an online survey was conducted in Germany. We used total paired comparison to uncover user preferences as an indicator of future travel mode choice [27,430]. Paired comparison is commonly used when subjective criteria need to be recorded [67]. As outlined earlier, this is the case when choosing travel modes, as user's preference for a travel mode is shaped by subjectively perceived partworth utilities.

The survey consisted of three parts. First, we asked for general participant demographic information and participants' current mobility behavior. Second, the participants were shown a video (https://www.youtube.com/watch?v=6WTNBZZGOIs) to familiarize them with AD in general and with fully automated carsharing. The third part consisted of the complete paired comparison of the travel modes: private car, automated private car, carsharing, automated carsharing, and PT. In this paired comparison, respondents were confronted with pairs selected from an item set and asked to select the more preferred item from each pair. With $n = 5$ items there were $n = (n - (n - 1))/2 = 10$ pairs. A complete paired comparison of n objects shows how often each object was preferred over the alternative objects. If these frequencies are ranked according to their size, the objects examined can be ranked. The value 1 in a cell (i,j with $i \neq j$) indicates that the parameter setting in row j was preferred over the parameter setting in column i. Accordingly, a value of 0 means that the object in row j is not preferred over the object in column i. Since a pair combination A–B is not queried again as B–A, the corresponding cells B–A are occupied with the logical negations for A–B. Since the parameter settings are not compared with themselves, the diagonal remains undetermined.

A clear ranking of the objects can only be determined if the participants consistently assess the objects. If a participant rates $A \leq B$ and $B \leq C$, then $A \leq C$ must also apply for a consistent rating. An inconsistent respondent assessment indicates that the respondent barely noticed any differences and chose randomly or based on varying parameters. To check whether the participants did assess the objects consistently, we calculated the presence of circular triads. Circular triads arise if a participant's assessments are inconsistent and no clear ranking of the objects can be determined. We additionally scaled sum values by applying the Bradley-Terry-Luce (BTL) model as one of the most commonly applied models for analyzing paired comparison data [455,471]. The resulting utility scale values (USV) provide a ranking of the different modes that reveals relative distances between the individual ranks [6].

We checked the questionnaire in pretests for comprehensibility and revised it accordingly. Subsequently, the survey was advertised in various social networks and online platforms between 12/16/2016–01/16/2017 and 06/06/2017–07/06/2017. Two survey periods were chosen to exclude seasonal and weather-dependent causes that influence travel mode choice. In total, the survey was completed by 302 participants. The participants were 49% male and 51% female. The average age of the respondents was 36.1 years; 57.9% of them lived in the city and 42.1% in rural areas. Of the 302 respondents, 97% held a driving license, 80.1% owned a car, and 34.4% held a long-term ticket for PT.

7.5 Results

7.5.1 Preferences of the Various Travel Modes

We start by exemplarily presenting the results from two participants. Table 6 shows examples of the judgement matrices of participants 40 and 205. P40 prefers the automated car to the car: (1) Car < Automated Car. Further, for P40 applies: (2) Car > Carsharing; (3) Car < Automated Carsharing; (4) Car > PT; (5) Automated Car > Carsharing; (6) Automated Car > Automated Carsharing; (7) Automated Car > PT; (8) Carsharing < Automated Carsharing; (9) Carsharing > PT; (10) Automated Carsharing > PT. Thus, P40 judges consistently, no circular triads occur (circular triads = 0). This makes it possible to derive a clear preference ranking: Automated Car > Automated Carsharing > Car > Carsharing > PT. The consistency coefficient of P40 is 1, and the ranking is reflected in the column totals. P205 is inconsistent in assessing travel modes. Since his ratings are Carsharing > Automated Car; Automated Car > Automated Carsharing and Automated Carsharing > PT, his Carsharing/PT rating should be Carsharing > PT. However, this is not the case; he rates PT > Carsharing. Here, the circular triads are 2; the consistency coefficient is 0.6. P205 still has the peculiarity that, despite partially inconsistent evaluation, there is a clear overall favorite: The car is preferred over any other travel mode. Here, the inconsistencies do not affect the first-choice, but they do affect the subsequent travel modes.

To provide an aggregate choice matrix for our sample, the individual response matrices have been totalized. Table 7 shows the frequency matrix of paired comparison representing the judgements of all participants. The values specify the frequency with which each item was chosen across all paired comparisons. For example, the value 180 or 59.6% in cell C/AC means that the traditional private car is preferred over the automated private car by 180 respondents, 59.6% of the sample, respectively (cell AC/C shows the equivalent of 122 and 40.4%). The values are printed in bold if the user preference is greater than 50%. An asterisk indicates values that deviate

Table 6: Sample decision matrices of participants 40 and 205

a							b						
P40	C [1]	AC	CS	ACS	PT	Total	P205	C [1]	AC	CS	ACS	PT	Total
C		0	1	0	1	**2**	C		1	1	1	1	**4**
AC	1		1	1	1	**4**	AC	0		0	1	1	**2**
CS	0	0		0	1	**1**	CS	0	1		1	0	**2**
ACS	1	0	1		1	**3**	ACS	0	0	0		1	**1**
PT	0	0	0	0		**0**	PT	0	0	1	0		**1**
Consistency coefficient: 1.0							Consistency coefficient: 1.0						

[1] C = Car; AC = Automated Car; CS = Carsharing; ACS = Automated Carsharing; PT = Public Transport.

Table 7: Aggregated paired comparison matrix

	C [1]	AC	CS	ACS	PT	Total	Utility Scale Value	(±CI)	Rank
	num	*num*	*num*	*num*	*num*				
C		**180** *59.6% ** [2]	**249** *82.5% **	**237** *78.5% **	**223** *73.8% **	889	1	(±0.08)	1
AC	122 *40.4% **		**199** *65.9% **	**224** *74.2% **	**193** *63.9% **	738	0.63	(±0.06)	2
CS	53 *17.5% **	103 *34.1% **		124 *41.1% **	122 *40.4% **	402	0.24	(±0.03)	5
ACS	65 *21.5% **	78 *25.8% **	**178** *58.9% **		**160** *53,0%*	481	0.3	(±0.03)	4
PT	79 *26.2% **	109 *36.1% **	**180** *59.6% **	142 *47.0%*		510	0.33	(±0.04)	3

[1] C = Car; AC = Automated Car; CS = Carsharing; ACS = Automated Carsharing; PT = Public Transport; [2] *: $p \leq 0.05$

significantly from 50%; the significance of a value (*p*-value < 0.05) was calculated using a binomial proportion test [384]. To determine the rank, the sum of the columns was formed [67].

Participants' overall ratings are largely consistent, i.e., free of contradictions [67]. The mean consistency coefficient of the paired comparative judgements is 0.947; most respondents therefore have a conscious or unconscious individual preference order of the presented travel modes. Overall, results show that the private car has the highest preference in the sample, the fully automated version ranks second, followed by PT, while carsharing-based modes finish last with autonomous carsharing still ranking higher than traditional carsharing. Using the BTL model to analyze the paired comparative data, we obtained information about the USV, showing the relative distances between the individual ranks [6].

Figure 5 and Table 7 show USV and the corresponding 95% confidence intervals for each travel mode. The USV shows that the values for the perceived utility of both the car and the automated car are dominant. It also shows that the perceived utilities of the public and shared modes are close together. They form a group whose value is below that of the private modes.

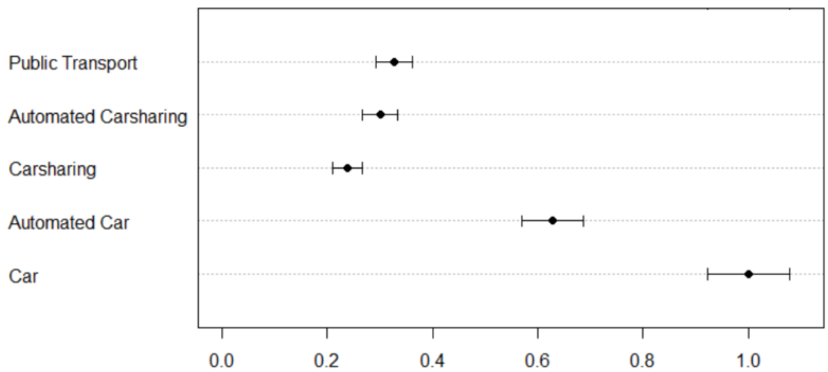

Figure 5: Utility scale values (BTL Model)

Still, the scale values must be considered with caution. The low goodness of fit ($\chi^2 = 19.47$) indicates the BTL model is a simplification concerning the utility structure of the *average user,* one that abstracts from the difference between preferences of individual users and user segments.

In addition to the one-dimensional utility scale, interesting results can also be seen in the comparison of individual transport modes. For private cars, the direct comparison of fully automated vs. the traditional variant shows a significant preference for the traditional car (59.6%; $p < 0.05$). Thus, there is evidence that Hypothesis 1 is true. For carsharing, exactly the opposite is the case. Participants prefer fully automated carsharing to traditional carsharing (58.9%; $p < 0.05$), supporting Hypothesis 2.

To see how the offer of autonomous modes affects eco-friendly means of transport such as PT, we examine changes in the preferences of PT compared firstly with traditional modes and secondly with autonomous modes. The paired comparison of PT and private cars shows that the preference for PT is 26.2% compared to the preference for the traditional car, and 36.1% compared to that of the autonomous car. Thus, automating the car does not lead to an increase in preference for the private car, which might have been expected due to the advantages that come with automation.

For carsharing, it is again the other way around. While 59.6% of users prefer PT to traditional carsharing, only 47% prefer PT to autonomous carsharing. The preference for PT decreases when carsharing is automated. In contrast to private cars, carsharing seems to benefit from full automation.

7.5.2 Changes in the First-Choice Preference

With the first-choice rule, the user always chooses the product with the highest overall utility of the alternatives offered [100]. This rule means that the alternative with the highest utility receives a choice probability of 1, and all other alternatives receive a probability of 0. In the context of travel mode choice, first-choice analysis is insofar useful as users usually preferred one travel mode that is used regularly as long as the circumstances remain relatively stable [115].

To analyze the overall effect of the autonomous modes of transport on the travel mode choice in more detail, we compared the results of the paired comparisons without new modes of transport (private car, carsharing, and PT) with the results of the paired comparisons with new modes of transport (private car, automated private car, carsharing, automated carsharing and PT, Figure 6). The results can be interpreted as current travel mode choices and possible future travel mode choices, respectively. The analysis shows that 93% of respondents expressed a favored travel mode, which is preferred to any alternative in a complete paired comparison. When only taking into account currently available means of transport, the participants preferred cars (69.9%)

over PT (21.0%) and carsharing (9.1%). If the paired comparisons are expanded by autonomous cars and autonomous carsharing as future travel modes, the respondents' preference structure changes. The proportion of decisions in favor of privately owned cars (traditionally and autonomously) remain stable at 69.9%. There are greater differences in the shares for carsharing and PT. While the share of carsharing (traditionally and autonomously) increases from 9.1% to 14.6%, the share of PT decreases from 21.0% to 15.2%. In addition, we perform an analysis at the level of the individual participants to understand how their decisions change when autonomous modes become available. P40, for example, prefers the car among the currently available travel modes. If all five travel modes are considered, he chose the automated car in accordance with the first-choice rule. This analysis is only possible for consistent valuations, since inconsistent valuations may not indicate a clear preference. Thus, n = 276 were included in this analysis.

On the basis of this analysis, concrete migratory movements between travel modes can also be depicted in addition to the relative changes in the proportions. The figures for the first-choices for currently available travel modes, the possible future first-choices, and migration are shown in Figure 6. A total of 185 participants remain loyal to the car; of the 193 people who opt for the car from the currently existing travel modes, 128 still chose the conventional car and 57 the automated car. Eight people who prefer the car from the current travel modes chose automated carsharing from all five travel modes. In addition, seven participants changed from PT to automated car and one participant from carsharing to automated car. Twenty-four participants remain loyal to carsharing. 13 of them continue to prefer conventional carsharing while 11 prefer automated

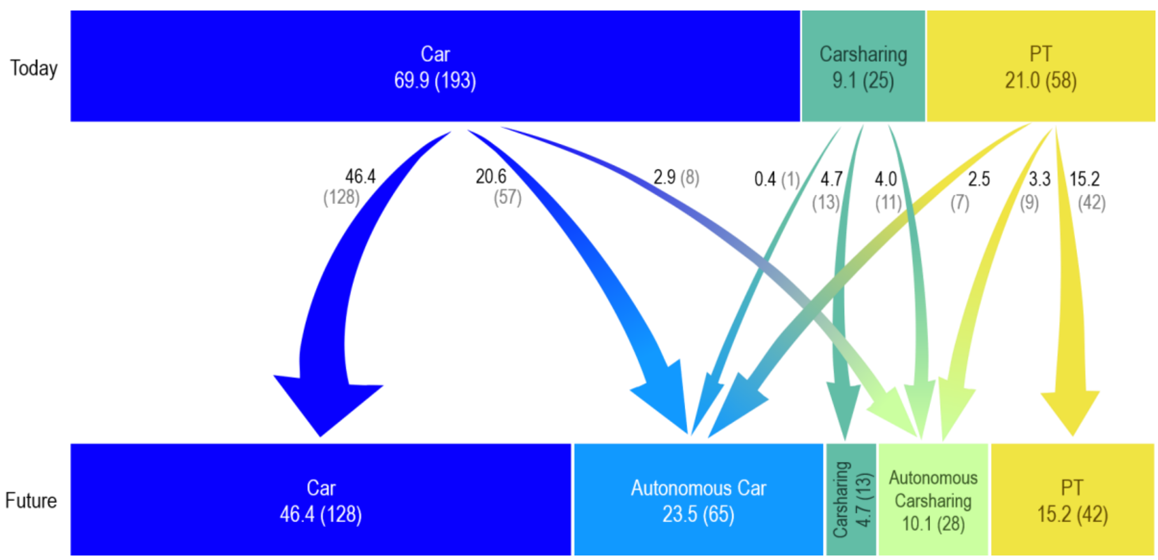

Figure 6: User's preference migration

carsharing. Another nine people switched from PT to automated carsharing. Consequently, of the 58 people who prefer PT among the currently available travel modes, 42 remain loyal to PT.

Our results suggest that the position of carsharing can be strengthened by introducing fully automated systems and that market shares can be gained. According to our participants' choices, however, the desired effect of reducing car ownership in favor of sharing offers is not achieved. Instead, the more intensive use of carsharing is to the detriment of PT.

7.5.3 Group-Dependent Results

When analyzed in depth, the results of the first choice show significant differences depending on the categories. For the analysis, the results of all participants were examined according to gender, age, place of residence, car ownership, education, and income. We examined the preferences of respondents in two ways: first, considering only the current travel modes car, carsharing, and PT and second, by additionally taking the future travel modes automated car and automated carsharing into account. This extraction is possible because the complete paired comparison method allows participants to compare all individual objects in pairs. If it can be assumed that preferences are indicators of actual travel mode choices, implications for travel today as well as in the future can be derived, allowing possible mode choice changes in the future to be anticipated.

The results of the in-depth category analysis are shown in Figure 7 and Table 8. In the following sections, we discuss the most important results sorted by category. We start with the categories that appear most interesting due to the high significant differences.

Place of Residence

The difference in preferred travel modes is greatest and significant for the place of residence (urban vs. rural), both for today's ($p = 0.00$) and for future travel mode choices ($p = 0.00$).

Today, the most sizeable differences are to be found in the preferences for the car and for PT. With 82.3%, the car is much more preferred by residents of rural areas than by city residents (60.7%). In contrast, PT is much more important for people living in urban areas: 30.7% prefer it, while it is the first choice for only 9.7% of rural areas' residents. The preference for carsharing is relatively low at 8.1% (urban) and 8.6 % (rural).

With regard to the possible future travel mode choice, there are similar differences between participants from urban and rural areas. The private car will continue to play a more important role for rural residents than for city residents while the opposite will continue to be true for PT. (Automated) carsharing will be more important for city residents (19.7%) than for rural residents (10.5%).

Table 8: Group-dependent analysis of first-choice preferences

	Today										Future											
Type	Total		C [1]		CS		PT		Sum [2]	*p* [3]	C		AC		CS		ACS		PT		Sum	*p*
	N	%	*n*	%	*n*	%	*n*	%	*N*		*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*N*	
	302	100	204	70.3	25	8.6	61	21.0	290		128	45.4	68	24.1	13	4.6	31	11.0	42	14.9	282	
Residence																						
rural	127	42.1	102	82.3	10	8.1	12	9.7	124	0.00	72	58.1	29	23.4	5	4	8	6.5	10	8.1	124	0.00
urban	175	57.9	85	60.7	12	8.6	43	30.7	140		56	35.4	39	24.7	8	5.1	23	14.6	32	20.3	158	
Car Owner																						
yes	242	80.1	190	80.6	15	6.4	30	12.8	235	0.00	117	51.1	61	26.6	8	3.5	20	8.7	23	10.0	229	0.00
no	60	19.9	14	25.5	10	18.2	31	56.4	55		11	20.8	7	13.2	5	9.4	11	20.8	19	35.9	53	
Age																						
<25	95	31.5	64	70.3	7	7.7	20	22.0	91		43	47.8	16	17.8	4	4.4	13	14.4	14	15.6	90	
25–50	139	46.0	92	69.7	8	6.1	32	24.2	132	0.15	52	40.9	40	31.5	3	2.4	10	7.9	22	17.3	127	0.03
>50	68	22.5	48	71.6	10	14.9	9	13.4	67		33	50.8	12	18.5	6	9.2	8	12.3	6	9.2	65	
High School																						
no	42	22.8	33	82.5	2	5.0	5	12.5	40	0.14	25	67.6	5	13.5	2	5.4	2	5.4	3	8.1	37	0.01
yes	233	77.2	151	66.8	22	9.7	53	23.5	226		90	40.7	57	25.8	10	4.5	27	12.2	37	16.7	221	
Gender																						
female	154	51.0	99	68.6	13	9.0	32	22.2	144	0.84	64	44.4	33	22.9	33	22.9	13	9.0	28	19.4	144	0.24
male	148	49	105	71.9	12	8.2	29	19.9	146		64	46.4	35	23.6	35	5.1	18	13.0	14	10.1	138	
Income																						
<1300€	124	41.1	78	65.0	11	9.2	31	25.8	120		49	42.2	25	21.6	25	21.6	14	12.1	22	19.0	116	
1300–2600€	72	23.8	49	73.1	4	6.0	14	20.9	67	0.36	34	52.3	12	18.5	12	18.5	8	12.3	9	13.8	65	0.49
>2600€	106	35.1	77	74.8	10	9.7	16	15.5	103		45	44.6	31	30.7	31	30.7	9	8.9	11	10.9	101	

[1] C = Car; AC = Automated Car; CS = Carsharing; ACS = Automated Carsharing; PT = Public Transport; [2] Number of consistent preference choice assessments for that category; [3] *p*-value of χ^2.

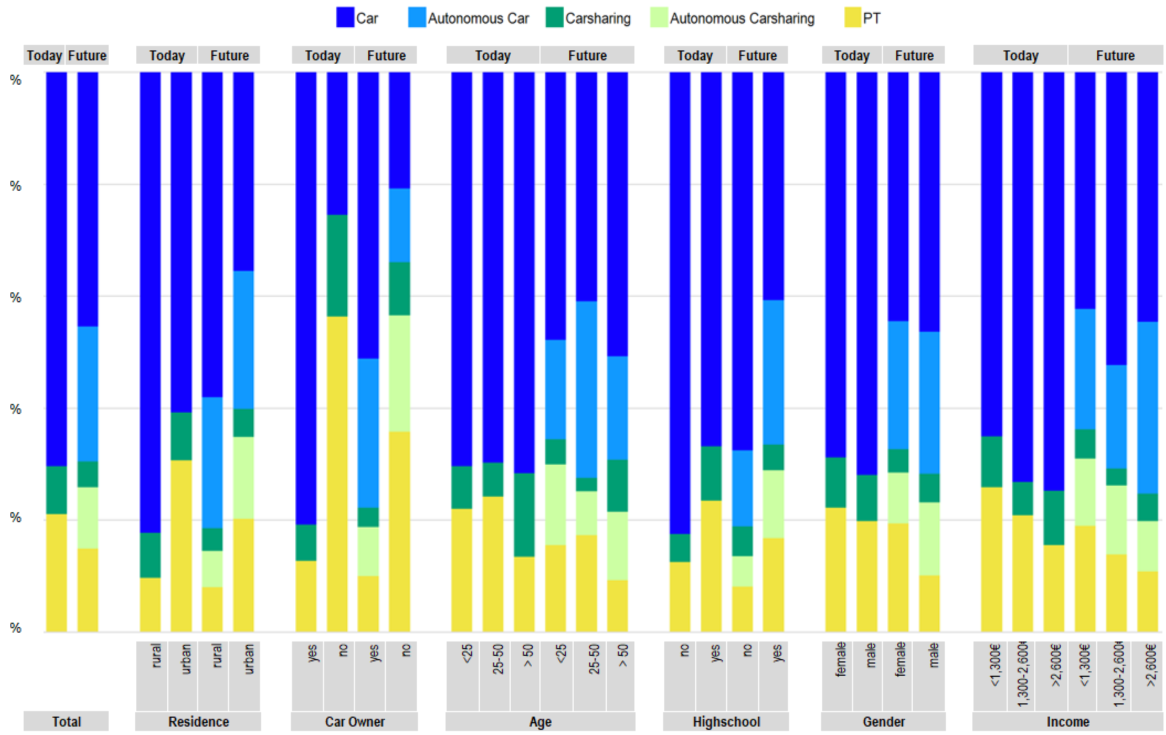

Figure 7: Group-dependent analysis of first-choice preferences

For the changes in travel mode choice brought about by the inclusion of automated travel modes, the results show that the preference for (automated) carsharing and PT changes, especially among participants from urban areas. It is noticeable that the preference for PT among urban participants will decrease from 30.7% now to 20.3% in the future while carsharing, irrespective of whether it is automated or not, will be preferred by 19.7% in the future instead of 8.6% now. Compared to today, the figures for the private car (total C/AC) in the future will remain stable at 81.5% in rural areas and 60.1% in urban areas. However, the conventional car will lose out with the automated car being preferred by 23.4% (rural area) and 24.7% (urban area). For rural participants, the figures for (automated) carsharing and PT remain comparatively stable at 10.5% (total CS/ACS) and at 8.1%, respectively.

Car Ownership

The largest significant differences in preference can be seen between car owners and non-car owners. As is to be expected the car today is the preferred travel mode for car owners (80.6%), while it is only the first choice for 25.5% of non-car owners. Most of the latter prefer PT (56.4%). The distribution of preferences for carsharing shows it is more attractive for non-car owners (18.2%) than for car owners (6.4%).

For future travel modes, 51.1% of car owners would prefer the conventional car, another 26.6% the automated car, so that a total of 77.7% of car owners would prefer the private car over usage-based travel modes. It is remarkable that the preferences of non-car owners for the future are almost evenly distributed among the three travel mode types; private cars (total C/AC; 34.0%) are just behind PT (35.9%), while carsharing (total CS/ACS) is narrowly less with 30.2%.

Consequently, the preferences of both car owners and non-car owners are affected by the advent of automated travel modes. For car owners, the greatest change can be found in their preference for carsharing: Overall, carsharing will gain slightly; its share will grow from presently only 6.4% to 12.2% (total CS/ACS), with 8.7% being accounted for by automated carsharing. This difference means that there are participants who will change preferences from private cars to carsharing in the future due to automation. Non-car owners' preference for the private car as a whole will increase from 25.5% to 34.0% (total C/AC). It is, therefore, likely that non-car owners will shift their preference in favor of the private car as a result of automation. For these non-car owners, automated carsharing will also gain significantly from 18.2% now to 30.2% in the future. Their previous majority preference for PT will be substantially reduced from 56.4% to 35.9% by introducing automated travel modes.

Age

Only in the future travel mode preferences can significant differences between age groups be found, especially in carsharing and PT. While the young and the middle age group currently only prefer carsharing with a percentage of 7.7 and 6.1, respectively, the percentage is higher (14.9%) among older participants. For PT, the opposite is true: 22.0% of the young and 24.2% of the middle-aged participants prefer PT while only 13.4% of the older ones do so.

There are similar differences in preferences between participants of different age group for the future travel modes. Here too, the middle-aged group stands out from younger and older users; private cars are even more important to them. Carsharing is least important among all age groups. The older generation is in particular striking in its future disinclination towards PT: at only 9%, they will be significantly less attracted to PT than the middle-aged (17.3%) and younger generations (15.6%).

As a result, the private car will gain in importance among middle-aged participants when choosing between travel modes (from 69.7% (total C) to 72.4% (total C/AC)) while the preference for the private car will decrease among young and older participants. Carsharing will gain through automation, especially among young people, and will increase in preference from 7.7% (total CS) to 18.8% (total CS/ACS). PT loses out in all age groups due to automation.

Education

There is a notable difference in the preferred travel modes when the participants are categorized according to their educational backgrounds. The preference for private cars is substantially higher among people without a high school degree than among people with a high school degree for both current and future travel modes. The contrary is true for PT.

In the current travel modes, these differences of travel mode choice correlate only slightly with the respondents' educational background (p = 0.14). Participants without a high school diploma (15.3% of our sample) have a stronger preference for cars (82.5%) than participants with a high school diploma (66.8%). The more highly-educated participants prefer PT and carsharing. Similar preferences apply to future travel modes. Here the two groups differ significantly from each other (p = 0.01).

Automation hardly changes the preferences for private (automated and non-automated) cars in the future. It is again carsharing that wins in the future travel mode choice, while PT loses attractivity in both groups. These differences between the two groups are significant (p = 0.01)

Gender

Slightly more male and fewer female participants currently prefer the car and vice versa applies for PT, for both present and future travel modes. The car is the most important travel mode for men (71.9%) and women (68.6%). After that choice, both groups prefer PT over carsharing.

With future travel modes, the differences between genders are greater for carsharing and PT. While 18.1% (total CS/ACS) of the males would prefer carsharing in the future and only 10.1% PT, among females there are 13.2% who prefer carsharing and 19.4% PT.

While the distribution of private cars among men and women remains almost the same when regarding changes in first-choice preferences, there are differences between carsharing and PT. Men shift their preferences much more from PT to carsharing when automation becomes available than do women. However, the gender differences are not significant here.

Income

With regard to income, there is a slight trend that participants today with rising income (65.0%; 73.1%; 74.8% for the three income brackets) increasingly prefer the private car among current travel modes, while participants with lower incomes increasingly prefer PT (25.8%, 20.9%, 15.5%). Similar distributions can be seen in future travel mode choices, indicating that carsharing is preferred as a result of automation at the expense of the private car but even more so at the expense of PT. However, the differences between the income groups are also not significant and may therefore only be a random result.

7.6 Discussion

The (fully automated) private car still seems to be of great importance in the future for the respondents even with alternatives increasing such as carsharing-based services. However, the preference could change significantly with the introduction of automated driving. To investigate changes in the preference structure, we now discuss the results of the paired comparisons in more detail as presented in Table 7, where possible changes in partworth utilities as well as preference migrations (Figure 6) and group-dependent results (Figure 7 and Table 8) are taken into account.

7.6.1 The Private Car is Still Preferred over Automated Alternative Modes

The participants expressed that the traditional private car for them still has a slightly higher total utility than the autonomous private car, and 59.6% of the participants still prefer the traditional version. As the privately owned car is the most popular travel mode today – both among our participants as well as in Germany in general [280] – its role in the future could be over-estimated. As travel mode choice is strongly influenced by socialization and habits, users familiar with using a private car are likely also to choose the private car to be the most preferred travel mode in the future [29]. From today's viewpoint, the subjectively perceived advantages of the conventional car over the autonomous car are predominant. While characteristics such as availability, driving time, flexibility, or transportation of objects are not expected to change substantially, the differences in characteristics might be perceived as greater between traditional and autonomous cars. According to some studies, users will see the autonomous car as being better in terms of driving comfort and improved time use, as well as being less restrictive (e.g., after drinking alcohol) [410]. In terms of driving enjoyment and control of the vehicle, however, the traditional model that needs to be actively controlled can score better. Studies such as [410] have shown that some respondents fear that automating the car will reduce the fun of driving. There are also reservations about the safety of the as yet unknown AV [253] and some users are concerned about privacy issues. They are particularly worried that their location and destination data will be disclosed [473]. These concerns could in sum lead traditional passenger cars to have a higher value among users.

Our analysis of preference migration with regard to the participants' first choice provides us with a more detailed insight into how users change their preferences when the travel mode choice is increased by automated travel modes. Most respondents expressed that they will adhere to their behavior patterns: participants who prefer the private car among today's travel modes will continue to prefer owning a car – either a conventional, or a self-driving one. In this respect, the aspect of ownership also plays a decisive role: either because users do not want to give up their car because of circumstances such as inadequate local mobility supply or because they do not want to give up advantages such as the high flexibility and guaranteed vehicle availability [406] as well as the psychological and emotional comfort of not having to share a vehicle with other people. Interestingly, a change in preference towards mobility as a service such as automated carsharing, as predicted by carsharing supporters or optimists [62,296,492], can only be observed in a very small proportion of today's car enthusiasts in our sample.

In addition, and especially interesting regarding indirect rebound effects, automation will make the private car attractive for some users who currently prefer PT, possibly resulting in mode shifts. This preference migration can be explained by these users who appreciate that they do not have to drive themselves but at the same time also appreciate the advantages of a private car, namely the availability at all times, high flexibility, as well as comfort [406].

7.6.2 Carsharing Strongly Benefits from Automation

58.9% of the participants indicated that they are interested in using automated carsharing services rather than conventional carsharing (when directly compared, see Table 7) because they see it as a possible remedy for current shortcomings in carsharing such as the lack of availability and flexibility, having to use more than one mode of transport, and because high costs are completely or partially eliminated [296,541,571]. Fully automated carsharing will offer numerous advantages: comfort and a better use of time will increase as the driving task no longer exists. In addition, the planning and coordination effort will be reduced because the user does not have to search for and locate a suitable vehicle and a station; the vehicle will come to the user on request [579].

The responses regarding fully autonomous modes for the private car and for carsharing show that 58.9% of the respondents prefer the fully automated version for carsharing, compared to only 40.4% for private cars. This significant difference in user preferences (binomial proportion test; $p < 0.05$) indicates that the acceptance of full automation depends on the increase in the total utility of the respective travel mode. From the user's point of view, full automation in the private car segment therefore results in comparatively minor improvements while at the same time it greatly increases the benefits and thus the attractiveness of carsharing. It is, therefore, interesting to see how the preferences for full automation shift between private cars and carsharing. In the traditional scenario, there is a significant preference of 82.5% for private cars. In the fully automated scenario, there is also a significant preference for the private car, but it decreases significantly to 74.2% ($p < 0.05$). In other words, the relative total utilities of private cars and carsharing will converge to some extent in the future. It can therefore be assumed that the full automation of carsharing can help to increase its market potential and expand its share in the modal split.

Furthermore, the analysis of preference migration indicates that some participants who currently prefer PT will shift their preference to automated carsharing services. This change can be attributed to these participants who are accustomed to using mobility as a service rather than having their own vehicle for permanent availability. These participants may also be convinced by their personal attitude that car ownership is generally not necessary, but at the same time they can imagine taking advantage of the greater comfort of a vehicle in the future. Automated carsharing thus offers this user group the optimal combination of flexible mobility, in which ownership does not commit them to regular costs and maintenance of a vehicle, while at the same time providing a high level of comfort in terms of privacy, ease of use, driving time, and short waiting times.

7.6.3 Public Transport as Loser of Vehicle Automation

If users shift their preferences as described above due to the automation of vehicles in favor of automated private cars and automated carsharing, fewer users will prefer PT. If the travel modes private car and carsharing can strengthen their attractiveness and competitiveness through automation, PT could lose their competitive advantage to the automated travel modes.

The paired comparisons of PT with both carsharing variants show that the preference for PT will decrease significantly from 59.6% to 47.0% ($p < 0.05$). This decrease can be attributed to a relative improvement in carsharing compared to PT, caused by the automation of carsharing. In this way, the availability and ease of use of carsharing are improved. In addition, driving skills no longer play a role in the use of autonomous carsharing. Using a travel mode without necessarily having to be fit for driving is so far one of the unique selling points of PT.

Generally, this improvement also applies to private cars. Surprisingly, the responses related to the fully automated private car, show an increase in preference for PT from 26.2% to 36.1%. Due to the fully automated system, the private car will lose attractiveness compared to PT. One explanation for this loss could be that due to a lack of confidence in technology, today's drivers would prefer to use PT instead of a fully automated car.

In the context of automated driving, initial steps have been taken in research and development to bring PT and carsharing together to a certain extent [387]. In the future, for example, automated minibuses that operate more flexibly but still transport more than one person are to be tested. Such new PT concepts are promising if the results of this study are considered.

7.6.4 The Impact of Individual Characteristics on Travel Mode Choice

In urban areas, a significant increase in sharing models can be expected. While this development certainly has advantages compared to private car use, our study suggests it will take place at the expense of PT, which is popular in urban areas today. For city residents, automated carsharing is an attractive alternative to PT, as it offers a similar travel time with greater flexibility and comfort and without the problem of having to park the vehicle oneself.

Among car owners, we found only a slight decline in private cars as the most popular mode of transport. Carsharing, on the other hand, is becoming more attractive for this group, especially automated carsharing. This change shows that some car owners expect that automated carsharing will continue to converge with private cars and that there will no longer be any major differences between these modes. However, the differences among non-car owners are much more pronounced. Automation makes the private car more attractive for non-car owners as they do not have to drive the vehicles themselves. A similar effect can be observed in carsharing. Accordingly, PT will become less attractive since its great advantage of free use of time while being driven is no longer a unique selling point. Consequently, the positive mode shift effects as far as car owners are concerned are overcompensated by the negative mode shift effects as regards non-car owners.

Our study shows no clear trends in preferences among users when categorized by age. AD and SAV seem to offer different benefits to different age groups. While the younger generation may be more familiar with the technology and therefore more open-minded, older users appreciate that they can continue to be comfortably mobile even with cognitive or physical impairments. Surprisingly, sharing-based models seem to become more attractive with age, both today and in the future. Possibly the emotive bond to the car decreases with age, and carsharing offers older users added value compared to PT, because it can accommodate the changing requirements and limitations of users later in life.

Regarding education, users with a high school degree are much more likely to prefer automated travel modes. This trend can be traced back to the fact that people with a higher education are generally more open-minded about (technical) innovations [4].

The higher a person’s income is, the stronger the trend towards car ownership is, while the preference for PT declines. These changes can certainly be explained by the cost of both travel modes. Regarding the share of autonomous travel modes, there is no clear trend when comparing groups with different incomes. The reason may be that respondents are not yet aware of the price of self-driving technology and automated travel modes.

7.7 Limitations and Implications for Future Research

Looking at the results as a whole, it is important to note that the study is not representative and that our results can therefore not be directly transferred to the population in general. In addition, it should be noted that the survey was carried out in Germany and that the German transport system and consumer habits certainly differ from those in other countries. These differences may also affect the participants’ assessment of future mobility concepts.

While the figures on user preferences in this study do not exactly reflect the current modal split, the ranking is the same, only the percentages differ. In particular, carsharing has a much smaller market share. Routines and habits also discourage users from choosing an alternative means of transport [29]. Furthermore, we did not consider automated forms of PT in our paired comparison since a recent study showed that, because there is generally no interaction between driver and passenger in PT, users do not perceive a significant difference between automated and non-automated PT [399]. However, it certainly makes sense to analyze how new automated forms of PT, such as automated minibuses for the last mile, will affect users' future preferences. Against the background that carsharing concepts and new PT concepts may converge in the context of automation, it is of particular interest whether this future development will make PT as attractive as carsharing appears to be in our study. Further research should be carried out on this in the future.

7.8 Conclusions

The literature on AD often assumes a positive effect on the environment since AV can operate more efficiently and could reduce traffic density, congestion frequency, and the overall number of vehicles [179,214]. Even though researchers agree that sustainability politics will only be successful if the various forms of rebound effects are taken into account [465], unintended rebound effects such as shifts in travel patterns have rarely been considered in this context. Furthermore, most studies argue from a theoretical perspective as empirical evidence is still lacking due to the fact that only few automated forms of travel exist at present. Our study attempts to address this gap by focusing on user preferences. This focus allows us to better understand factors considered when users opt for or against the use of self-driving vehicles in the future, and thus to forecast how users will adapt their mobility behavior with novel offers such as automated carsharing (SAV).

Our empirical analysis supports the hypotheses that, first, users will still prefer traditional cars over fully autonomous ones, and second, they will prefer autonomous carsharing over traditional carsharing. As automation becomes a strong benefit to carsharing, this will increase carsharing's utility in various ways. Our in-depth analysis of the preference changes further shows that users anticipate these benefits in a way that makes desired effects, such as a shift away from the private car towards mobility as a service, likely. However, it is only a small minority of users who are shifting their preference away from private cars and towards automated carsharing. At the same time, undesired preference changes become apparent, as twice as many users are moving away from PT, towards the automated private car and automated carsharing, so that the effects of this undesirable preference migration may considerably outweigh the positive. Thus, it is quite possible that carsharing will not become more popular at the expense of private cars, as hoped for, but at the expense of PT. In summary, indirect rebound effects in the form of mode shifts from more sustainable modes such as PT to SAV are to be expected.

To address the outlined rebound effects, action must be taken at all levels: users, policymakers and mobility service providers. As people are not always intrinsically motivated to behave in a sustainable manner [277] – as our study also shows – they need additional motivation. Gamification could be used to trigger behavioral changes towards sustainable mobility options. By offering people incentives regarding their health and well-being they could possibly be motivated to walk or cycle more often instead of using an inexpensive and comfortable AV [274,561]. Since there is evidence that not-environmental-related criteria such as comfort and reliability are decisive for travel mode choice [352,501], it is important to strengthen those aspects in sustainable mobility services. The government and public research and development must put more effort into their transportation policy by making sustainable PT more attractive for people and providing incentives for private companies to offer sustainable mobility. Our study provides insights into how automation can play a role here, and that PT also has to change to compete against the possible further development of carsharing and its effects on user behavior. In addition, research results such as those from our previous study on the partial added values of the various travel modes [406] reveal which exact adjustments PT needs to make in order to improve its competitive position or make its service more attractive than automated carsharing. In particular, this would require improvements in travel time, waiting time, and flexibility as well as in comfort and ease of transportation of goods. These requirements can be met if PT relies on smaller units working on demand, so that it converges to a certain extent with automated carsharing. This indicates a need for more research on hybrid models between autonomous carsharing and PT – aspects which we intend to study in future work.

8 STUDY 4: THE USERS' PERSPECTIVE ON AUTONOMOUS DRIVING – A COMPARATIVE ANALYSIS OF PARTWORTH UTILITIES

Digitization has brought a major upheaval to the mobility sector, and in the future, self-driving cars will probably be one of the transport modes. This study extends transport and user acceptance research by analysing in greater depth how the new modes of autonomous private cars, autonomous carsharing and autonomous taxis fit into the existing traffic mix from today's perspective. It focuses on accounting for relative added value. For this purpose, user preference theory was used as a base for an online survey (n=172) on the relative added value of the new autonomous traffic modes. Results show that users see advantages in the autonomous modes for driving comfort and time utilization whereas, in comparison to conventional cars, in many other areas – especially in terms of driving pleasure and control – they see no advantages or even relative disadvantages. Compared to public transport, the autonomous modes offer added values in almost all characteristics. This analysis at the partworth level provides a more detailed explanation for user acceptance of automated driving.

8.1 Introduction

Self-driving vehicles [458] represent a technological leap forward that can offer solutions to current traffic problems and dramatically change the way people deal with mobility [253,417]. For some years, fully automated vehicles have been tested in several pilot projects [386]. The leading automotive manufacturers and IT companies in the autonomous driving sector assume that full automation could be ready for series production within the next five to ten years. Experts expect driverless cars to reduce the number of accidents and traffic problems as well as improve the efficiency of traffic flow [179,296,300]. Automated driving technology will also create new, innovative business models such as vehicle-on-demand [179,400]. Additionally, mobility services such as self-driving taxis or autonomous carsharing could especially benefit from the self-driving technology: lower personnel costs mean that driverless taxis can operate much cheaper [179], and fully automated carsharing promises improvements in availability as the car comes to the user instead of vice versa [296]. In this context, researchers see a strong convergence of taxi and carsharing [400]. Various authors expect a significant reduction in the number of private cars through strengthening usage-based mobility services [91,179,400]. To gain a better understanding of user acceptance and to be able to better predict future changes in mobility behavior due to new autonomous modes of transport, we performed a study that examines autonomous travel modes and compares them to existing modes on the basis of their respective characteristics.

8.2 Theoretical Background

8.2.1 Travel Mode Choice

To satisfy the human need for mobility [559], various travel modes are available to the user. From the various alternatives, the user chooses the one that has a relative, often subjectively perceived advantage over the others and thus maximizes his or her personal benefit [341]. In addition to user-related and external influencing factors, product-related influencing variables play a major role. According to Lancaster, it is not the product as a whole but its special characteristics that provide consumers with a benefit, the so-called partworth utilities [301]. In the past, in addition to demographic, socio-economic, psychographic, geographical, and situational factors, a number of product-specific characteristics could be identified that influence travel mode choice. Those studies come to different conclusions regarding the ranking of those factors, but they show that travel time, travel costs, and reliability play a decisive role [158,296,420,565]. Further studies such as that by Steg have analyzed the characteristics of passenger cars and public transport as the most frequently used travel modes from a user's point of view [499]. The ratings reflect the users' usage patterns by clearly showing that the car is rated better than public transport in many respects – e.g. in terms of convenience, independence, flexibility, flexibility, driving comfort, speed and reliability.

8.2.2 User Acceptance of Autonomous Vehicles

The transformative advantages of the self-driving technology can only be realized if the majority of users accept self-driving cars [253]. Researchers have recently devoted themselves to the topic of user acceptance. Their studies show that most people have a positive attitude towards autonomic driving and can imagine buying and/or using autonomous cars [410,445,473]. Thus, many respondents gave a positive opinion on the technology and had optimistic expectations of its benefits [473]. Users see added value in improved road safety, a more efficient traffic flow [168,253,594], and the convenience of not having to find parking spaces and of better use of time while driving [253,400]. At the top of the advantages' list, users can imagine autonomous driving for driving on the motorway, in traffic jams, and for automatic parking [410]. At the same time, the studies report on respondents' concerns: they fear software hacking and abuse and are concerned about legal issues, security and reliability of technology [300,473]. Many respondents think that humans are the better driver [168] and are afraid of handing over control to technology [253]. From the users' point of view, the high acquisition and operating costs [168,253] one expects from autonomous vehicles and the loss of driving pleasure associated with eliminating the driving task [168,386] speak against their use.

Since new modes of transport such as autonomous private cars, autonomous taxis or autonomous carsharing could extend the options for choosing a travel mode, the question arises as to which travel mode users prefer and how this choice will change mobility behavior as a whole. Although there are many acceptance studies on autonomous driving, these studies generally view the autonomous car in isolation. To our knowledge, transport mode selection analyses have so far neither included the new modes nor compared these with existing modes of transport. In a previous complete pair comparison study, we have therefore allowed users to choose between the current traffic modes car, public transport, carsharing and the new modes autonomous car and autonomous carsharing [403]. The results showed that, from a user's perspective, the autonomous modes of transport are significantly better than public transport, while they are almost identical or worse than conventional passenger cars. However, the question remained as to what exactly was the reason for the participants' choices – in which factors they see relative advantages or disadvantages of the respective modes of transport. Therefore, this follow-up study analyses the partworth utilities to obtain more precise information on the composition of user acceptance. The central research questions are

1. *How does the decision in favour of or against a travel mode relate to the relative overall benefit?*
2. *What relative partworth utilities do automated travel modes offer?*

8.3 Methodology

A two-stage survey was conducted to answer the research questions carried out in Germany. In a qualitative preliminary study, the criteria identified in the literature with regard to their relevance for the new modes of transport were verified and adapted. To this end, ten qualitative interviews were conducted in which the interviewees were asked to assign characteristics to both traditional and new modes of transport and to explain their relevance. Based on this preliminary study, a quantitative questionnaire was created.

The questionnaire began with a comparison of the traditional car with the autonomous private car, the autonomous carsharing and the autonomous taxi. The participants were asked to identify advantages and disadvantages of the new modes in relation to the conventional car with respect to 13 characteristics: driving time, waiting time, availability, flexibility, driving pleasure, driving comfort, ease of use, control of the vehicle, safety, transport of objects, reliability, costs and time utilization. Similarly, public transport was compared with autonomous travel modes. Subsequently, respondents should indicate which travel mode they would use or own regularly in the future. Traditional and automated travel modes were available. Finally, demographic data and information on current mobility behavior were collected.

A total of 172 people took part in the survey, 49% of whom were female. The age range was 17 to 79 years (average 35.6). 64.7% lived (rather) urban, the other 35.3% (rather) rural. Almost all participants (95%) had a driving license and 80% owned a car. Of those surveyed, 71% were employed, 26% were pupils or students and 3% were retired. About 63% of respondents used the car as their main travel mode and 20% used public transport.

8.4 Findings and Discussion

8.4.1 Relative Part Worth Utilities Compared to Private Passenger Cars

Figure 8 shows the participants' subjective evaluation of the individual partial utility utilities. From the respondents' perspectives, the automated modes only have advantages over traditional cars in terms of driving comfort and the use of time during driving. In all other characteristics, the participants saw minor advantages for the traditional car in terms of driving pleasure and control. With an (unweighted) average of -0.28 for the autonomous car, -0.52 for autonomous carsharing and -0.49 for autonomous taxis, the direct comparison showed the relative advantage of traditional cars in each case: users would be expected to go for those when having the choice.

In the following, we investigate in more detail some of the prominent characteristics and reflect on why the participants came to their assessments. Autonomous vehicles offer greater

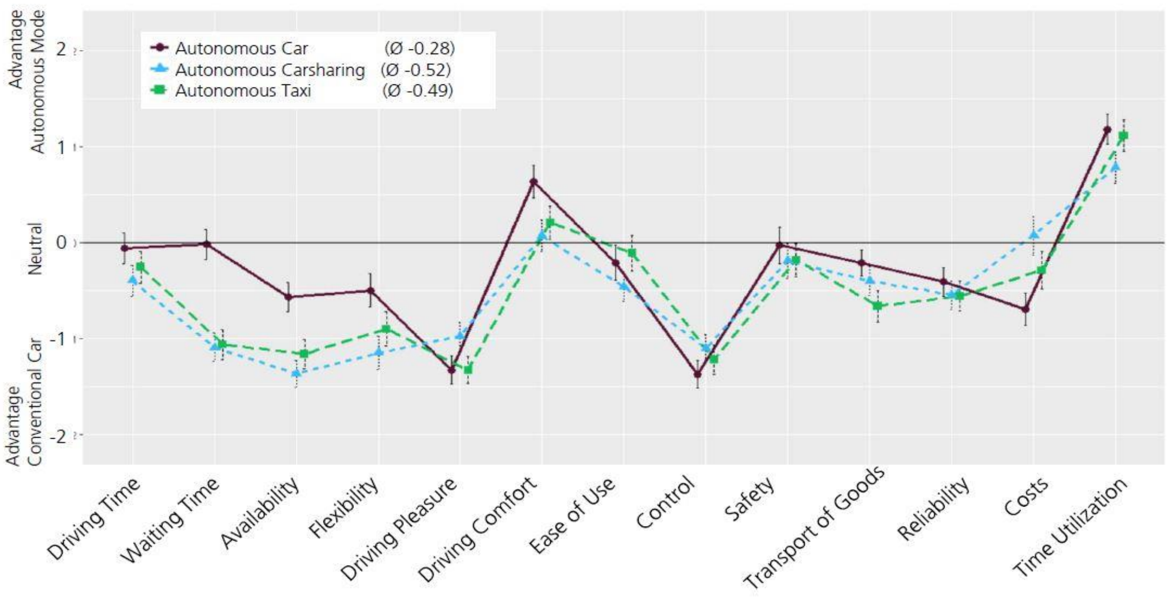

Figure 8: Comparative assessment of autonomous travel modes and the conventional car
(n=172, confidence interval = 95%).

driving comfort and greater time saving than traditional cars. Both benefits are closely linked. Driving comfort is a multidimensional construct under which almost every user understands something different [210]. It includes coziness, comfort, and psychological hygiene. These characteristics are judged negatively if a travel mode must be shared with many others (external people) (especially public transport; [284]). Autonomous modes of transport offer the great private space and comfort of a private car, but also the advantages of public transport.

The use of time while driving a traditional car is limited to passive activities such as listening to the radio or making telephone calls. Because the driving task is eliminated, self-driving technology makes it possible to make better use of time in the car [130]. This levels off one of the advantages of public transport because the driver becomes a passenger [399]. For this reason, the attested added value in the use of time for the autonomous car is in line with expectations. However, it is surprising that the partial benefits of time utilization for autonomous carsharing and taxis are not as high as for autonomous cars. One explanation could be that the private car seems to be more individualizable so that the time can be used more effectively than e.g. in a non-private taxi.

In terms of driving pleasure and control, the traditional car offers significant relative added value over autonomous modes of transport. This result confirms the results of studies such as those by [168,175,386], which show that some respondents fear that automating the car will reduce driving pleasure. Driving pleasure for the user arises from the satisfaction of a personal desire for nerve-racking thrills by risky driving styles when actively driving a vehicle. Due to the necessity of active control, the car does indeed offer users a higher potential for much more driving pleasure than modes where the user does not actively control. The survey confirms this assessment: The participants see a clear added value for driving pleasure in the classic car compared to all driverless modes. Active steering is closely linked to control over the vehicle, which also encompasses the entire physical and organizational power over a travel mode and is of great importance to users [168,253].

Waiting time, reliability, availability and flexibility are disadvantageous in all autonomous modes compared to the classic car but more so in autonomous vehicle-on-demand services. In the case of autonomous carsharing and taxis, the waiting time is evaluated significantly worse than in the case of car variants. This result is not surprising since, from the moment a user is ready to drive and places an order for autonomous taxi/carsharing, a waiting time can arise until the actual start of the journey if the vehicle has to reach the passenger's location.

The neutral evaluation of the waiting time for the autonomous private car was to be expected. However, an explanation is required as to why the assessment of flexibility/independence and availability is significantly lower for the autonomous version of the car than for the traditional one. Here, the criteria also seem to depend on reliability. The poor evaluation of reliability can probably be attributed to the novelty of the technology that users are still inexperienced with and in which they do not yet trust. Participants in previous studies expressed concerns that the technology could fail [300,473]. These concerns would explain why it is believed that autonomous cars are not equally available and flexible in every situation.

Model simulations assume that data-driven control, automatic relocation and automatic retrieval greatly increase the availability, especially compared to today's carsharing, so that the user has to wait on average less than one minute [179]. Users usually lack such knowledge and thus apparently lack the confidence that quick availability can be guaranteed (e.g. if vehicles are occupied or not in the immediate vicinity), so that the rating is lower than with their own cars. The private car on the doorstep creates a feeling of flexibility and independence, which apparently cannot be achieved in the same way by a mobility service provider – even with full automation. The flexibility also includes free and autonomous time and route planning. The fully automated system actually makes the car even more flexible since autonomous cars can, for example, pick up users directly in front of the door, drop them off at their destination, and then park on their own. However, the survey shows that the traditional car is rated better. One explanation is that flexibility/independence does not only include flexible time and route planning, but also, from the user's point of view, physical control of the vehicle and freedom over driving style and spontaneous decisions (sudden stop or change of direction). Here, the fear that autonomous technology may limit users in their own (ad-hoc) decisions may play a role. Thus, the perceived loss of control (see above) also has a negative effect on independence and flexibility.

In terms of costs, respondents also saw a disadvantage – especially in private autonomous cars. In contrast to the use-based modes, the latter would not only incur usage-dependent variable costs but also fixed costs of ownership. In addition, users also expect higher start-up costs due to the self-driving technology as well as higher operating costs due to the additional technology, which may cause new faults and require more maintenance [168,253].

Due to the fully-automated system, there are improvements especially in carsharing, if the user does not have to carry the luggage to the pick-up station. Although it could be assumed that the transport with similar fully automated vehicles, which always pick up the user at the front door, is equally possible, the interviewees still saw a slight advantage in the classic car. Here, it can only be assumed that users prefer to transport things in their own vehicle or, in particular, rate the services less highly, as they transfer their current image of taxi and carsharing to the automated modes. There were no significant differences between the driving time, ease of use and safety criteria. From an objective point of view, the criterion ease of use requires an explanation since driving a car today is currently one of the most complex and dangerous cultural skills.

Autonomous driving frees the user from this complex task so that, for example, children, the elderly and the disabled can use an autonomous car on their own. However, as almost 95% of the respondents have a driving license, this complexity no longer seems to be decisive once vehicle control has become routine. Rather, users fear that they will have to learn new usage techniques. Although studies of fully-automated vehicles predict a higher safety than for the classic car [168,175,253], users are skeptical, have little confidence and often consider themselves to be the better driver than a machine [168]. These two contradictory arguments lead to a neutral evaluation in total – this is also supported by the consistently high dispersion in the respondents' response behavior (standard deviation 1.14 to 1.28).

Overall, it can be seen that the autonomous modes of transport have (subjectively perceived) relative disadvantages in almost all characteristics compared to classic passenger cars. Only the driving comfort and the use of time during the journey are considered to be much more positive for autonomic vehicles than for classic cars.

8.4.2 Relative Part Worth Values Compared to Public Transport

When comparing the profile lines (Figures 8 and 9) it is noticeable that the relative added value of the fully automatic modes compared to traditional passenger cars is much lower than that of public transport. While the partial benefits of the new autonomous travel modes are seen in many aspects as worse or equivalent to conventional cars, the opposite is true for public transport. This

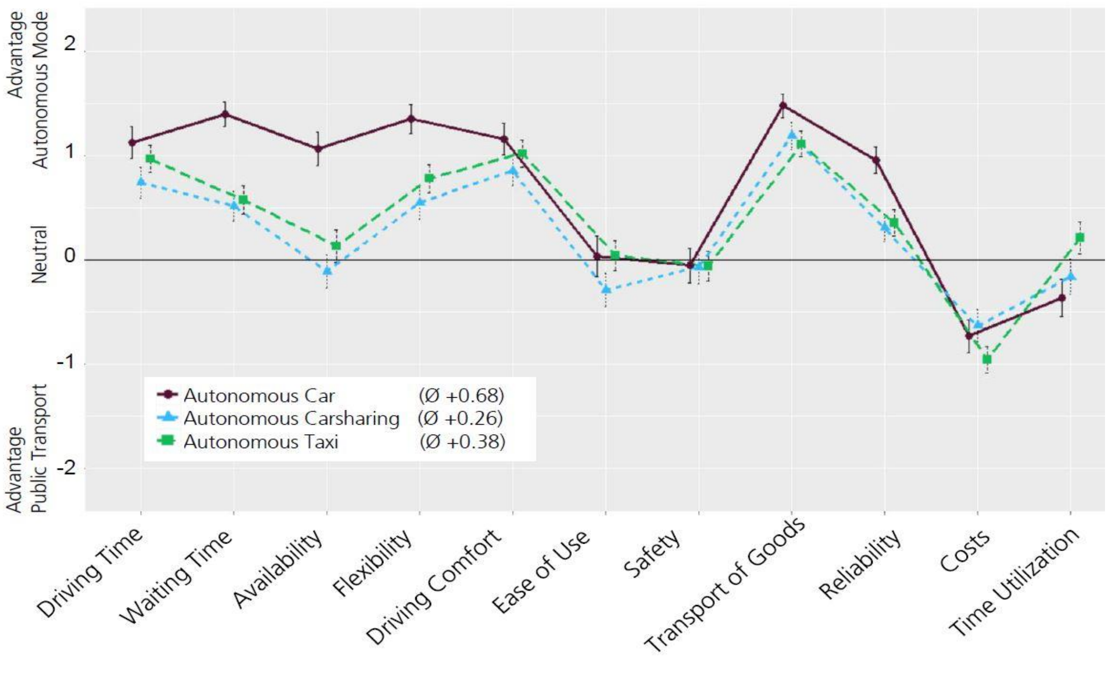

Figure 9: Comparative assessment of autonomous travel modes and public transport
(n=172, confidence interval = 95%).

confirms the results of our preliminary study, which showed that users would prefer autonomous modes of transport over public transport, but not over today's private car [403].

Compared to public transport, all three autonomous modes offer a significant relative advantage (of +0.68 for the autonomous car, +0.26 for autonomous carsharing, and +0.38 for autonomous taxis). As Figure 9 shows not only does the autonomous private car perform better in almost every aspect but the autonomous mobility services taxi and carsharing also do except for costs, ease of use (only for carsharing), and time of use (for autonomous cars). In all other areas, respondents consistently attest the benefits of autonomous modes. In this context, due to its access at any time, the private autonomous passenger car again outperforms autonomous mobility services as expected in the criteria of waiting time, reliability, availability, and flexibility.

8.4.3 Intention to Use Future Travel Modes

The answer to the question as to which mode of transport the respondents could envisage owning or using regularly in the future shows that private cars will continue to occupy a central position. Almost 90% of the respondents (very) likely would continue using private cars, followed by public transport with about 65%. It is only after these two conventional modes that the autonomous car (37.5%) follows before the classic taxi (27.4%), the autonomous taxi (22%), the autonomous carsharing (16.7%) and the classic carsharing (14.3%). Carsharing is also rejected most strongly – respondents cannot imagine using either the conventional (65.5%) or the autonomous (63.1%) variant in the future.

Although the automation of the car can objectively be expected to bring many added value compared to the conventional car – even more so than to public transport [175,253,400,579] – the participants prefer the traditional travel modes, i. e. passenger car and public transport.

Against the background of the partworth utilities of the conventional car in comparison to the autonomous modes (cf 8.4.1), it is only reasonable that the private car is assigned the highest intention to use. However, the fact that the intention to use public transport in the future is higher than the intention to use autonomous modes of transport cannot be deduced from the partworth analysis in Section 8.4.2. After analyzing the partworth values, it would have been expected that the many relative advantages of the autonomous modes would have led to them being given preference over public transport. A high relative advantage – as in the case of those autonomous modes compared to public transportation – of an innovation or alternative product increases the probability of a takeover [446]. However, Figure 10 shows that this is not the case. One explanation is that, for public transport users, costs are a central aspect. Furthermore, this contradiction points to the fact that not all relevant factors have been included in the survey, such as the factor

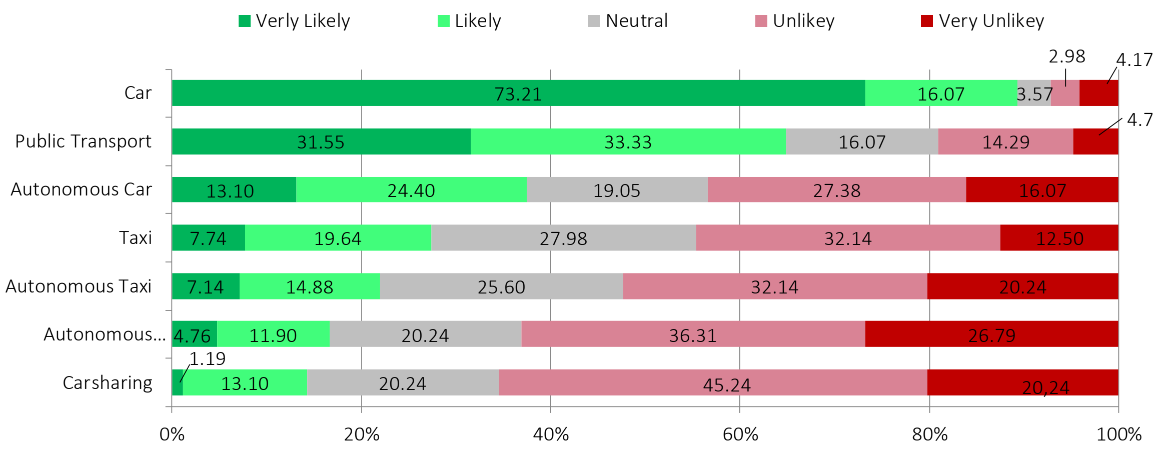

Figure 10: Intention to use/own a travel mode regularly in the future

of environmental friendliness or other non-product-related properties such as user-related (custom and mobility socialization [210]) and external influencing factors [446]. The importance of experience and routines in this context particularly points out that the perceived advantage will only slowly assert itself in practice – but in principle there will be latent, serious competition to public transport with the autonomous mobility services.

In the taxi sector, too, respondents placed their trust in the already familiar conventional version; in these fully automatic travel modes, skepticism about innovations and safety prevails over the supposed added value of automation by making use of familiar features. Only when it comes to carsharing could respondents imagine using the autonomous variant rather than the conventional variant. This finding is in line with a previous study [579]. In this mode of transport, the advantages associated with automation (particularly to be picked up and driven instead of having to search for the vehicle) outweigh the disadvantages (uncertainty, complexity of new technology, appropriation). The change in carsharing through automation was thus perceived by the interviewees as greater and more positive than in the case of cars. The evaluation also shows that the traffic modes taxi and carsharing are converging due to the self-driving technology, as predicted by Fagnant et al. [179] and Krueger et al. [296] for example.

8.4.4 Interrelation Between Part Worth Benefit and Intention to Use

The proponents of autonomous driving rated the autonomous car in all characteristics as being more advantageous compared to the traditional car than the skeptics did. We call those users proponents who could imagine using an autonomous car regularly in the future (Figure 11: regular use is (very) likely) and those skeptics who cannot imagine using an autonomous car regularly in the future (regular use is (very) unlikely). It is not clear in which direction the interdependence

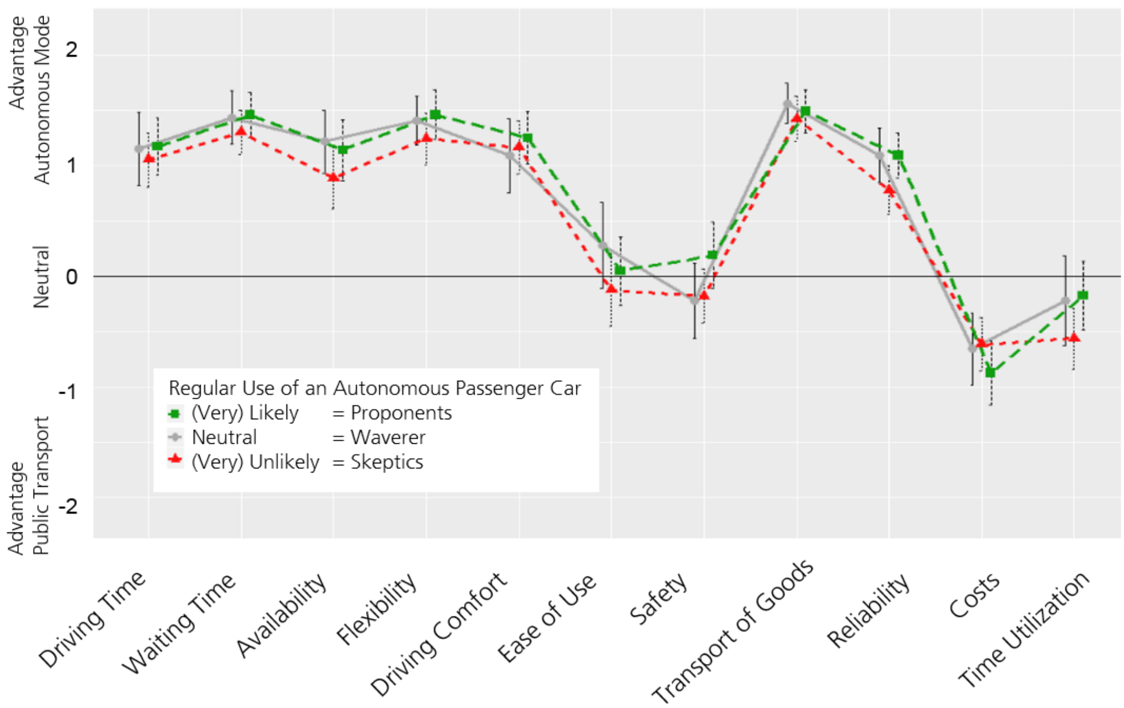

Figure 11: Partworth assessment of proponents and skeptics in comparing conventional and autonomous car (n=172, confidence interval = 95%).

works. The proponents could have a generally positive attitude towards autonomous vehicles and assess the partworth benefits accordingly positively. Alternatively (according to the order in which they appear in the survey) they could see relative advantages in the individual characteristics, which consequently lead to their intention to use the future travel modes. In particular, the partworth utilities of waiting time, availability and flexibility are rated higher. There was also a significant difference in driving comfort. This evaluation clearly shows that the proponents are much more open to the new modes and anticipate the advantages of the self-driving technology. There are not only significant differences in the characteristics of driving time, ease of use, safety, and the transport of goods; while here skeptics see the relative advantage of conventional cars, proponents consider the autonomous car to be generally advantageous.

8.4.5 Convergence of Taxi and Carsharing

Although the evaluation of the individual characteristics of the autonomous taxi and the autonomous carsharing indicates a convergence of the two modes, individual partworth utilitiy differences show that users still see differences between the two modes. Overall, there was a slight preference for the autonomous taxi. There are two reasons for this. First, users tend to prefer a well-known alternative. The carsharing business model is generally less well known than the taxi business model. Second, users prefer non-binding offers. In this respect, the two concepts differ in that one makes a regular and longer-term commitment (membership) for the use of carsharing while with a taxi one pays only for the actual use. This insight should be taken into account by practitioners when designing autonomous mobility services.

8.5 Limitations

A limit to this study is that the sample is not representative nor can any claim be made to completeness with regard to the selected product characteristics. Other factors such as habits, symbolism, etc. could also influence travel mode choice for autonomous vehicles and services. In addition, the subjective relevance (weighting) of the individual criteria was not included in the evaluation of relative partial and total benefits. However, the study helps to improve the understanding of user acceptance of autonomous driving by taking into account alternative travel modes.

8.6 Conclusion

User studies show that the à priori acceptance of autonomous driving is relatively high [410,445,473]. However, they usually view autonomous driving in isolation so that conclusions about future changes in mobility behavior are difficult to draw. Initial studies have therefore analyzed user preferences for the new traffic modes in comparison with existing traffic modes and have shown that users continue to prefer private cars, regardless of whether they are traditional or fully automated. However, in a direct comparison, carsharing benefits much more from full automation than do individual passenger cars [579]. The present survey showed that users see advantages in the automation of cars, taxis and carsharing in terms of driving comfort and time utilization, but in many other areas they fear no added value or even significant disadvantages compared to the conventional car. The opposite is true for public transport: All three autonomous travel modes offer significant relative added value compared with public transport. From the user's point of view, public transport only retains a competitive advantage in terms of costs and ease of use. The intention to use a travel mode in the future is still the highest for traditional passenger cars, ahead of public transport, autonomous private cars, conventional taxis, autonomous taxis, autonomous carsharing and conventional carsharing. A closer look at the user ratings shows that the proponents of autonomous vehicles anticipate a higher partworth utility in all properties than the sceptics do.

Overall, the results suggest that autonomous driving will gain acceptance in the short to medium term, especially for private transport, while usage-based (sharing) models can only become established in the long term. It is only through experience and new routines that the relative advantage of autonomous mobility services will prevail, which could then become a serious competition for public transport.

9 STUDY 5: USER ACCEPTANCE OF FULLY AUTONOMOUS PUBLIC TRANSPORT

The development of fully automated vehicles is becoming more and more present in the social discussion. The image of fully automated cars is determined by automobile manufacturers and placed in the context of individual traffic. In contrast to fully autonomous private cars, fully automated public transport is already operating in some cities and is to be expanded in the future. Autonomous public transport offers great potential for the development and promotion of sustainable mobility concepts. However, the user acceptance is important for the enforcement and widespread use of these technical innovations. An online study on the acceptance of fully automated public transport based on quantitative data of a sample of N = 201 is presented. The results show a high level of familiarity with the topic and a very high level of overall intention to use fully automated public transport in the future.

9.1 Introduction

Autonomous driving is currently on everyone's lips – when it comes to the automotive sector. Until now, this development has mainly been linked to individual traffic. Driverless public transport plays a minor role in current research and development. In contrast to the fully autonomous car, fully autonomous buses and trains are already on public roads. In the Swiss town of Sitten autonomous buses have been in operation since 2016; people can also use autonomous buses in Lyon (France) and Michigan (USA). The buses have already traveled more than 50,000 kilometers and have transported 100,000 people. Driverless rail-bound trains and trams have been in operation for a considerably longer time, e.g. railway shuttles on airport grounds such as the Skyline at Frankfurt Airport (Germany, since 1994) or the subway in Paris (France, since 2012), Vancouver (Canada, since 1986) and Singapore (since 2003).

Public transport is an important part of urban mobility, as it relieves congestion in cities. But still, the private car is the most popular and most used means of transport, and its automation will probably increase its popularity, to the detriment of many forms of public transport. Automating the private car will cause many disadvantages that exist in the non-automated car to disappear: Users will not have to control the car themselves, or find a parking space and can spend their travel time with other activities such as sleeping, reading, etc. – aspects that, so far, are competitive advantages of public transport. These exclusive features of public transport will thus be eliminated by the automation of the car and therefore have initially contra-productive effects for public transport. Resultingly, existing public transport business models are increasingly under pressure and have to be questioned and rethought. And, in particular, while it is true that high-performance public transport systems (high-speed railways) will remain advantageous over autonomous vehicles in terms of performance, travel time and reliability, this does not apply to bus and rail transport outside the main axes or in medium-sized cities [557].

On the other hand, the automation of public transport also opens up new opportunities and could increase competitiveness. The advantages of fully-autonomous public transport include a lower error and accident rate, greater availability through reduced dwell times and shorter headways, and increased punctuality. Moreover, passenger transport costs could probably drop and passengers would not have to suffer from staff strikes. These advantages would make traveling on train and other forms of public transport more attractive and lead to an increase in passengers.

The fact that autonomous driving in public transport has not yet been able to spread further despite the advantages is primarily a result of the high investments in a fitout or conversion. Existing systems, rails and stations would have to be reconstructed. This is why new projects and closed systems are particularly suitable for automation. First successful conversions of existing systems show that automation can be achieved more cost-effectively and more smoothly than previously expected [545].

In addition to the development of existing business models, new disruptive models are also being discussed. Fully autonomous vehicles, such as autonomous taxis or autonomous car sharing, can be used as public transport. These shared autonomous vehicles could strengthen public transport by overcoming the “last mile” and are also an alternative to owning a private car. Both the available and disruptive business models offer the opportunity to make traffic more sustainable and to reduce the number of private cars, which is currently rising and leading to increased congestion, especially in large cities. Mobility could be realized with fewer and more efficiently operating vehicles, whereby car traffic would decrease and public transport would increase [557].

The question therefore arises as to whether a combination of automated driving and public transport is a flexible and efficient transport solution that can also make public transport attractive to former non-customers. An important factor for the successful implementation of such a concept is the acceptance of new technologies. Therefore, the present study examines whether the use of autonomous vehicles in public transport is accepted by existing and potential customers. A survey was conducted on the attitude towards autonomous public transport. The survey results are presented and discussed below.

9.2 Fully Autonomous Driving

In general, fully autonomous driving (FAD) is understood as the autonomous, targeted driving of a vehicle in real traffic without the driver's intervention [458]. Public transport includes both local public transport services with buses and smaller vehicles that are not rail-bound and local rail-bound services. For both areas, international standards of full automation have been defined. According to the J3016 standard [458], six levels of automation can be distinguished for road traffic: no automation (0), driver assistance (1), partial automation (2), conditional automation (3), high automation (4) and the last stage of full automation (5).

Similarly, the International Association of Public Transport (UITP) defines five grades of automation [545]. Level 0 describes conventional on-sight train operation, as is known from ordinary roadways. Grade 1 is a combination of manual travel and train control. The driver controls the journey, starts and stops the vehicle and operates the doors. The train operation is not automated, but some parameters of the trip can be controlled via a train control. Grade 2 is semi-automatic train operation (STO). The driver triggers the start and controls the doors. Otherwise, the journey will be carried out fully automatically from the start to the stop. If necessary, the driver can immediately take over the driving control. There are already many Grade 2 automatic train operation systems. Grade 3 is the driverless train operation (DTO). There is no longer a driver, but only a train attendant instead of a constant control by a driver. The train attendant controls the doors and, in the event of an emergency, takes over control. Grade 4 is unattended train operation (UTO, or manless train operation MTO) with no staff on the train and all operations being automated. The control center can intervene in the train operation. In the following, we refer to the fully automated systems, i.e. to level 5 of the J3016 standard in non-railbound traffic and to grade 4 of the UITP.

User acceptance is decisive for the success of technological innovations. According to Davis' Technology Acceptance Model (TAM), the actual acceptance of technology is crucial to whether a person intends to use this technology [136]. The person's intention is, in turn, determined by perceived usefulness and perceived ease of use of that technology. Currently, fully-automated vehicles are a technological innovation that is not yet market-ready and therefore has not yet or seldom been tested by users. Exceptions are the already operating examples of fully automated trams and autonomous buses, which are in test phases. For those buses, user acceptance can only be determined a priori. An à priori acceptance analysis determines the user evaluation of a technology before the users could test the technology [410]. Naturally, in assessing the new technology, the individual imaginative power of the persons interviewed plays an important role. However, it seems reasonable to expect that the intention to use a technology such as the fully autonomous public transport could be predicted to some extent by its a priori acceptability.

9.2.1 Private Autonomous Vehicles

In the last years, the research on fully autonomous vehicles for private individual transportation has witnessed a boost in work covering topics such as advanced driver assistance systems, connected cars or autonomous, self-driving, or driverless vehicles. Several studies have focused on particular technological issues. In addition to technical feasibility, ethical and legal aspects [438] as well as user acceptance play an important role. User acceptance can only be assessed by means of a priori evaluation, since the potential users can not yet gain experience with the fully automatic vehicles.

Some studies analyzed the users' a priori acceptance of autonomous cars. With regard to autonomous cars in general, a recent study by Payre et al. reveals that a large majority of the population have a positive attitude and can imagine buying and/or using autonomous cars [410]. The literature further shows that acceptance depends on several other parameters. Studies such as the one by Ernest and Young show that some respondents are afraid that the enjoyment of driving will decrease as a result of full automation and they welcome the option of taking over control whenever they want [175]. Other factors are age and gender, individual personality, pre-experience with partly autonomous cars, characteristics of the innovation, the driving environment, and the manufacturer's reputation [211,386]. At the same time, other studies report that people are concerned about self-driving vehicles [253]. These concerns seem to be cultural, country and gender dependent: females seem to be more concerned than males [473].

Most studies focus on autonomous cars in general but neglect ownership as a relevant category. In particular, the surveys do not differentiate between ownership and usership models but focus on private cars only – whether explicitly or implicitly. Only a few investigations look at self-driving mobility services, e.g., self-driving taxis, in detail [95,238]. However, such usership-oriented business models are becoming increasingly important, especially for the new generation Y that tends to use things instead of owning them. A development away from ownership towards usership in the field of mobility could lead to completely new, disruptive business models [400].

9.2.2 Shared Autonomous Vehicles

Some studies have examined shared autonomous vehicles (SAV) as a form of public private transport in more detail. These include in particular simulations of SAV fleets, which could be used in medium to large cities [93,492]. Burns et al. [95] find that the average SAV cost per mile is 31 percent less than the average cost of a privately owned vehicle. They calculate that all trips could be executed with a fleet of only 15% of the number of privately owned vehicles. Similar results are presented by Fagnant and Kockelman [177] and Fagnant et al. [179] who respectively replace only 3.5% and 1.3% of private cars through SAV. They conclude that each SAV can replace around eleven, respectively nine conventional vehicles with a reasonable wait time (one minute or less). Owczarzak and Żak [396] develop eight different concepts of passengers' public transportation solutions based on autonomous driving and compare them with traditional forms of passenger transportation. Their results show that either the variant *Autonomous Vehicle Only* or the variant *Combination of Buses and Autonomous Vehicle* serve best as urban transportation solutions.

These simulations show that new mobility concepts in public transport can be sustainable solutions and efficient extensions to existing concepts. Acceptance studies for SAV are rare. Krueger et al. [296] recently published a study on the preferences of potential users. They identified multimodal travel patterns to be typical characteristics of potential shared autonomous vehicle users. In addition, current carsharing users are more likely to use shared autonomous vehicles with dynamic ride sharing. Results of their stated choice analysis showed that service attributes, including the given travel time, waiting time and travel cost, are significant determinants of shared autonomous vehicle use and dynamic ride sharing acceptance. As expected, respondents were willing to pay more for a shared autonomous vehicle without dynamic ride sharing than for a shared autonomous vehicle use with dynamic ride sharing.

9.2.3 Public Transportation

The implementation of unattended train operation (UTO) systems allows operators to increase the average speed of vehicles, to optimize the running time of trains, to shorten headways, and to reduce dwell time in stations [545]. Although automation in public transport has progressed, the automobile industry is placing far more effort into developing autonomous cars. One reason for this is that politics is preferably promoting the automotive sector. In addition, effort and expense are involved in reconstructing existing public transport routes – not only for technical but also for financial reasons [545].

In contrast to private transport, some fully autonomous vehicles have been used in public for many years, especially in rail-bound public transport. However, few available studies have examined the acceptance of autonomous public transport. Since fully-automatic vehicles are already in use in public transport, some studies have, at least, deduced the user's acceptance, looking at user numbers for these systems. For example, the Copenhagen Metro is operating fully autonomously and records an increasing number of passengers. According to the Danish Transport Research Institute, a lot of users from other transportation modes have moved to the Metro since it was first established in 2002. The Metro received up to 47% of the bus passengers and up to 20% of the local train passengers during its first two years of operation. Up to 13% of the car drivers and 9% of the bicycle riders also chose to switch to the Metro in some areas during the same first two years, 2003 and 2004. The operator, The Metro Company, regularly surveys users' satisfaction. The latest satisfaction inspections showed that 98% of the users were either “happy” or “very happy” with the Metro. The satisfaction with the Metro can also be seen in the increasing number of passengers with 3.3 million passengers in 2002 to 40 million trips in 2007 [19].

As another example, the fully automated Line 1 in Paris (France) carries 725,000 passengers daily. Line 14 of the Paris Metro, the first wide-gauge automatic metro in the world, serves 500,000 passengers daily. The number of passengers grew from 3.5 million in 1998 to 80 million in 2009 [545].

These figures show that the acceptance of rail-bound, fully automated trains is very high. Since autonomous buses have only been in test phases, there are considerably fewer user experiences in this area that can provide information on the acceptance. In Sitten (Switzerland) the SmartShuttles “Tourbillon” and “Valère” are on the road. They have traveled more than 1,000 kilometers through more than 800 laps through the old town of Sitten so far, transporting around 7000 passengers. Passengers are regularly interviewed. Some are somewhat skeptical before the trip, but after the ride most of them are very positive. The rating does not depend on the age: many travelers over 55 years are enthusiastic. The under-20s use the fully automated shuttle quite naturally as if it were a conventional bus [422]. But since studies on the acceptance of autonomous vehicles have not clearly shown significant dependencies between age and intention to use such vehicles [296,445], we would like to examine the relationship of age and acceptance of autonomous public transport.

On the basis of the above findings, we formulate the following hypotheses, which we want to analyze:

H1: Acceptance of fully-automated public transport depends on age.

H2: Previous experience with autonomous vehicles increases acceptance of fully autonomous public transport.

H3: The acceptance of fully-automated rail-bound vehicles is greater than the acceptance of fully automated non-rail-bound vehicles.

9.3 Methodology

To investigate the acceptance of fully autonomous public transport, we conducted an online survey, which consisted of three parts. In the first part, the participants were briefly informed about the topic of autonomous public transport in an introductory text. They were made aware of operating examples such as driverless airport shuttles and driverless trams (Nuremberg, Germany), in order to remind them that there are already autonomous public transport services and to remind them of possible experiences. The second part began with questions related to the use of current means of transport, experiences and attitudes of the participants towards autonomous public transport and an assessment of first, the intention to use automated public transport in general and second, the willingness to use different autonomous means of transport. Answers could be given on a five-point Likert scale. We used open questions to get insights about the participants' previous experiences with and the attitudes to autonomous means of transport. Demographic data were collected at the end of the questionnaire. The questionnaire was tested in pretests for comprehensibility and revised. Subsequently, the survey was advertised in Germany in various social networks and online platforms and released from 21.11.-19.12.2016. The survey was completed by 201 participants, 49.3% of whom were female. The average age of the participants is low at only 26.2 years, and ranges from 18 to 81 years. The sample shows a disproportionate percentage of students, whose choice of transport is strongly determined by external conditions (financial budget, well-developed urban transport in cities, and presence of a student ticket at reasonable costs). This can be seen in the figures for the most frequently used mean of transport: 17.4% mainly use private cars, 49.3% use subways and trams, 21.9% mainly trains, and a further 8.5% use buses. The sample therefore uses the public transport system disproportionately highly in comparison to the general public.

9.4 Results

9.4.1 Experience with Autonomous Driving

With 91%, the majority of the participants in the survey had already heard of autonomous driving. 37.1% of respondents had already tested at least one autonomous vehicle. 22.9% of the participants had experienced an autonomous train, 20.9% an autonomous tram or metro, and one respondent (0.5%) stated having been driven in an autonomous vehicle, both a bus and a car (multiple mentioning was possible here). The participants stated in a free text field that they were transported by autonomous airport shuttles at the airports in Frankfurt and Dusseldorf, the autonomous subway in Paris and the autonomous mobile Dockland Light Railway in London. Respondents who have already had experience with an autonomous vehicle (n = 76) felt safe (8.5 out of 10 points). The few participants, who did not feel safe said that they do not fully trust the electronics and programming of the vehicle and feel insecure as they cannot estimate what would happen in the event of operational disturbances or accidents. Also, a user had bad experiences when he saw people or luggage being pinched in the automatic closing doors. The most common reason for a secure feeling during the autonomous voyage was that the systems used are controlled, closed and rail-bound traffic systems where there is neither oncoming traffic nor other road users (13 entries).

"Because the train cannot deviate from the rail and the system is well secured."

"They were simple routes without any other traffic and the routes were very short. I see no reason to feel unsafe."

Some other participants consider the technique to be more reliable than a human driver (13 entries).

"The autonomous train feels just as secure as a traditional train. The system has passed many tests and has worked so far without any problems."
"Because a well-programmed computer is more reliable than any human being."

Other reasons were that participants had hardly noticed that they used an autonomous vehicle, that the journey was smooth and that they trusted the advanced technology.

9.4.2 Intention to Use Fully Autonomous Transport

Approximately three-quarters of the respondents (77.6%) can generally imagine using autonomous public transport regularly in the future. The characteristics gender, age and current main means of transport have no significant influence on the basic setting for or against the future use of the autonomous public transport (Pearson's chi-square test $p > 0.05$). The results also do not indicate a relationship between age and the assessment of the various automated means of transport (Table 9). Hypothesis 1 therefore cannot be confirmed.

The collected data show that the previous experience with autonomous transport has an influence on the willingness to use autonomous transport in the future. 88% of the interviewees, who had already experienced autonomous transport, can imagine using it in the future, while the figure for participants without previous experience is only 72%. There is a significant difference in the scores for experienced ($M = 0.880$, $SD = 0.327$) and non-experienced ($M = 0.720$, $SD = 0.451$) participants (Contingency Coefficient: 0.184; $p = 0.008$). There is therefore evidence that hypothesis 2 is true. The previous experience with autonomous driving also influences the evaluation of different transport modes. Participants who have already gained experience with autonomous driving have a higher willingness to use different and new transport modes than those who have no experiences with autonomous transport. An exception is in their evaluation of the autonomous car (Table 9).

The interviewees see advantages, especially in the innovative and advanced technology, the expected improved flexibility, and in the higher availability of the systems, and they expect a reduction in traffic accidents. On the other hand, the interviewees see uncertainties because of their lack of experience and the high degree of reliance on technology. When the participants were asked which of the autonomous modes of transport they would most likely use on a scale from 1 (low) to 5 (high), they preferred the subway (3.89), the train (3.83), and the tram (3.77) (overall mean rail-bound vehicles: 3.83) over the autonomous bus (2.98), the autonomous private car (2.98), and the autonomous taxi or carsharing (2.64) (overall mean non rail-bound vehicles: 2.87). The use of a one-sample t-test shows that the mean value for rail-bound vehicles differs significantly from the mean value for non rail-bound vehicles (p = 0.000). The results of this sample support hypothesis 3 that autonomous rail-bound means of transport are preferred to autonomous non-rail-bound means of transport.

Table 9: Group statistics and t-test for equality of means

	Age	N	Mean	SD	Mean Diff.
Evaluation FA_Car	>= 30.0	29	3.00	1.581	.024
	< 30.0	170	2.98	1.479	
Evaluation FA_Bus	>= 30.0	29	2.83	1.490	-.178
	< 30.0	169	3.01	1.302	
Evaluation FA_Train	>= 30.0	30	3.60	1.221	-.271
	< 30.0	171	3.87	1.109	
Evaluation FA_Metro	>= 30.0	29	3.69	1.285	-.228
	< 30.0	171	3.92	1.140	
Evaluation FA_Tram	>= 30.0	29	3.69	1.228	-.088
	< 30.0	171	3.78	1.152	
Evaluation FA_Taxi/ Carsharing	>= 30.0	28	2.57	1.476	-0.08
	< 30.0	171	2.65	1.339	

	Sex 0=m; 1=f	N	Mean	SD	Mean Diff.
Evaluation FA_Car	.0	101	3.38	1.475	.805 ***
	1.0	98	2.57	1.400	
Evaluation FA_Bus	.0	101	3.52	1.331	1.112 ***
	1.0	97	2.41	1.068	
Evaluation FA_Train	.0	102	4.20	1.099	.742 ***
	1.0	99	3.45	1.033	
Evaluation FA_Metro	.0	102	4.26	1.033	.775 ***
	1.0	98	3.49	1.160	
Evaluation FA_Tram	.0	102	4.15	1.066	.780 ***
	1.0	98	3.37	1.125	
Evaluation FA_Taxi/ Carsharing	.0	101	3.08	1.426	.885 ***
	1.0	98	2.19	1.118	

	Main Mean of Transport 0=PT; 1=Car	N	Mean	SD	Mean Diff.
Evaluation FA_Car	.0	159	3.05	1.500	.491 †
	1.0	34	2.56	1.375	
Evaluation FA_Bus	.0	157	3.00	1.340	.257
	1.0	35	2.74	1.221	
Evaluation FA_Train	.0	160	3.80	1.132	-.143
	1.0	35	3.94	1.056	
Evaluation FA_Metro	.0	159	3.86	1.163	-.116
	1.0	35	3.97	1.098	
Evaluation FA_Tram	.0	159	3.77	1.148	.024
	1.0	35	3.74	1.197	
Evaluation FA_Taxi/ Carsharing	.0	159	2.74	1.374	.514 *
	1.0	35	2.23	1.190	

	Experience fAD	N	Mean	SD	Mean Diff.
Evaluation FA_Car	.0	123	2.90	1.484	-.203
	1.0	76	3.11	1.502	
Evaluation FA_Bus	.0	122	2.70	1.290	-.716 ***
	1.0	76	3.42	1.278	
Evaluation FA_Train	.0	125	3.66	1.121	-.441 **
	1.0	76	4.11	1.090	
Evaluation FA_Metro	.0	124	3.67	1.167	-.567 ***
	1.0	76	4.24	1.069	
Evaluation FA_Tram	.0	124	3.56	1.150	-.549 ***
	1.0	76	4.11	1.102	
Evaluation FA_Taxi/ Carsharing	.0	123	2.50	1.283	-.364 †
	1.0	76	2.87	1.445	

FA = Fully Autonomous; PT = Public Transport; FAD = Fully Autonomous Driving; SD = Standard Deviation

a) Significance: †: p ? .1; *:p ? .05; **: p ? .01; ***p ? .001

Gender, on the other hand, plays an important role. The male respondents rate the autonomous traffic modes systematically higher (M = 3.77, SD = 1.03) than the female participants (M = 2.92, SD = 0.85, p = 0.000). Regardless of the nature of the means of transport, the willingness of men to use autonomous transport is significantly higher than that of women. The previous experience with autonomous driving influences the evaluation of different transport modes, too. Participants who have already gained experience with autonomous driving have a higher willingness to use different and new transport modes than those who have no experiences with autonomous transport. An exception is in their evaluation of the autonomous car.

Taking account of the particular composition of the sample, which, in contrast to the total population, generally uses public transport as the main means of transport, a more differentiated discussion of the result of the preferential autonomous modes of transport is required. The review of this results shows that the preferences of users that currently use the private car as the main means of transport are partly different from the preferences of the participants traveling by public transport. Respondents currently using the private car are less likely to use an autonomous car (M = 2.56, SD = 1.38) than public transport users (M=3.05, SD=1.50; p = 0.08). The car drivers also gave lower rates for autonomous taxis or carsharing (M = 2.23, SD = 1.19) than the public transport users (M = 2.74, SD = 1.37; p = 0.04). With regard to the other autonomous modes of transport, car drivers do not differ significantly from public transport users. The results of this sample support hypothesis 3 that autonomous rail-bound means of transport are preferred to autonomous non-rail-bound means of transport.

9.5 Discussion

The present study confirms that autonomous driving has reached a high degree of familiarity among the population. While some studies found acceptance rates for fully autonomous cars around 68% [410,473], the willingness to use autonomous public transport in the future is slightly higher in our study with 77.6%. In particular, prior experience with autonomous transport systems positively affects user acceptance. Only a few users have had bad experiences with autonomous public transport. Our results are consistent with previous studies that have shown that prior experience with technology increases the acceptance of that technology [97,527]. This result was evident not only in the general willingness to use autonomous public transport regularly, but also in the comparison of the various fully automated means of transport.

While there is no difference in the overall intention to use automated public transport between males and females, the results show distinct differences in the willingness to use different automated transportation means. Males are more willing to use every single one of the automated transportation means than females. These results confirm findings of prior acceptance research that has shown females have higher levels of concerns with self-driving vehicles than have males [473]. Thus, females are less open-minded to the use of automated transportation means than men, regardless of the type of transport.

The fact that the participants seem to prefer rail-bound means of transport and even buses against autonomous cars and autonomous carsharing is not surprising. Since the choice of transportation modes is usually marked by routines [2], it can be assumed that existing preferences in the choice of transportation modes also affect the choice of future means of transport. The cause of this result could lie in the car motives locus of control and sensation seeking. Studies on the adoption of Advanced Driver Assistance Systems show that locus of control and sensation seeking are character traits that influence driving behavior when using Advanced Driver Assistance Systems [456,494]. Locus of control is defined as the extent to which a person can control the occurrence of an event [454]. Sensation seeking is defined as a character trait that is looking for new experiences and stress stimuli [595]. Both properties are extremely important in the evaluation of fully automated vehicles, since users give up control over the vehicle and cannot evoke driving excitement by themselves. Driving with an autonomous vehicle can, however, be also an exciting experience for some people. Todays' users have no control over non-autonomous public transport and thus presumably no locus of control even at current levels. Sensation seeking is not a motive why users choose public transport. For the user, there is no big change when public transport will be automated. Users are passengers before and after the automation of the public transport, in both cases the user have no contact to the driver. This is different in the case of cars, which users previously controlled themselves, an activity now done by the car itself. Through the automation of cars, the user's role changes from a driver to a passenger. In this respect, drivers appreciate the possibility to have the locus of control and sensation seeking. Both aspects are lost in fully autonomous vehicles. From the point of view of users, the automation of cars leads to a substantially greater change than the automation of public transport. This could be a reason for the poor rating of autonomous cars and autonomous carsharing. For an accurate assessment, it would be important to investigate the motifs locus of control and sensation seeking within the context of a further study. As the participants were asked which means of transport they were most likely to use, and not to which they would convert completely, the evaluation of the participants might also be understood to mean that drivers would retain their previous car and would only use the autonomous public transport as a supplement.

In contrast, public transport users rate the autonomous public transport not significantly higher. This result could indicate that public transport users are also latent car drivers and appreciate locus of control and sensation seeking on passenger cars and cannot imagine doing so without a car.

Considering all results, it is important to note that the study is not representative in terms of age and the current use of transport; therefore, the results are not directly transferable to the whole population. In addition, it should be noted that the survey was carried out in Germany and that the German public transport system certainly differs from the public transport of other countries in various aspects. Such differences may also affect the participants' assessment of future concepts. Nevertheless, the study provides interesting and important insights into the groups of young and well-educated individuals, who will be an important target group in some years, following the progressive automation of public transport. In addition, the group of young people who are still in training is a group whose traffic behavior has not yet been consolidated and can therefore be influenced. The study thus makes an important contribution to the exploration of the user acceptance of autonomous public transport systems.

9.6 Conclusion and Implications

Modern societies are mobile societies characterized by highly individualized lifestyles. This mobility is facilitated by transport systems, with cars being the main means of transport. In this context, autonomous driving is currently one of the major research and development activities. A major challenge to the development of these transport systems is their implementation as they involve a great investment for public transport operators. For new transportation lines, automation costs have a relatively low comparative weight within the overall budget [545]. It is true that investments in the expansion of the public transport system are very high. Existing examples such as Paris' Line 1 demonstrate that it is possible to convert high capacity lines without service interruption. To minimize impact, conversion projects should be at the end of the lifecycle of the existing equipment. In addition to technical feasibility, ethical and legal aspects [438] as well as user acceptance play important roles. Recently, the a priori user acceptance of autonomous cars and autonomous taxis has been investigated in various studies [175,296,410]. There are hardly any studies on the acceptance of autonomous public transport. This paper should close this gap.

Autonomous public transport offers great potential for the development and promotion of sustainable mobility concepts. Our study has shown that autonomous driving is well known among users and that some users have already experienced autonomous traffic systems in the past. It also shows that the willingness to use the autonomous public transport in the future is high among the participants. Approximately three-quarters of the respondents (77.6%) can imagine driving regularly in the future with autonomously moving public transport. Previous experience with autonomous transport has a positive influence on the acceptance of autonomous public transport. Policies and research should allow users access to autonomous public transport even in test phases so that users can have positive experiences. Particularly at a young age and in phases of the so-called windows of opportunity, which can lead to a change in the mobility behavior, users can thus develop routines and develop long-term sustainable mobility behavior.

10 STUDY 6: "THERE MUST BE A TAXI DRIVER" – EXPECTATIONS AND ATTITUDES OF PROFESSIONAL TAXI DRIVERS TOWARDS AUTONOMOUS VEHICLES

Advocates of autonomous driving predict that the occupation as taxi driver could be made obsolete by shared autonomous vehicles (SAV) in the long term. Conducting interviews with German taxi drivers, we investigate how they perceive the threats caused by advancing automation for the future of their business. Our study contributes insights into how the role of taxi drivers could change in the advent of autonomous driving: While many standard trips could be taken over by SAVs, taxi drivers are certain that there is a core area of their business which will still require supplementary services and human assistance, shifting the taxi drivers' profession into that of an attendant. Our findings also open design implications for tools that take various forms of assistance into account, and demonstrate how important it is to consider taxi drivers in the codesign of future taxis and SAV services to meet the requirement of *all* customers.

10.1 Introduction

Digitization and automation have caused many industries to change radically, some products to go extinct, and thousands of jobs to disappear [21,27,183,191]. If workplaces are digitized and tasks are increasingly automated, occupations can change dramatically or become obsolete [5]. Emerging trends in the transportation sector, such as advances in autonomous driving expose professional drivers such as taxi drivers, train and bus drivers, truckers, parcel deliverymen, and many more to this risk. In the worst case, the taxi drivers' jobs could disappear completely: experts see great potential in shared autonomous vehicles (SAV) to replace traditional taxis [133,317] as these are expected to provide the same service at reasonable cost [95,176,179]. While members of the taxi industry are certain that "the profession of taxi driver will not disappear, but will redefine itself" [365], many researchers believe that "there will be no more employment for taxi drivers" [10,116,328,571]. As a consequence, many rather low-skilled workers could be affected, as those are primarily present in this profession, due to missing entry-level education requirements for becoming a professional taxi driver in the US [92] or Germany [98].

Consequentially, disruptions from technological advances should be of great concern to the taxi industry. The taxi business has already been put under pressure by gig economy models such as the spread of transportation services such as Uber or Lyft that are facilitated by mobile technologies [34,523]. The emergence of these new transportation network companies (TNC) highlight how working conditions might be subject to substantial changes, forcing the drivers to adapt their working practices accordingly [108,589]. SAVs would have an even higher impact on the necessity for employing human drivers, potentially rendering their work obsolete and changing transportation services to an even larger extent. Looking at the uptake of these disruptive services allows research to better understand potentials of new ICT-based services, as well as their impact on existing practices and traditional organizational concepts. By understanding how the profession of taxi drivers adapted to past innovations, such as Uber, we can better anticipate how they will adapt to emerging innovations such as autonomous vehicles. The emergence of these new transportation network companies (TNC) highlight how working conditions might be subject to substantial changes, forcing the drivers to adapt their working practices accordingly [108,589]. SAVs would have an even higher impact on the necessity for employing human drivers, potentially rendering their work obsolete and changing transportation services to an even larger extent. Looking at the uptake of these disruptive services allows research to better understand potentials of new ICT-based services, as well as their impact on existing practices and traditional organizational concepts. By understanding how the profession of taxi drivers adapted to past innovations, such as Uber, we can better anticipate how they will adapt to emerging innovations such as autonomous vehicles.

In this study, we therefore want to analyze how technology has recently changed existing practices in the taxi business in order to draw conclusions for the future impact of SAVs on the industry. We do so, by looking at the case of Germany, where Uber struggles to succeed in entering the market on a sustainable basis. By comparing our case to studies carried out in other countries such as the US [326,327,432], UK/US [205], or India [589], we can better understand how contextual factors influence the uptake of innovations, the acceptance of new technologies and how they influence the profession of taxi drivers.

Our approach is in line with the recent turn to practice within Human Computer Interaction (HCI) [299], which suggests that successful system design has to take into account various contextual factors instead of merely focusing on the interaction between user and system. These contextual factors depend on the practices, which are carried out and where the "interaction is no longer at the center, but is one aspect among many, serving its specific part in the performance". Following this approach, we consider it necessary to involve affected stakeholders into research to find out how roles might change, in this case the taxi drivers. While there is this reasonable amount of studies, that have mainly investigated TNC drivers, we focus on traditional taxi drivers whose clientele substantially differs from i.e. Uber drivers, thus serving slightly different needs.

Thus, we contribute to the prior literature in three ways: First, by analyzing why otherwise successful disruptions failed in Germany, we provide a complementary study to these that have investigated the impact of these disruptions in other countries, second, by working out the specific practices of traditional taxi drivers and their unique context in line with the turn to practice we highlight current changes that illustrate possible influences of further automation and allow us to derive design implications for HCI researchers, and third, we further extend prior works by reflecting the potentials of SAVs on the backdrop of existing practices of taxi drivers.

Our study is based on 19 semi-structured interviews with German taxi drivers. The interviews centered on their working practices, experiences with current technologies such as e-hailing and ridesharing apps as well as their attitudes towards possible future developments such as SAVs. Our analysis provided a rich picture of how emerging technologies affect their work, and how they adapt to changes in their infrastructure, as well as how they take advantage of new technologies and adapt to potential threats.

The rest of this paper is organized as follows: After a discussion of the related work on taxi driving, in which we provide contextual information regarding the specifics of the taxi industry in Germany, the gig economy, digital mobility services and autonomous vehicles (AV), we will present our study as well as our methodology. In the findings, we cover the areas of current digital services as well as the expected impacts of AVs, which we then discuss with regard to their impact on taxi driving as a technologically supported practice. Finally, we summarize our findings and derive design implications for futures of transportation.

10.2 Background and Related Work

10.2.1 The (German) Taxi Industry

To understand the attitudes and perspectives of taxi drivers, it is important to consider the context of the German taxi industry, which is quite distinct from the situation in the USA, for example [171]. In 2018, there were around 21,700 German taxi companies, operating around 53,000 taxis, and generating sales of 5.3 billion euros [89]. As in other countries such as Norway or cities such as New York, too, the German taxi market is strictly regulated by federal laws and regional restrictions. Regulation includes quantity, service as well as price regulation, and regulation of the industry structure. To be allowed to establish a taxi company, entrepreneurs must apply for a "Taxikonzession" (in the following referred to as taxi concession), a license that is similar to American taxi medallions, as it is intended to regulate the quantity of taxi companies. However, applicants often wait 20 years or longer until they get a taxi concession (i.e. interviewee T06). Further, trading of taxi concessions is prohibited in Germany, therefore, the taxi companies in possession of such a concession are sold in order to trade taxi concessions [149]. The approval of a taxi concession is linked to the fulfilment of various admission criteria, which can be classified into subjective (guarantee of the safety and capability of the business, the reliability of the applicant as well as his or her professional background) and objective criteria (viability of the local taxi industry with regard to transport orders in taxi traffic, taxi density, development of the revenue and cost situation). Taxi drivers must hold a passenger transportation license without which she or he is not allowed to transport people commercially. To apply for a passenger transportation license, the applicant must be at least 21 years of age, hold a German driver's license for a minimum of 2 years, hold a valid identity card or passport, present a medical certificate of mental and physical fitness, an ophthalmologist's certificate, a police certificate, and pass a local knowledge exam. Traditionally, three main parties are involved in the taxi service: the customers, the taxi drivers and the taxi dispatchers. The taxi dispatchers take over the organization of the taxi ride in their role as an intermediary. Their main task is to plan the connected taxis according to the customer's requests and to broker trips. Other core functions of the taxi dispatchers are administration (e.g. accounting) and representative duties (representation of taxi drivers vis-à-vis institutions). Currently, 80% of taxi drivers are members of regional taxi dispatch services [150]. Most of the taxi companies are additionally organized in the German taxi association BZP (Bundes-Zentralverband Personenverkehr – Taxi und Mietwagen). This institution represents the interests of taxi companies[5] and has repeatedly lodged complaints against different TNCs by putting pressure on the European Court of Justice to reach a decision. However, membership is not mandatory.

The taxi driver is responsible for all executive activities: first and foremost, driving, meaning the execution of the trip, but also the route planning, which is why prospective German taxi drivers still have to prove their knowledge of their district by exams. Routing is the first activity that has changed as a result of digitization and has increasingly been carried out by technology in the form of GPS navigation. As most taxi drivers today make use of GPS-supported routing, many consider a mandatory local knowledge exam to be outdated [105]. The taxi drivers themselves usually consider their knowledge as superior to GPS routing [202].

As in many other countries, critics of the regulation have long been calling for the opening and deregulation of the German taxi industry [105,240]. Through innovations such as taxi apps (or e-hailing apps) and TNCs such as Uber, regulation critics expect an increasing transparency and new options for customers in terms of price and quality. The taxi branch itself, in contrast, is generally positive towards the existing regulations as they protect them from competition by alternative models. The entry of UberPop into the German market in October 2014, for example,

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[5] The task of the BZP is to represent the overall interests of passenger transport operators with passenger cars at national and international level vis-à-vis ministries and other authorities, organizations, and the public. The BZP and its regional associations as well as the local organizations of the taxi and rental car industry affiliated to it at federal level do a great deal of work for them by looking after and promoting the common interests of the association members. The BZP also represents the overall socio-political interests of the industry, and can therefore act as a central organization within the meaning of the collective bargaining law and as a party to collective agreements for the members who belong to it as companies [90].

provoked great resistance from taxi drivers and taxi associations. As in many other countries, action has been brought against the authorization of such transport services [182]. Plaintiffs relied on the strict regulation of the taxi industry to which every lawfully operating taxi driver is subject. On March 18, 2015, the service was declared anti-competitive by the Frankfurt Regional Court, as Uber drivers were driving without a taxi concession and a passenger transportation license, and as fares regularly exceeded the operating costs of the trips [86] (which implies that there is an intention to make a profit and that there is no pure cost sharing between peers). On December 20, 2017 the European Court of Justice (ECJ) ruled that Uber corresponds to a transport service and must be regulated accordingly and thus cannot operate legally with its current business model. Uber reacted to this decision and is now offering UberX in several German cities since May 2019, a business model with professional drivers that corresponds to the German model of *hired cars with drivers.* Like taxi drivers, these drivers require a passenger transportation license, whereas these companies do not need a taxi concession, making it easier to start a business. However, this service can only take requests at the company's registered office and must immediately return to its registered office after finishing a ride. Thus, hired cars with drivers neither are allowed to be hailed at the side of the road nor to wait for customers at attractive places like airports or train stations and customers may only book the service via the office. As the Uber App directly matches drivers and customers, the Regional Court of Cologne issued a temporary injunction on July 19, 2019, stating that it is no longer permitted to broker rides by app in Germany. So far, Uber has ignored this ban and continues to offer its service. For an even more detailed comparison of the regulation between taxi and Uber in different countries we refer to Visser et al. [439] and OECD [393].

Contrastingly, taxi apps – apps that broker rides with professional taxi drivers of existing taxi business holding a taxi concession – are becoming increasingly popular in Germany, 11.5% of all taxis were ordered via app in 2017 [496]. The clientele of both, TNCs and taxi apps is considerably different from this of traditional taxis: While the average Uber passenger is 32.7 years old with 0.3% being 70 years or older, the average taxi passenger is 47.6 years, with 11.4% being 70 years or older [586].

By addressing opportunity-based mobility, taxis are still an important part of modern public transportation [226]. Most taxi customers use cabs for getting from and to parties or events (59%), for getting from or to airports and train stations (11%), for medical reasons (10%), if private or public transportation is not available (7%), or for journeys with a transport of goods or objects (2%) [258]. Taxis thus provide mobility especially in situations where customers cannot or do not want to drive themselves, or where no alternative modes of transportation are available for a one-way journey [134]. A study among taxi customers showed that 77% of taxi trips happen in situations where no other adequate means of transportation are available [258].

In addition to ethnographic studies on taxi drivers [272,421] and health of taxi drivers [16,285,286], the regulation of the taxi industry has regularly been discussed and analyzed in economic literature [3,148,186,332,368,468,528] as the taxi industry is highly regulated by local governments in many countries. Regulation defines market access restrictions, fares, services and quality [186] and is advocated and maintained mainly for customer protection [186,368,468].

10.2.2 ICT-based Innovations in the Taxi Industry

The aforementioned business models of the TNCs Uber or Lyft are attributed to the so-called gig economy. The gig-economy is “the sub-form of the platform economy, in which personal contact between client and contractor takes place” [288]. As such, in contrast to cloudwork, the gig economy is dependent of location, and in contrast to crowdwork, gigwork is based on complete and singularly occurring services provided by individuals [288]. In this part of the labor market, small jobs – or “gigs” – are awarded at short notice to independent contractors over digital platforms acting as an intermediary between the client and the contractor, while algorithms take over the matching process [305,580]. The operator of the online platform keeps a commission and defines usage conditions. By flexibly matching peers, the digital platform business models are disrupting their respective industries [342] and can replace traditional forms of businesses.

In a broader sense, taxi driving has always been part of the gig economy, as an on-demand service is being offered, that is subject to fluctuations in demand. However, it slightly differs from the gig economy in four essential aspects: First, while gig workers can flexibly choose when and how much they work, taxi companies are subject to a duty to operate in order to ensure mobility at all times. Secondly, gig workers are basically free to either accept or refuse orders, while German taxi drivers are subject to the obligation to carry and are not allowed to refuse trips [205]. Thirdly, Uber offers dynamic pricing while the German taxi industry strictly applies tariff regulations. And finally, gig economy platforms do not regard their drivers as employees but as independent contractors, whereas in the German taxi industry 86% of taxi companies have employees to whom they pay a fixed monthly salary (not just on a commission basis) [190].

Within the gig economy in general, HCI and CSCW researchers have investigated the workers’ motivations to participate [74,580], working conditions [11,20,234], the impact of platforms on workers [11,305,327] and analyzed optimization approaches [20,38]. Researchers such as [20,333] analyzed how digitally mediated TNC platforms coordinate and organize work, how they influence drivers and how drivers react to their digital “principals”. The impact of Uber’s algorithm-controlled price system has been topic of Chen's and Cachon's research as they investigated how surge pricing effects workers and consumers [101,111]. Ma et al. [327] and Kim et al. [278] have analyzed the drivers' stakes of earning, autonomy, and satisfaction. The results of the following studies are of particular interest for our study: How the advent of TNC app Ola has changed the work practices of Indian auto rickshaw drivers has been subject of Zade and O'Neill's research [589]. Regarding working conditions and workers' rights, Alkhatib et al. [11] note that it is difficult for drivers to unite and assert their interests against the Uber corporation. Addressing uneven power between gig workers and platforms, some studies have analyzed workers' rights in more detail [359,537] and worked out how workers' rights could be strengthened [141,506]. Much work has been done on the pressure that rating systems put on ridesharing drivers [17,20,205,326,432]. They investigated how the strong pressure of the ratings influences the behavior of the drivers and the design of the service. With a look at the high service orientation and how the ridesharing drivers respond to the platforms' rating systems, for instance Glöss et al. [205] and Arita et al. [20] outlined how important new tasks and skills such as empathy and emotional labor in general are. In the same line, Raval and Dourish [432] and Anderson [17] worked out, how ridesharing drivers try to create a personalized and pleasurable experience for their passengers always having the pressure of the 5star rating system in mind. Kameswaran et al. [270] analyzed how drivers and riders can benefit from interaction in the form of social capital and cultural capital. Rekhviashvili and Sgibnev [436], however, when comparing Uber with the traditional Marshrutkas (informal paratransit in some post-Sovjet cities), state that Uber's habits of not subjecting themselves to regulations, exploiting workers and existing infrastructure are not a new phenomenon, but were already ubiquitous among the Marshrutkas.

In contrast to Uber, e-hailing apps that broker trips with licensed taxi companies legally operate in Germany and are becoming increasingly popular. Across Europe, over 100,000 taxis can be booked via at least one taxi app [496]. Offering similar functions like TNC apps, e-hailing apps enable professional employed or self-employed taxi drivers to take over the most important function of taxi dispatchers – the brokerage of rides [240]. Studies such as those of [3, 17, 41, 99] analyzed how conventional taxi drivers reacted on the advent of e-hailing apps, how drivers adopt those apps, how they interact with them and how this influenced their work practices.

Customers and taxi drivers can get in touch directly and arrange a trip, instead of going through a classic taxi dispatcher. Taxi drivers who use taxi apps benefit from an increasing outreach as brokered trips are not bound to a specific region – in contrast to traditional taxi dispatchers – but are actual location-dependent. Thus, shift of roles can already be observed in the taxi business: drivers are empowered by new apps to overtake tasks from dispatchers (matching, administration, etc.), but are also subject to increased transparency, thus need to provide a better customer experience.

In addition, also in the German taxi industry, the economic trend can be seen that drivers are increasingly less likely to receive a fixed monthly income in a classic employer-employee relationship, but more likely to earn a share of the turnover [187]. Overall, the use of e-hailing apps gives taxi drivers more flexibility and autonomy and at the same time there is a growing pressure to make as many journeys as possible in order to get a decent salary. On this note, the taxi industry in Germany is also approaching the gig economy.

Gig economy experts Lieber and Puente forecast the end of the gig economy, as understood at present, for low-skilled, commercialized workers, as they are currently to be found in the logistics and transport sector:

> "In the past few years, analysts and reporters have obsessively focused on transportation technology platforms such as Uber and Lyft and delivery technology platforms such as Instacart and the workers needed for these on-demand services. […] these tasks are overwhelmingly likely to be automated over time, performed by selfdriving cars and drones." [311]

Others go a step further and argue that platform operators are instrumentalizing the gig workers to automate their services. Michael Osborne argues, Uber and Lyft can feed their algorithms with the data collected during the trips on user demand, traffic and road conditions until the computers are finally smart enough to perform the complete driving task without human intervention [526]. In this respect, the era of the human gig worker is only a transitional phase for the automated execution of services. Taking up this issue, we contribute to a better understanding of how future technology could change gig work in the taxi industry. In this respect, we contribute to the existing literature on the gig economy, which focuses primarily on current developments and technologies, by analyzing the future of gig work against the background of self-driving technology.

10.2.3 Future Technological Impacts – Shared Autonomous Vehicles

In the future, besides automated routing and brokering, the technology could perform the central task of the ridesharing service: doing the driving itself in SAVs. Aspects and possibilities of building safe and reliable autonomous vehicles for facilitating innovative and efficient future transportation have recently been investigated [i.e., 5,247,307,325]. For a long time, this has been a predominantly technical discourse that dealt with technological feasibility [206,476,510], (resource) efficiency [79,215,369] and ethical issues [176,207,314] relating to automated driving without taking into account the different roles of humans associated with these vehicles.

Transportation research has focused on the acceptance of semi and fully autonomous vehicles [i.e., 300,386,399,410] as well as on the use and applicability of fully autonomous vehicles as not privately owned but publicly shared vehicles. In this discourse, the term “shared autonomous vehicles” (SAVs) has become established [179,317,403] drafting scenarios with driverless taxi fleets, indicating “there will be no more employment for taxi drivers” [571]. In this vein some studies have undertaken simulations of SAV fleets [93,179,337,492] showing that new mobility concepts in public transport based on SAVs can be sustainable solutions and efficient extensions to existing concepts and thus could compete with and endanger the existence of traditional taxis in the future.

Concerning HCI, research mainly addresses driver-vehicle-interaction especially in handover situations [213,289,348,418], interaction of drivers or pedestrians and driverless vehicles [80,360,453], the dashboard design derived from user surveys [212], and in-car-interaction [349,413,503]. These studies, however, regularly do not raise the question of ownership or usership, thus can from their narratives be understood as implicitly focusing on privately-owned vehicles. One exception is the recent study of Kim et al. [279], who simulated an SAV in a Wizard of Oz experiment that was tested with 43 participants. In their study, the authors created a customer journey for taxi use based on observations and interviews with taxi customers. This customer journey describes the touch point of the passengers and the classical taxi service, which the authors then use for the further analysis of the service design. Their participants, however, seem to represent the average Uber or taxi-app user regarding age, thus being different from Germanys taxi customers [586].

Given this prospect, we want to analyze possible future changes to the profession of taxi drivers. To do so, we also consider the social part of the taxi driver profession as relevant to look at, as this aspect might be the decisive difference between human driven taxis and automated driverless taxis. As outlined before, recent research has begun to investigate the work practices of professional drivers and the experiences of passengers empirically in order to provide a broader context for design in the area of e-hailing apps and mobility services [7,156,205,272,352,530]. While they have already gained valuable insights into the working lives of drivers, such as the importance of emotional labor and empathy [17,20,205,270,432], these works focus on Uber drivers [205,305,326,327,432,436] or drivers of other TNCs [589]. That costumer clientele, however, substantially differs from the clientele of the traditional taxis; in particular ridesharing is not used by older people, while traditional taxis are [586]. Further, all these studies have in common that they focus on existing technologies and do not transfer the findings to future technologies such as driverless taxis.

Therefore, we extend this work by analyzing the perspectives of German taxi drivers on the threats of new forms of competition especially SAVs. To do so, we focus on a set of research questions to help us assess the consequences of the non-yet-existent technology.

RQ1: How do taxi drivers assess the potentials for the automation of their profession by SAVs?
RQ1.1: Based on experiences with recent innovations, how do German taxi drivers perceive the general influence of digital innovations on their work?

Our rationale for focusing on RQ1.1 is that it allows us to understand how taxi drivers experience and generally respond to changes of their work practices. We argue that this understanding helps to draw conclusions for possible future disruptions.

RQ1.2: What specific working tasks would still require human work in the age of SAVs?

As previous literature has already shown, (professional) drivers can stand out from the competition particularly through their customer orientation and service level [17,20,205,270,326,432]. We expect that it will be similar in future competition in the form of SAVs and that the role of the driver will be determined in particular by the interaction with the customer. Thus, focusing on RQ1.2 may allow us to learn from the taxi drivers' actual experiences which we can analyze in the context of SAVs.

RQ2: What contextual factors shape the adaptation of the profession to increasing automation and how can those factors inform the design of new technologies?

On the basis of the findings of RQ1.1 and RQ1.2, focusing on RQ2, we would like to analyze how the job of the taxi driver will change if the driving task will completely be taken over by the technology. So, we would like to work out to what extent the person of the taxi driver is or may in the future be superior to a fully automated taxi. Focusing on these factors is in line with the "turn to practice" in HCI and emphasizes the specific role of the driver as user of technology and practitioner within the taxi profession in the advent of possible IT-driven disruptions.

10.3 Methodology

We have chosen a qualitative approach towards our open-ended research question and conducted semi-structured interviews with 19 taxi drivers aged 19 to 65 in Germany (excerpts in this paper have been translated by the authors) [81]. Participants were recruited randomly by addressing them at taxi stands in the urban Cologne-Bonn area. We offered the taxi drivers a financial compensation based on the length of the interviews, roughly amounting to the same price of a taxi ride with the same duration. Some taxi drivers were willing to do the interview without compensation. We tried to create a typical sample of respondents for the German taxi driver community, which is characterized by male drivers with a migration background. To ensure diversity of opinions, we interviewed one female taxi driver and five who did not identify as having a migration background (see Table 10). The interviews ranged from 15 to 45 minutes in length (average 27 minutes).

After we had obtained the consent of the taxi drivers to record the conversations, we conducted the interview in the car as the workplace, following a semi-structured interview guideline

Table 10: Socio-demographics and background information on participating taxi drivers

NO	SEX	AGE	STATUS	PERSONAL BACKGROUND	TAXI APP
1	m	59	self-employed	Driver for 35 years, immigrated from Afghanistan, could not return home due to war, taxi driving as a compromise	Yes
2	m	65	employed	Driver for 20 years, immigrant, gave up job for taxi driving to become independent, retired, drives occasionally to increase pension	Yes
3	m	53	employed	Driver for 29 years, immigrant, switched from courier to taxi driver, appreciates the customer contact	No
4	m	52	self-employed	Driver for 21 years, immigrant, was printer but lost his job	Yes
5	m	64	self-employed	Driver for 37 years, immigrant, dropped out of his studies, took a taxi as short-term solution	No
6	m	54	employed	Started taxi driving as part-time job while studying, more than 20 years ago, 'loves' his job	No
7	m	19	employed	Started taxi driving a year ago as sideline beside vocational training	No
8	m	62	employed	Driver for 7 years, immigrant, prior employer shut down factory	No
9	f	61	employed	Was driver in transportation sector before (school bus, trucks, blood transport), appreciates customer contact	No
10	m	61	self-employed	Has held taxi concession for 21 years, immigrant, dropped out of studies for financial reasons, became taxi driver	Yes
11	m	48	self-employed	Has held taxi concession for more than 20 years, dropped out of studies, got stuck in taxi driving	No
12	m	50	employed	Driver for 23 years, immigrant, no other occupational perspective	No
13	m	51	self-employed	Has held taxi concession for 23 years, dropped out of studies, got stuck in taxi driving	Yes
14	m	62	self-employed	Driver for 39 years, became taxi driver after having conflicts with superior	Yes
15	m	50	employed	Driver for 25 years, was unhappy with former job as educator	Yes
16	m	48	employed	Taxi driver for 10 years, 4 years self-employed at the beginning, since then only part-time, originally from Russia	No
17	m	44	self-employed	Taxi driver for 20 years, started in his brother's company, now self-employed, usually at taxi rank at the station	No
18	m	45	employed	Taxi driver for 20 years, trained communication electrician, appreciates the communicative aspects of the job	No
19	m	55	self-employed	Runs a taxi company for 24 years, which exists for over 80 years, with at times more than 50 employees	Yes

with open ended questions and encouraged the participants to elaborate on their answers or to report on concrete examples from their daily work. We started with questions about their career and reasons for choosing the profession of taxi driver as an entry point for narrative interviews [39]. Then, we continued by asking the drivers to tell us how they typically work, how they see the taxi industry changing in recent years and what changes they expect to see in the future. If the drivers did not address it independently until this part of the interview, we enquired about the digitalization of their profession and how that affects their work life, their customer clientele and interaction with them. The last part of the interviews was focused on their expectations regarding the future of their business in the light of innovations such as self-driving vehicles. Depending on how much the taxi drivers knew and could imagine about autonomous driving, we asked more open questions or had to become more concrete with our inquiry.

To avoid influencing our participants, we generally focused on the open questions and waited if the participants mentioned the subtopics (apps, TNCs, autonomous driving) themselves. However, if the core topics of our research questions were not covered by the participants in these narrative passages, we asked the more detailed questions that included the mentioned. If a participant addressed a topic on their own, we followed up on his or her comments and changed the order of questions accordingly.

We only provided taxi drivers with additional information on the concept of autonomous driving when it became apparent that they had little or no knowledge of this technology and therefore found it difficult to imagine possible consequences. The information we gave to those participants related to general definitions of autonomous driving (T7, T10, T12) and pilot projects to inform them that the development is already progressing and is “real” (T3, T7, T10, T12, T15), or to some car manufacturers' announcement that autonomous vehicles will come onto the market in five to ten years (T10). Finally, in a view of their very personal opinions, we asked the participants how they see their future in the taxi industry and whether they would recommend the profession of taxi driver to their children.

All interviews were recorded, fully transcribed, and analyzed independently by two people following thematic analysis procedure based on Braun and Clarke [73]. Thematic analysis is a method for identifying, analyzing and creating topics from datasets [72], which is used to meaningfully summarize the key aspects of a large amount of data. Thematic analysis highlights similarities and differences between datasets. It also enables unforeseen new insights to be generated. It is often used for the analysis of qualitative data and is flexible because it is not bound to any theoretical framework as e.g. structuration theory conversation analysis is [200]. For our analysis, we first familiarized ourselves with the material. As transcription of the interviews was divided up among the researchers, some familiarization had already been achieved during the transcription, as well as through close reading of the other transcribed interviews. In the next step, we started to code the interviews using MAXQDA software. To do this, we chose a deductive semantic approach. We followed this more theory-driven, rather than inductive, approach. In the context of thematic analysis, theory-driven does not mean that the analysis is based on a superordinate theory, but rather on our specific research questions that had already shaped the structure of the interviews. We knew, for example, that we wanted to extract the advantages and disadvantages of taxi services, which therefore had corresponding codes. Not only were passages coded that were related to our specific interview questions, but also interesting passages such as subordinate clauses explaining other concerns. During the initial coding, we began to assign topics and subtopics by making color mappings. Once we had systematically coded the complete data set, we checked the pre-structured codes, searched for topics and combined them into motifs. We then reorganized the code system by grouping the codes into themes and subtopics before finally sorting the themes. In the next phase, we checked whether the topics were consistent with the elaborated, coded passages and the entire dataset. The coding system was then applied to all of the interviews and iteratively refined, extended and adapted as and when new interviews required it. Finally, we selected meaningful examples of the most relevant topics, representing the diversity and breadth of the interviews, prior to working up the analytic results in text form as findings.

10.4 Findings

In the following we will present the findings of our interview study structured according to time: We will start with what has happened in the *past* including how our participants came to be taxi drivers and in how far technology has lead to changes in existing work practices so far (10.4.1), before we will outline how drivers react to *present* IT-driven innovations within their industry (10.4.2). Finally, we will present the drivers attitude towards *future* innovations – particularly SAVs – enriching their personal opinions with examples of interactions, a human might be relevant for also in that scenario.

10.4.1 General Background and Experiences of Taxi Drivers

The professional careers of the interviewed taxi drivers were very different from each other. None of the participants chose the career of a taxi driver voluntarily when they entered the job market. For eight respondents, taxi-driving was more of a sideline for vocational training or retirement. Five taxi drivers made a conscious decision to take up the profession of taxi driver, although they already had other permanent jobs at that time. Nine of the interviewed taxi drivers started driving a taxi only as temporary solution and then stayed with it due to the lack of alternatives. They had either lost their job, quit their jobs themselves, or had dropped out of their studies. Table 10 gives an overview on the various reasons and backgrounds of our participants.

Fifteen of the respondents reported they had been working as taxi drivers for over 20 years. They described that both the competition and their clientele had changed considerably in the last decades. Increased competition from the expansion of urban public transport in terms of routes and destinations, and new mobility services such as carsharing were seen as main drivers of this change. Customers allegedly changed their habits, particularly in the context of a declining purchasing power of the population and a decline in the urban pub and party culture, resulting in a lower demand for (night) trips.

Many of the taxi drivers' work practices have already changed because of technical progress. Nowadays, taxi companies use digital mobile systems to coordinate their fleets and satellite navigation plays a huge role for the drivers. All surveyed drivers had GPS systems and used them routinely via text or voice commands to plan a ride. As a rule, drivers use the GPS as a supplement to their own local knowledge and planning ability: they describe situations in which the systems were inferior to their own knowledge and recommended longer distances than necessary. Drivers mainly use GPS if they do not know the specified destination well, appreciating the efficiency of these systems in such cases.

Regarding the organization of customer orders, technology has enabled taxi drivers to work more autonomously, as described by T17:

> *"We now have very many small companies that have only one taxi concession or a maximum of two. And there is no point in having a dispatcher, that is the problem. You need to get someone to do the coordination, who costs money, day and night, then you have to rent an office. (...) Since there are mobile phones – everybody [taxi driver] has a mobile phone – with very few exceptions people can call you. In former times it was just that the taxis were not available because the mobile phones did not exist." (T17)*

This respondent has observed that taxi companies have become smaller in recent years, and that it is very costly for a single company to have one position only for coordinating the trips, for example to receive telephone calls from customers and then distribute them to the drivers. Since the advent of mobile phones, customers have been able to contact taxi drivers directly in their cars during their working hours and request rides. This was not possible when the drivers could only be reached via radio, so the customers had to go through a dispatcher. Mobile phones have made it possible to skip this intermediate layer.

Also, new GPS-based systems enable fully automated brokerage of taxi rides. These systems allow taxi drivers to view the locations of other colleagues. This results in a significant improvement in taxi drivers' trip planning, as our interviewees reported: *"You can log into the stopping places online. In the past, you were forced to go there and stand in the back"* (T01). Another taxis driver explained what advantage this change has for him in more detail:

> *"Because in the past (…) if you were unlucky, there were already ten taxis there – and you waited endlessly. At another stop there was none at the same time, there you would have been needed. Well, and now you can see everything [points to the app in the smartphone]: there are fewer, then I'm going there now, or here are so many taxis." (T19)*

T19, an experienced taxi entrepreneur, describes how uncoordinated the taxi business was without the digital tools that are common today. In addition to taxi orders that were placed via the taxi dispatchers, they had to wait at stopping points or hope for being hailed directly by customers on the streets. Without digital systems to provide awareness, drivers had to decide for themselves which waiting area would offer the best chance of finding the next customer. They could rely to a certain extent on their experience, but luck played an important role, especially as other drivers positioned themselves based on similar preferences. As T19 explains, the digital system now enables him to go to waiting places where there are few competing taxi drivers, which increases his chances of getting a customer. Thus, increased transparency and awareness helps drivers to coordinate demand and supply much more efficiently, reducing unnecessary and uneconomical waiting times and lost revenues.

The taxi drivers were generally quite open-minded towards innovations such as e-hailing apps like mytaxi – eight taxi drivers had already been using them and expressed a positive opinion. Only four of them mentioned negative consequences of increased digitization, especially regarding the reduced contact between colleagues and taxi dispatchers (T01, T05, T06, T19). One of them expressed his frustration with a declining sense of togetherness. He appreciated listening to his colleagues' over the radio, even when only small requests were involved:

> *"The contact, that is regrettable. (...) Everything has advantages and disadvantages (...). In the past this was just more pleasant with voice radio. One has heard where things are going on. Ehm, you heard your colleagues. You could only shake your head, why doesn't he know the street? (...) That was easy, it was more communicative." (T06)*

The respondent found it "more pleasant" to be in contact with his colleagues because it gave him the feeling of being able to get a better overview of the overall situation ("where things are going on"). His comment shows that communication via voice radio was not only about efficient coordination, but that the social aspect played an important role as it was "more communicative." T01 explains the aspect of social contact further: taxi drivers traditionally used to meet at typical waiting points such as taxi ranks at train stations or tram stops, while waiting for the next passengers or dispatch requests. As drivers are increasingly using e-hailing apps, fewer drivers are to be found at the waiting points:

> *"Nowadays, this social exchange does not take place at all anymore due to the introduction of digital systems, and some of our colleagues can no longer be seen for months. Unfortunately, everything has become anonymous." (T01)*

T01 describes a growing anonymity because of e-hailing apps and expresses that his colleagues are no longer as close as they used to be. He deplores this aspect of digitization. While anonymity is a common effect in the gig economy, the difference here is that the gig workers have usually never met in person and are only logically networked via their job or internet forums, whereas for traditional taxi drivers personal contacts and meetings used to be common. Self-organization via the apps thus leads to a transition to a less collegial work environment. T01 thus sees the danger that the drivers' cohesion with each other will diminish. However, other respondents did not bring up this topic.

10.4.2 Facing Current Innovations in the Taxi Industry

10.4.2.1 Usage of Taxi Apps

Eight out of nineteen interview partners reported that they actively use an e-hailing app. These participants were overly positive about their experience with them, primarily appreciating advantages that the app offers them as well as their customers compared to using a classic taxi dispatch. Arguments about these benefits included that customers would value the additional service features such as tracking the location of the ordered taxi, getting the estimated time of arrival, and paying the fare cashless. One respondent also mentioned the greater field of his service district as a benefit for taxi drivers:

> *"In the past, you could not take trips in Cologne or Düsseldorf [when coming from Bonn]. Today I take a passenger to Cologne and get a new ride via my app. (…) You can log in to the taxi stops online. In the old days, we were forced to go there and get in line." (T01)*

Regarding effects on their work, T01's comment shows that using the apps offers drivers the possibility to get trips outside their core areas more easily. Regional taxi dispatchers only broker trips in their core areas. If drivers leave those areas, they are on their own. E-hailing apps help taxi drivers to find customers at their current location even when they are outside their actual service area. With luck, they can thus avoid an empty return trip. However, in some German cities mytaxi has meanwhile been prohibited to broker trips to drivers who do not have a taxi concession at the starting point of the trip.

T19 reported that he uses a taxi app because he gets additional customers through it. He made the experience that especially foreign customers prefer to place orders via the app because they appreciate the easy access without having to place a call to a German dispatch center, and because they can pay directly via the app. These advantages lead T19 to accept the additional costs of orders placements via the app.

The situational awareness provided by the e-hailing apps empowers the driver to coordinate the collection of passengers independently from the taxi dispatchers and their predefined service district, thus allowing the taxi drivers to work more independently and make better use of their taxis. E-hailing apps hence influence the relationship with the taxi dispatchers, colleagues, and customers.

Three drivers reported that they are no longer members of regional taxi dispatchers. The commission-based costs of the app reduce the financial risk of taxi drivers, as costs are not fixed monthly fees like in case of the dispatch memberships, but only incur if drivers have actually undertaken trips. T10 told us that his taxi dispatcher demanded a high fee of 800 Euros per month, putting him at great risk if he should become ill or otherwise unable to work. Hence, he cancelled the membership and now exclusively uses a taxi app to get orders or find taxi stands with high demand. Thus, the revenue-dependent costs make taxi apps an attractive alternative to a membership in a taxi dispatch service, especially for occasional drivers:

> *"I'm a member [of a taxi app]. If I have to drive once a week, I use my cell phone. I'm not a professional [fulltime] driver." (T02)*

T02 is a retired driver with more than 20 years of experience who still occasionally drives taxi to supplement his pension. He has a stock of loyal customers who still contact him because of his cleanliness and reliability, as he claimed, and he uses an app to get additional orders. Using a taxi app as a complementary channel, he gets sufficient customers without being a member of a regional taxi dispatch service. T14 highlights another advantage of the taxi app he uses:

> *"Yes, of course, at mytaxi I have now... I've got over 250 regulars already. That means that if these 250 people are in Cologne, or if they are halfway close to me and order a taxi, I'm first in line to get the order." (T14)*

He describes how he benefits from the fact that customers can define preferred drivers within the app whose requests are assigned to him and not to other colleagues when he is close to these customers. This customer retention helps him in his independency. Further, T14 reports, he could *“even forego his membership in the regional taxi dispatch service today”* as he has these regular customers who book trips via mytaxi. The reason he is still a member of the dispatch service is more of loyalty than of necessity.

For T19, the membership in a taxi center has other benefits. He also appreciates the advantages of using the app, but he believes it makes sense to make use of both the dispatcher and the app:

> *“I think it is all about the right mix. What a lot of drivers do are patient trips. Chemotherapy and whatever. And that all goes through the dispatcher, because they also settle accounts with the health insurance companies and that can’t be done through the app. Not yet. I’m not saying what’s in five years, we’re always just talking about today. Otherwise I’d have to settle accounts with every health insurance company, write letters, I could really hire someone in the office who takes care of such things. And that’s all done by the dispatcher. Then I just give my receipts and say here, and ten days later I have the money in my account. Collected once a month – and that’s it. That's a big advantage.” (T19)*

T19 thus points to a special clientele which, according to him, cannot be coordinated via taxi apps. He refers to patient trips which neither fall into the category of business trips nor into the category of private trips. In Germany, health insurances pay for taxi trips if it is medically necessary. This is for example the case when patients are at home but need to go to chemotherapy, irradiation, dialysis, etc. He describes the accounting of patient trips as an important activity, which would cause him a lot of overhead work if he was doing it himself. Since the patient trips are not billed directly to the patients, but to the health insurance companies of the patients, a higher organizational workload arises compared with regular taxi rides. His expression *“I could really hire someone in the office”* indicates how much work these billings can actually cause. Thus, when it comes to patient trips, the dispatchers take over the time-consuming task of billing. The fact that the dispatcher is responsible for invoicing the health insurance companies means that the drivers only have to *“give [the] receipts”* to the taxi dispatchers *“once a month”*. Interestingly, when T19 declares, that these billings cannot be conducted via taxi apps nowadays, he adds *“Not yet. I’m not saying what’s in five years, we’re always just talking about today”,* showing he believes it is possible that the taxi apps will also map such services in the future. These rather open-minded thoughts could probably stem from his status being a taxi entrepreneur with his taxi company having a more than 90 years tradition, who – as such – might probably be more concerned about the future of the taxi industry than other employed taxi drivers.

So, the taxis drivers who make use of taxi apps in their daily business, appreciate the fact that they gain new customers through the app, that the costs are revenue-dependent and not fixed, and that they can build up a regular customer base through the features of the app.

10.4.2.2 Reasons for Resisting Taxi Apps

Eleven taxi drivers in our sample did not make use of e-hailing apps. Some drivers deliberately decided against using such apps as an additional broker next to their usual taxi dispatchers. These drivers have informed themselves about the taxi apps and weighed advantages and disadvantages for their own business. They do not consider the benefits outlined above to be advantageous over the traditional way using a taxi dispatch service. This was usually explained by the fact that the drivers could get trips via the taxi dispatcher free of commission (T05, T12).

> *“Well, it’s a very clever, very sophisticated model. (...) However, for us it is a big competition, so that’s what we have to say. Because the people here [taxi drivers using taxi apps], they don’t understand, they’re now driving doubly. That’s the seven percent for the mytaxi that they pay for. If they weren’t on mytaxi, they would have had the trip with us [classical dispatcher].” (T05)*

T05 argues here that the journeys, which are requested via the app, would otherwise have been requested via the dispatcher. Hence, drivers using the taxi apps pay both the fixed costs for the dispatcher, of which many are still a member, and the turnover-dependent costs of the taxi app. He believes that the costs of the app could be saved. T11 is of the same opinion and considers *“some of the drivers pretty […] stupid”* that they demand tariff increases on the one hand, but on the other hand willingly accept apparently higher costs when using a taxi app. What they do not consider at all is the opportunity of gaining new customers and additional requests, as some of the other drivers have experienced, which might outweigh additional costs.

T17, who is self-employed, prefers to leave it at his usual work routines as long as he gets enough jobs even without an app:

> *“If nothing was going on at all, then I would also register with mytaxi. But if it works without mytaxi, then gladly without mytaxi. That is my attitude. I also have colleagues who use it a lot. Everybody must know that for himself. And you never know if they will increase the fees, and then you stand there.” (T17)*

He raises another point, namely the risk of being dependent on the app operators' decisions, i.e. to raise the fees for the participating taxi drivers. As an entrepreneur who is not a member of a regional taxi dispatcher but gets his request via direct telephone call or on the street, T17 is not dependent on any brokering institutions, thus does not need to pay these institutions and has no risk of rising costs caused by these.

T06' decision not to make use of taxi apps is driven by a completely different reason. While he generally likes some of the features of taxi apps, especially the reputation system, his main concern regarding the use of taxi apps is the disclosure of private data. But he seems to generally be sensitive when it comes do privacy, as he refuses to use very widely used apps such as Facebook and WhatsApp.

Three other taxi drivers have not dealt with taxi apps yet as they leave such decisions to their employers (T07, T16, T18). T18 explains this decision with his employer being "loyal" to the taxi dispatcher, however, his boss is struggling with the decision to use taxi apps after all:

> *"Yes, if things go on like this (...) he has to think about it. (...) But that hurts when one [app operator] is sitting there earning money and you see, that's your own money going away, and you give it to him, and so far he [boss] has refused to do that, hoping that it will get better, but it won't get better." (T18)*

His boss's thoughts are driven by the deteriorating business, and both see from their colleagues that taxi apps can help getting more customers. Nevertheless, they so far have a negative attitude towards the apps, as they only see that they have to pay costs, while the app operators are "earning money," apparently without doing much for it. Further, they condemn the fact that taxi app operators use the existing infrastructure of the taxi industry without participating in its maintenance (T05, T18) or they didn't like how taxi apps gave discounts to customers in the early days (T09), which led to taxis with taxi apps being preferred to those without. This behavior of taxi app operators seems to have triggered a negative attitude towards taxi apps that lasts.

T03 sees e-hailing apps as similar forms of internal competition in the same category as Uber:

> *"Mytaxi and so on (...) Well, if I were a customer, I wouldn't even get in with them. Because they're not insured at all. No exam of the local geography, so as I said, that's just moonlighting. (…) They're not professional drivers – Uber and mytaxi." (T03)*

He is obviously not correctly informed about the business model of these apps and is unaware that taxi apps only broker trips by licensed drivers. His decision not to use such apps is therefore due to their limited information and ability to judge.

So, those taxi driver who do not use taxi apps, do so out of different reasons. While some just see additional costs but no additional revenue, others fear possible dependencies or refuse to use apps for privacy reasons. Some have not yet used taxi apps, because they (or their employers) tend to stick to their routines. Further, there seems to be a negative attitude towards taxi apps in general that prevents drivers from using the apps.

10.4.2.3 Competition by Transportation Network Companies

Due to the general ban on Uber, which was imposed for the German market very quickly after its market launch, taxi drivers did not notice any effects on their own business and trips. Only one taxi driver had not even heard about Uber so far (T07), while most of the respondents reported a negative attitude towards this competitor. Their criticism included assumptions that Uber would work *"illegally"* (T10), drivers would *"go moonlighting"* (T11) and work without clear insurance cover for themselves and their passengers. They argued that taxi drivers offered a far more reliable and safe service due to the examinations which they must pass to be licensed.

> *"I've only heard of it from hearsay. I don't find it correct that they [Uber] want to get on the market here. Because you don't know who you're getting in the car with, do you? We have to do driving tests, they don't. We have to undergo our exams every four years. And they don't need to do anything." (T09)*

Contrary to many studies that show the negative impact of Uber on the traditional taxi industry, most interviewed taxi drivers do not consider business models such as Uber as a threat to their own job. Most of the interviewees referred to the strict laws and regulations prevailing in Germany.

> *"I don't think so, in Germany, because the laws are somewhat stricter here." (T04).*
> *Others trust in bodies representing them such as their regional taxi dispatchers or the nationwide taxi association who have already in the past put pressure on policies and the law.*
> *"The dispatchers will also resist against them [Uber], so that nothing will happen." (T09)*

Those drivers were firmly convinced that these provisions will continue to apply in the future and thus protect their profession. These statements show that laws and regulations contribute to their sense of security, but also that the membership in a taxi dispatch service strengthens their position and interests against authorities and large companies as individual or small entrepreneurs.

Regarding the possibility that regulations are weakened or dropped, one taxi driver in particular argued that customers would remain loyal to taxis because of the high quality of the service;

at the same time, his expectation was that no matter how the regulation was changed, Uber drivers and their vehicles would be subject to the same rules as the taxi industry which would then be able to adapt and limit the possibility for undercutting their services with cheaper prices.

> "My regulars. There's no one to ride with Uber. Certainly not. They know what they get from *me, what quality. [...] Then Uber drivers must of course also compete under the same conditions. And if that should happen, I don't have to worry about my colleagues. If they have to do everything the way we do, and they also have to pay tax, etc. Then it won't be so cheap anymore." (T14)*

Only one respondent, T06, feared that the regulation of the taxi industry in Germany could be relaxed, opening the market for competitors such as Uber drivers. He hence expects the competition to get harder and even more difficult times for the classical taxi industry to come.

10.4.3 Attitudes and Expectations towards Shared Autonomous Vehicles

10.4.3.1 Perceived Impact on the Transportation Market

When asked about potential concerns regarding the possible introduction of autonomous cars into their business, most drivers did not feel threatened. Only five drivers brought the topic of AVs up on their own during the narrative passages of the interviews (T04, T06, T08, T13, T19), before the interviewers addressed it. These drivers mentioned different expectations regarding the market penetration, the use of SAVs, and their impact on private car ownership, or the risks of taxi drivers becoming obsolete.

Most of the respondents in our study (14) did not bring up the topic of AVs in the interviews on their own. While some taxi drivers regard the emergence of AVs as a given (T04, T06, T08, T11, T19), most of the respondents were generally skeptical about the feasibility of replacing drivers with autonomous cars in the first place. In their view, autonomous driving will have hardly any impact on the taxi industry in particular. Their reasoning for this view was an assumed lack of security and reliability, the expenses for buying and maintaining the cars, unsettled liability issues in damage situations, as well as the strict legislation of Germany.

Especially older drivers were usually not feeling threatened as much as younger drivers, likely because autonomous cars were considered a topic of the future, most of the older drivers did not expect to experience this innovation in their work life:

> *"I'm very curious about electric cars and self-driving cars. I'm 60 now. That means I may stay here for another three to four years. That means it's not a terrible thing for me when that happens." (T08)*

Other taxi drivers (T02, T19) think that even with the spread of autonomous vehicles, not all population groups will accept them, so they will not use them and will continue to rely on traditional drivers.

"It's gonna come. It's already there, but in practice it's difficult. Not difficult, but people don't trust." (T02)

They see a major hurdle in the fact that customers will not rely on self-driving technology and would therefore not make use of such innovative services in the long term. At the same time, taxi drivers describe different effects for the future scenario with autonomous taxis which would affect them to a greater or lesser extent. When it comes to the question of what the taxi industry could look like in 10 to 20 years' time, T06 predicts that the business model of SAVs could have a really fundamental impact on the whole mobility sector:

"I mean, we are at the gateway to autonomous driving where the driver will no longer be necessary. And I can well imagine that if this works properly, then basically there will only be taxis on the road. I mean, why would you want your own car if it drives on its own anyway and you can't or don't have to drive it yourself? And if you just walk through the city and somewhere on the corner there is a [shared autonomous] vehicle and you know you can get in there and know the prices and you know that it takes you from A to B." (T06)

He fundamentally questions the fact that in the age of AVs and autonomous taxis, people still have any interest in owning their own car. He argues here with the fact that it makes no difference whether one uses one's own vehicle or a vehicle on demand if one does not drive the vehicle in either of the two variants. Hence, he expects that only taxis will be on the road – no more private vehicles. He paints a picture of people who use SAVs spontaneously according to their needs, and expects the future presence of autonomous cars on the roads to improve traffic flow and reduce accidents, as he explained further:

"The sooner and the more interlinked the vehicles are with each other, the faster moving it'll all be. And even if they can communicate with each other, there won't be accidents anymore." (T06)

The positive-minded taxi drivers generally expect positive effects from the emergence of AVs. Regarding the taxi industry, they consider changes to be realistic but agreed that the taxi industry will change in such a way as to divide the market between traditional and driverless taxis.

"Maybe... there are certain lines that go to the airport or something." (T03)

T03 can imagine that there will be taxis that will travel completely without a driver. He does, however, make a restriction and does not see this new variant of the taxi service suitable for all trips. Rather, he considers there will be fixed, standardized trips, such as to the airport, which will be carried out by driverless taxis. In this respect, this idea corresponds to that of T04:

> *"Parallel business to the taxi. Taxis, these classic taxis, I don't think there will be that many anymore. Of course, taxi will always exist because there are elderly people, patients. You can't do anything else. You must take a taxi." (T04)*

In contrast to T03, T04 immediately gives reasons why there will not be exclusively driverless taxis. He names elderly people or patients as two customer groups, who will rely on taxis with a human driver also in the age of autonomous driving. He is convinced these groups do not have a choice but opt for the taxi with a human driver. This opinion might be shaped by the experiences he has gained with these customer groups. He gives similar reasons why exactly the taxi driver is needed.

T11 expects autonomous taxis to compete less with traditional taxi drivers than with the alternative driving services already available today, such as hired cars with drivers or shuttle buses. Those differ from taxis in that they can only accept planned driving orders and not spontaneous orders, i.e. they are not allowed to serve customers hailing taxis on the street or at taxi stops. He sees autonomous vehicles as particularly interesting for the operators of such companies:

> *"After all, the competition already exists. That will be the operators who, for example, previously offered only airport transfers. There are also travel agencies that offer this, or entire tour operators. Or companies that offer shuttle services because they are remote and take their guests to the airport by company car. They could say: We save the chauffeur and use an autonomous vehicle instead. That would really pay off for them." (T11)*

In summary, while some drivers question a successful implementation of AVs due to a lack of trust, others see great potential in automated taxis in terms of less accidents, an improved traffic flow and reduced personnel cost. They expect that some routes and customers could be served with SAVs while they mention specific customer groups, they consider not to be able to be served with SAVs. However, most taxi drivers do not regard SAVs as threat to their own person as they are at the final phase of their career.

10.4.3.2 Limitations of SAVs Regarding Customers' Needs

While the previous section highlighted that taxi drivers expect certain trips and services could be taken over by SAVs, they are sure that even in the age of autonomous taxis they will still be needed by their customers. Their argumentation is based on the customer structure of taxi services. He and other interviewees mentioned specific services that they provide, which are requested by many of their customers. In the following, we will provide quotes that illustrate how frequent and diverse these interactions and supports are:

> *"I see the proportion of people in need of help and that is pretty substantial. That's why you call a taxi because you can't drive yourself. If people could drive themselves, they would also use an autonomous vehicle." (T11)*

According to T11's experience, there is a large proportion of customers who need help with the transportation – so they would not be able to for example board the vehicle on their own. T11 emphasizes that many customers request a taxi because of additional services. For example, he points out that the actual trip also includes the way e.g., from the apartment to the vehicle and from the vehicle to the destination, e.g. the entrance area of a doctor's surgery. Other drivers also argue that human assistance will still be required for certain services which cannot be easily offered by AVs. As example, several taxi drivers mentioned the needs of elderly people or persons with physical disabilities which make up a significant proportion of their passengers and regular customers.

> *"We have to go up sometimes, sixth floor. Need to help bring a patient or elderly person down. There must be a taxi driver. Cannot be abolished completely." (T04)*

T05 reports similar experiences with this clientele:

> *"Taxi is a special industry where the driver is 100% needed. For example, when loading suitcases, helping people who need help, bringing seats to the front and so on. Helping people get in and fasten their seat belts. Some passengers have rollators, wheelchairs." (T05)*

These customers need support when walking and climbing stairs, so that the drivers pick them up at their front door and accompany and support them all the way to the car. The assistance ranges from helping to get in and out of the car, store bulky objects such as wheelchairs, walkers or luggage for them in the vehicle or running out errands for their customers. T11 also explains he has customers who need additional support:

> *"I have regular customers who can't do it alone. They can't drive to the doctor with an autonomous vehicle because they can't get into a car on their own. They don't come down the stairs alone, they don't get their shopping bags carried alone. Nobody folds*

the walker when it is an autonomous vehicle. Yes, so there will always be a segment where this support is present." (T11)

He refers to some activities that in his opinion autonomous vehicles would not be able to conduct. However, this statement refers to a specific customer *"segment":* people requiring assistance. T18 also sees some disadvantages in transporting this clientele in need of help, as these orders require ("*incredibly*") more time to be spent without any extra compensation for this time and service. Yet he explains, that these services are inseparably linked to the profession of taxi driver:

"It takes an incredibly long time for them to come. You ring the bell, many have no elevator, have to come down the stairs – you can understand it all, that's, one day it happens to us too, we will also depend on others for help – they come with their rollator, very heavy, so you take a little time, take them by the hand, take them to the car, some also need help to fasten the seat belt. But that's just part of it. Sometimes you have to have nerves for such things." (T18)

For this segment of customers, such situations where supportive services are demanded occur regularly. More than that, the close interactions he mentioned *("takes them by the hand"* when the situation demands it; fasten the seatbelt, etc.) are not mere optional services, but central requirements for those customers. Hence, the example shows that taxi driving is a service business rather than merely a chauffeur business, and that taxi driver like T18 are well aware of that fact. Like T18, other taxi drivers are also very service-oriented. For them, it is a matter of course that they take their customers' wishes and needs into account. T19 runs a third-generation taxi family business and attaches great importance to customer satisfaction:

"(...) taxi is a service business. Service means I open the door for the passenger, I ask if I can help, and if there is a little old mother, it goes without saying that I bring the bags at least to the front door. Or if we bring ladies home in the dark at night, it goes without saying that I wait in front of the door. I wait until she is through the door." (T19)

He not only helps elderly people and brings their bags to their front door without being asked to. If he drives women home in the evening or at night, he waits until the women have arrived safely in their apartment before he drives to his next customer. He points out that some customers are particularly happy about this help and attention, show their gratitude which is *"reflected in the tip"* and he emphasizes that this service orientation is decreasing more and more with other colleagues.

Furthermore, taxi drivers also see communication as an important topic. Some passengers cannot articulate themselves clearly, either because they don't speak the language, or because they are permanently or temporarily disabled (e.g. because they are drunk), which makes it difficult for the taxi driver to find out what the taxi customer's destination is. T01 already had customers who just held out a note with the customer's destination on it:

> *"There are guests who can't speak and only have a note that says where they want to go." (T01)*

Today's taxi drivers react to this problem: They interact closely with their customers, often already knowing the destination of frequent passengers from memory. Communication with customers also plays an important role in other respects: In addition to knowledge of location and routes, customers also rely on the drivers' knowledge of other infrastructure-related tips, such as restaurants or specialized clinics and doctors:

> *"Some people come: 'I need a good doctor for this or that', and then we know that this clinic is specialized for that, and that clinic is specialized for that. The very fact that you give the impression of giving information often makes them feel better. Or words of consolation, we sometimes drive mourners, or I don't know. Even if the content is completely irrelevant or just empty words, but if the passenger feels good, that's basically the goal. That he says: 'Geez, taxi driving in Cologne – the taxi driver was nice'." (T19)*

T19 has the impression that it is not so important for customers that what is said is meaningful, but that *"the impression of giving information makes [the customers] feel better."* Rather, in some situations it is more about the driver radiating competence or sometimes also acting as an interlocutor, listener or comforting person. T13 also sums up these functions as follows: *"[A] taxi driver is sometimes like a psychologist."* For T19, being there for customers on an emotional level too, so that customers can pour out their hearts, is an important part of the overall service. He wants his customers to leave the taxi in better shape than they entered it. This is illustrated by T19's the statement *"if the passenger feels good, that's basically the goal,"* making it clear again that one of his job goals is to satisfy his customers.

Two taxi drivers do not use a taxi dispatch service or an e-hailing app but place themselves in busy locations such as train stations and mainly serve walk-in customers (T16, T17). Although they also report on occasional trips in which they have to help older passengers carry and stow their shopping and help them get in the car, their clientele consists mainly of mobile, rather young passengers, often business customers, who travel with little luggage and therefore do not need any additional support and services around the trip. In this respect, they describe their regular trips as exactly those that could simply be replaced by SAVs.

> *"I guess the problem is a lot of people just look at the price. And if the car drives by itself and is – so autonomous taxis will be considerably cheaper than taxis where someone is sitting in it, that's clear – maybe half the price. Yes, and the business customers and the young people anyway. They will take their app and order the thing and ... I don't think taxi drivers will die out, there will be a lot less use, I guess." (T17)*

T17 thus describes that his customers are very price-sensitive, especially his business and young costumers, and as he expects autonomous taxis to be able to offer their services much cheaper than human-driven taxis, causing a substantial amount of taxi drivers not to be needed in that future. Confronted with this scenario, they see their future tasks primarily in vehicle maintenance such as cleaning and reconditioning the vehicle for customers.

T09 thinks that AVs may be able to replace traditional taxis, and she becomes particularly concerned when she thinks of her young passengers:

> *"They are all just texting and looking at their smartphones. There are no more nice conversations. Then we won't need a taxi anymore. Do we?" (T09)*

She describes that the interaction with many young customers is minimal. Just like the customers of T16, her customers often neither ask for support e.g. for stowing objects is necessary, nor do they linger for conversations. As she is not using a taxi app, there is still a verbal exchange to communicate the destination and to process the payment. If this type of customer is now served by taxis that have a taxi app that is capable of placing orders, determining destinations as well as payment, no interaction with the driver is required, in fact the driver then is only needed for the driving itself. For others, though, that may not be the case.

Thus, the taxi drivers agree that there will still be human drivers in the future, as there is a substantial proportion of their customers who are in need of assistance with taking a ride. Such assistance ranges from walking customers from or to the taxi, over helping them enter the car and prepare them for the ride, storing luggage or walkers, giving personal advices and social comfort, to communication problems. However, taxi drivers do consider the probability high, that their rather young, fit and cost-sensitive customers will prefer SAVs in the future.

10.5 Discussion

Our study expands the discussion on the future of the gig economy in the mobility sector by analyzing the perspective of taxi drivers on SAVs as well as on innovations in the field of mobility apps and services as a mean to approach the effects of a future with AVs on their working lives. Additionally, we highlight the role of the specific local context for designing successful mobility services as proposed by Raval and Dourish [432]. Although some studies show the danger of the gig economy and SAVs for the taxi industry, our participants expressed that they are not afraid of said innovations. Their reasoning is not only based on the specific regulatory situation in Germany, which has so far protected the taxi drivers' profession through existing regulations, but also on their work experiences and additional services they provide for their customers – a clientele that substantially differs from TNC app users. Consequently the taxi drivers report of social and physical interaction that goes beyond the need for social bonding that has been worked out in gig economy research [17,20,205,270,326,432]. These aspects are important to consider in the context of informing the design of new mobility services such as SAVs [156,205], and provide an interesting contrast to existing studies in other, maybe less regulated and protected markets.

10.5.1 Adapted Work Practices in the Age of Shared Autonomous Vehicles

Although apps such as Uber have been banned in Germany, the traditional taxi industry is developing towards a gig economy. Our study revealed that even though Germany represents a specific case, with a stronger regulated market, characterized by taxi drivers being permanently employed in taxi companies, being paid by the hour, and communicating with each other in person, liberating technology has taken its tolls. Nowadays, it can be observed that more and more employed taxi drivers are using new technologies, which turn out to be a "two-edged sword." While apps provide drivers with more autonomy and increased service quality, they also come with drawbacks, such asbeing paid by turnover, i.e. carrying similar risks to the self-employed. Further, technology is also responsible for an perceived decrease of personal exchange and feelings of togetherness among taxi drivers [187]. These issues have also been noticed in the gig economy [11]. In the following, we will go into more detail about the changes and developments in the taxi industry on the backdrop of trends seen in the gig economy. Especially we want to outline possible futures of the taxi industry based on future technological innovations, such as self-driving technology.

10.5.1.1 The Impact of Recent Technological Innovation in the Taxi Industry

The results we present emphasize a growing mismatch between traditional service structures (client, dispatcher, driver) and new informal practices that are enabled by mobile tools. With the introduction and widespread use of e-hailing apps and TNCs, further (central) changes are taking place for the taxi industry. By ordering a taxi via an app, the taxi driver and the customer are connected directly, and the customer can easily be picked up by the driver at the location indicated in the app. This function eliminates the need for the customer to search for nearby taxis thereby changing the way taxi services operate fundamentally, especially with regard to spontaneous trips. In the past, central stopping places such as airports, train stations, bus stops or event locations were set up which may only be used by licensed taxi drivers in order to simplify this (analogue) search. So far, these stops have represented a structural advantage for taxi drivers over competitors such as hired cars with drivers or private non-licensed drivers (e.g. Uber drivers), as the drivers meet a high demand at these locations, and thus are protected from the before mentioned competitors.

Yet, this structural advantage loses importance due to the presence of e-hailing apps and TNC apps. With an increasing convenience and usage of these apps, it is less important to be available at points of high demand, but instead be available within the different apps to reach out to potential customers at any location. Even at official taxi stops, e.g. at the airport, taxi drivers who use an app have an advantage: Generally, taxi drivers have to line up at the stopping places and have to wait their turn for a job. If, however, a taxi driver receives a direct order via an app, he or she can pick up the customer directly at the agreed location, thus he or she may receive an order faster than his or her waiting colleagues, as e.g. T01 explained. In addition, their advantage of exclusive use of official taxi ranks is also reduced by the fact that TNC drivers regularly undermine these rules [432].

The introduction of e-hailing apps has consequently increased the transparency of the market in terms of available taxis and potential passengers, enabling drivers to get aware of customers that they would have missed through the standard dispatch service. This shift in power from the dispatcher to the drivers themselves is making taxi drivers operating more independently since processes such as coordination, localization of passengers and payment can be carried out by themselves using the apps. As a consequence, some taxi driver, such as T02 and T10, have quit their taxi dispatcher membership and only use taxi apps and place themselves in busy areas. Acting as an intermediary, bringing together demand and supply in a bundled way, was classically one of the most important functions of taxi dispatchers. Yet, this intermediary role is exactly the kind of function that is suitable for being represented by e-hailing apps and has also informed the development of apps in the taxi industry [137]. However, the tasks of taxi dispatchers go far beyond simply arranging trips: they take over negotiations with health insurance companies, accounting for patient trips and advance the driver's travel expenses, which gives those a liquidity advantage, as e.g. T19 has referred to. In addition, they deal with municipalities and authorities when it comes to organizing major events and coordinate the use of taxis if individual taxi drivers or taxi operators do not offer their services around the clock. Such representative tasks are clearly less prominent in the gig economy [192,359] making it hard for i.e. Uber drivers to unite [11].

Particularly the work of those drivers who now almost exclusively receive their driving orders via a taxi app is very similar to the work within the gig economy: they receive the driving orders – the gigs – via smartphone and don’ t necessarily need to go to common taxi stands. Due to the similar app functions, these drivers are also rated by the passengers via a reputation system. As a result, some drivers have increasingly recognized the importance of service orientation and are investing in emotional labor. As such, these findings are in line with insights from HCI research in the sharing economy [205,326,432].

Although the degree of flexibility and autonomy of taxi drivers increases through the use of e-hailing apps, it does not fully match the degree of flexibility and autonomy achieved in the gig economy. The reasons for this are the rules imposed by the taxi regulation, firstly the obligation to carry (although an Uber driver at least feels a pressure to carry, as she or he has to expect a negative evaluation or even account deactivation when refusing trips [305]), and secondly the obligation to regularly operate – while in contrast an Uber driver can decide freely not to offer any trips for a while.

So far, there is still a lively social exchange between the taxi drivers, especially when waiting at taxi stands. Although the drivers are basically in competition with each other, there is a collegial relationship. In contrast to what is usual in many gig economies, the contractors (taxi drivers) know each other, also due to the local proximity to each other. However, as e.g. T06 described, the increasing elimination of waiting times at taxi stands through the use of apps leads to less interaction between the drivers, and thus possibly leads to alienation and increased anonymity.

10.5.1.2 Anticipated Impact of Autonomous Vehicles in the Taxi Industry

With a view to the further development of the gig economy, the influence of automation is controversially discussed. Many experts and scientists make the claim that taxi drivers are no longer needed in the age of autonomous vehicles [10,116,328,571]. This argument often stands on its own in studies on future mobility. So far, a deeper and more differentiated examination and discussion about the role of taxi drivers in the age of autonomous cars is lacking. These experts consider taxi trips to be work that could be automated particularly well, since they are often commoditized and not particularly differentiated [311]. However, our participants strongly argue against this description of their profession. In fact, the taxi drivers reported personal experiences from their everyday professional life, demonstrating in what respect they consider the human driver to be indispensable. They describe different situations that occur regularly, in which they need to interact closely with their customers – not only in terms of communication and service but also physically. Social competence and service orientation play a decisive role in this context. Especially on the backdrop of studies focusing on autonomous vehicles, that render the profession of taxi drivers obsolete [e.g., 5], the view of the taxi drivers provides a more nuanced assessment and explains their opposing opinions.

Our drivers highlight that their profession will rather transform with regards to its core focus and work practice. Although many studies predict that the trip demand could be met by fewer and therefore more efficient SAVs in the future [66,308,515], and although many taxi drivers consider SAVs to be generally feasible, they are convinced that their jobs will not be replaced by automation. The respondents expressed that their job would entail more than the driving itself, highlighting other aspects such as the trust of their clients as well as the provision of additional services accompanying the transportation that AVs and to certain extent even existing TNCs would not be able to provide [75,352,397]. In fact, they described to be largely dealing with a loyal clientele, which regularly requests a service from taxi drivers that goes beyond transport from A to B. As those customers specifically appreciate the physical assistance and social contact, our drivers expected these customers to be reluctant to changing the mode of transportation.

While previous studies have already identified the importance of the aforementioned social connection between driver and passenger [17,270,432], and emphasized the importance of emotional labor [20,205,326,333,432], our study highlights how this emotional labor extends to additional, not-transport-related tasks that are required when dealing with certain customer groups, e.g. with physical or age-related impairments which leave those unable to physically perform certain activities. Talking to traditional taxi drivers whose clientele differs significantly from that of TNCs made us understand this important difference and the need for additional services and the involved emotional labor to inform the design of new tools and services in the taxi market following the emergence of the envisioned SAVs. So far, special needs have not yet been discussed in recent studies regarding SAV. For example, Kim et al. [279], conducted a Wizard of Oz study and have drawn up the customer journey of a taxi customer in detail. They identified which touch points should be considered in the transition to autonomous taxis. However, their customer journey did not cover supportive services as outlined by our taxi drivers and have therefore not been addressed by the authors. As our investigation shows, these are important aspects to consider in the design of SAVs and supportive service models [5,75,352,397].

Even though it is justifiable that in the longer term the so far loyal clientele could be replaced by a cohort that is more open and used to self-service models such as SAVs [296], it is an open question if the loyal clientele’s preferences will prevail in the future, i.e. if these preferences are due to a cohort or e.g. an age-related effect. Based on our findings, we therefore argue to consider both options and suggest that it is likely that the taxi business will be differentiated into a personal-service infrastructure and a self-service infrastructure [571], as i.e. T04 suggested or T11 described implicitly. Consequently, future design research should consider both forms equally.

The personal-service infrastructure will then address special target groups and cover trips such as patient trips or trips where the passenger requires special individual support or physical assistance, e. g., if he or she is carrying luggage, or if he or she needs help with getting in and out of the vehicle or if social interaction plays a special role. This part of the taxi industry requires a very close interaction between passenger and taxi driver, flexible support as well as social skills, as i.e. T05 or T18 have pointed out (section 10.4.3.2). In this segment, taxi drivers might have a long-term right to exist. However, the activity of driving will become less and less important, while at the same time the demands for customer and service orientation will continue to rise – also against the background of ageing societies. Thus, based on the data we gathered, it is reasonable to expect a change in task priorities within the taxi industry, focused on assisting and social tasks turning the former taxi driver into a taxi trip attendant or trip steward. This kind of change in working practices will certainly only be of interest to taxi drivers who already enjoy the social part of their work and who have a strong service orientation, such as T19. Those drivers, who like their job mainly because of the driving task, will not be satisfied with this kind of change. In the argumentation of the taxi drivers regarding their right to exist, it is very interesting that they always equate the role of the assistant with the role of the driver. Nowadays, of course, these two roles are inseparable. In the future, when one role – namely that of the driver – becomes obsolete, the role of the assistant could be taken over by someone else, for example a nurse for the elderly or a nurse for the sick. The self-service infrastructure, on the other hand, is particularly suitable for trips that can be standardized and carried out without fulfilling special requirements, and whenever lower prices or special circumstances (such as trips between remote locations that are not well serviced with classic means of transportation) make such offers more viable [317]. For instance, T09 has outlined, how little importance young customers attach to interaction or communication with taxi drivers, and T17 has described that business customers and young costumers in particular act very autonomously and even today make very little use of taxi driver services such as helping with luggage. No human driver will be needed for the execution of these journeys. Analogous to the user groups of taxi apps and TNC apps, one could assume that the target group for these trips will probably consist of rather young, pragmatically thinking, digitally affine and mobile users who do not attach any importance to the individual care by a person replacing the driver (just as T17 predicts).

Trying to forecast the market shares of the two services is certainly difficult and of course highly speculative. The current figures for taxi journeys (section 10.2.1) can only provide an indication. In particular, journeys for medical reasons (12%) are among the journeys that are likely to require human assistance. In addition, the journeys in which goods and objects are transported (2%) and minor parts of the remaining journeys in which passengers wish to be assisted by a human driver may also be counted. That leaves the conclusion that in the age of AVs, only a small fraction of today's workforce would be needed to travel in the taxis and accompany the passengers.

For those drivers who are less engaged in the social aspect of their work, other professions could emerge. As suggested by T16 and T17, for example, their future role could focus on car care and maintenance. This could be interesting for those drivers who generally like to work with cars and are more interested in the technical part of the job. For some self-employed drivers, it might be particularly interesting to coordinate their own fleet of SAVs and take more care of the business aspects of taxi driving, including billing and marketing. Taking into account the impact of e-hailing apps, one could argue, this would be in line with the previously seen extension of autonomy (and liberation from dispatchers) provided by e-hailing apps. For other drivers, who especially like the driving task and the coordination of trips and routing, it could be exciting to work as a teleoperator. A teleoperator is a person who remotely controls one or several (semi-)automated vehicles [378]. Currently, the potential of teleoperating (semi-)automated vehicles is well being tested with regard to its technological feasibility [252,379,482]. Especially in the transitional phase, when SAVs need remote control in case of problems or blockages, drivers could use their valuable knowledge of maneuvering alternative routes or shortcuts.

10.5.2 Context matters: Legal, Cultural, and Social Factors

It is noteworthy how few taxi drivers regard an internationally successful business model such as Uber as a threat (i.e., T06, T09, T14). Especially since taxi drivers refer to the protectivist and regulated system in Germany on the hand but observe a shift to less regulated work practices.

In contrast to TNCs, the example of regulation-compliant e-hailing apps such as MyTaxi show how the socio-cultural conditions in a country can be successfully dealt with. MyTaxi, one of the market-leading taxi apps in Europe, is an application that nowadays offers the same functional concept as Uber concerning the matching of driver and passenger, live tracking and interaction with the driver, payment, reviews, etc. This app has – in contrast to Uber – taken the regulatory framework as well as prevailing rules, values and practices into account and successfully integrated it into their business model. As a result, in Germany, taxi drivers find the use of legal taxi apps enriching as they give them greater flexibility and autonomy. Although taxi drivers have to take on new tasks in coordinating driving, their dependence on regional dispatching is reduced by the use of the apps. This is in stark contrast to markets with little or no regulation, such as India, where the Ola app has changed existing practices and consequently limited the flexibility and autonomy of drivers [589]. Thus, while taxi apps enable drivers in highly regulated countries, they have a restrictive effect in less regulated markets.

We draw the conclusion that the legal and cultural context matters for the success of a business model and/or technological disruptions. The failure of Uber in connection with the simultaneous success of myTaxi, which promotes similar work practices but takes into account existing legal and power structures, suggests a more contextualized or staged introduction of technology [447], thereby emphasizing that "interaction is no longer at the center, but is one aspect among many" [299] even when it comes to potentially disruptive innovations. Studies on the adoption of new mobility services such as Uber have so far been strongly influenced by an Anglo-American perspective [272], but have hardly reflected the socio-economical context in which those innovations have been implemented. In the case of Uber in the USA, the situation could be characterized by a liberal market economy, which allows new companies to operate in a partially unregulated and less protectivist market. While strict regulations apply regarding the number of concessions and the suitability of potential taxi drivers, competing services such as Lyft or Uber can operate legally in the USA, respectively Ola in India, in contrast to Europe. In this respect, it is not just the regulation but also a question of representation and organization. In Germany, unions play a major role, representing the taxi driver community and negotiating with policy makers when there are changes in the market. Thus, the German unions and interest groups repeatedly lodged complaints against different TNC thereby putting pressure on the European Court of Justice to reach a decision. As a result, UberPop's service with private drivers was defined as a transport service and thus equated with taxi services. And also with its other divisions UberX and UberBlack, Uber still did not submit to regulation in the same way as taxis have to in Germany. The result is a renewed ban on the ride brokerage in Germany. In our case, the strong employee protection, that is encultured in the German labor market, successfully prevented new TNCs to take hold in Germany without considering those who are affected by the new services directly or indirectly. As a consequence, drivers such as T01, T04 and T09 indicated, they feel strengthened and protected by German laws, unions and dispatch services.

In addition to legal and cultural factors, social structures are of particular relevance for the successful implementation of a business model. As the taxi drivers have reported, their clientele is characterized by regular customers and also by those customers who not only need social interaction but also physical support to complete the taxi ride. Especially the latter customers do not seem to belong to the clientele of TNC apps and e-hailing apps, so that their needs were not reflected in the previous studies on the gig economy.

Regarding mobility services based on SAVs, then, it is crucial for such service infrastructure to be embedded in the respective country-specific regulatory framework and align services with the interest of affected stakeholders. As the regulatory framework sets out who could be the operator of such an SAV fleet, taxi drivers or dispatchers may be the ones who will be (legally) responsible of managing AV-fleets, further shifting their role to new tasks. On the other hand there might also be a free, unregulated market in which everyone can operate his or her own SAV [337].

10.6 Implications for Design

From the conversations with taxi drivers we learned that the profession of taxi driver has evolved and consists of more than just driving. The job also encompasses logistical as well as communicative tasks and often enough also requires empathy and other social skills. Those supplementary services are unlikely to be replaced by technology as they are situated, customer-specific and thereby in continuous flux. For exactly that reason, these supplementary services could provide new business opportunities for taxi drivers even when AVs become fully available. On the other hand, there is a specific share of rides where the utilitarian aspect of getting from A to B matters most.

At this point it is important to highlight that from the taxi drivers' perspective the adoption of technology in the German taxi industry especially streamlined coordination tasks and made finding customers or drivers for both parties respectively more flexible. Yet, by doing so the supplementary services provided by drivers have gotten out of the picture, which not only influenced the relation between driver and passenger but extended to the interactions between drivers as well.

In summary, regarding the design of future mobility services, we suggest considering these two aspects: 1) Design of utilitarian interaction with SAVs and 2) Design of supportive services and social exchange.

10.6.1 Design of Utilitarian Interaction with Autonomous Vehicles

If we consider the following insights, (1.) that all organizational activities such as ordering, destination determination and payment can be handled through an app, (2.) that some passengers do not require supportive services or other interactions with the driver, and (3.) that in the future vehicles may be able to operate automatically, we conclude that this particular group of passengers can be well served by SAVs in a self-service infrastructure. To perform the pure driving task, no further requirements need to be placed on SAVs apart from the functional self-driving car technology.

This is quite different to a future in which SAVs will replace *all* taxi drivers and trips – even those trips with passengers that nowadays need the assistance as described by the taxi drivers.

High demands will be placed on the design of SAVs. SAVs must then not only support the standardized self-service trips, as i.e. recently worked out by Kim et al. [279], but also the value-added services in the personal-service infrastructure. Communication must be possible exclusively via the vehicle and its technology. It is indeed the case that today all relevant data for the transport of a passenger can already be transmitted to the driver via app, especially concerning the starting point and destination of the trip. In this respect, this seems to be easy to implement also for SAVs. However, as soon as the passenger has entered the vehicle, there is usually a verbal exchange and comparison of the information, even in the case of trips organized via an app. T01, for example, reported experiences with passengers who used notes to communicate their destination because they could not communicate in any other way. Unfortunately, we cannot reconstruct these situations to find out whether these people deliberately sought to communicate with a human driver instead of transmitting their journey request via app. All we know is they chose this way. For those people who cannot articulate correctly, the system must therefore be able to explore the customer's destination with the help of stored data or offer other forms of communication such as voice commands and touch displays that i.e. mirror information as seen in the app, as also proposed by Brewer and Kameswaran [76].

To make the taxi driver completely redundant, additional logistical services that the drivers would otherwise have taken over would have to be able to be carried out automatically by the vehicles. This requires, for example, support to load and unload the vehicle (e.g. shopping baskets and rollators) or to assist passengers getting in and out of the vehicle. These possibilities could be realized by ramps or chairlifts. In addition, SAVs would also have to offer the possibility of automatic seatbelt fastening and securing of passengers in order to serve the needy customer clientele described by taxi drivers.

The realization of such assistance represents a major challenge as soon as in particular the physical assistance required exceeds the normal level and as the technical system of the vehicle must be compatible with the environmental systems. In this regard, it is questionable if such transportation services are in competition to traditional taxi services or represent an advancement of public transportation. As long as technology cannot map these value-added services, the profession of taxi driver will continue to exist – even if in the age of AVs his profession may develop in the direction of a taxi trip attendant. This especially holds true for the trips that were routinely ordered. Many of the contextual information (e.g. pick-up location or which doctor etc.) are taken into account by the taxi drivers automatically and are central to their customer relation.

10.6.2 Design of Supportive Services and Social Exchange

Our study revealed a critical issue regarding the evolvement of taxi drivers' tasks. The introduction of e-hailing apps or more ICT-supported coordination in general caused a decrease in social interaction, as e.g. phone calls to order a ride became obsolete (i.e., T09). While this kind of interaction is accepted by younger customers for standard trips and resembles themes known from other areas of the gig economy [496], our interviewees emphasized the crucial nature of supplementary services for specific situations or individual needs.

Taking their arguments seriously, new transportation service applications could focus on extending the services provided by taxi drivers, moving the focus away from the organization of routes and trips to include further service offers that are tailored to special needs. As literature (2.1) and empirical data have shown, taxi trips can be classified according to types of people or trip purposes. New apps could support such a distinction by client and by driving purpose [102,501]. If the application passes on the type of customer, whether he or she is mobile, physically or communicatively restricted or ill, the taxi driver can prepare his services accordingly and adapt them to his next customer.

At present, patient trips are among those that cannot be automatically coordinated and executed with the currently available technologies and applications. Patient trips still offer room for design, particularly regarding the tasks that are currently provided by the dispatchers. Patient trips could, for example, be coordinated and billed directly between the health insurance company, hospital, customer and driver via an ICT enabled application. If the patient passes on special requirements via the application, the taxi driver can equip the vehicle accordingly before starting the journey; she or he can adjust the seats or the temperature in the vehicle.

If the application supports the transmission of the purpose of the journey, the driver can offer his customers special experiences and thus increase his customer loyalty. If a customer orders a taxi for a trip to a party, the number of people, requests for food and drinks could be transmitted via an app. The driver can then equip his vehicle with snacks or sparkling wine, for example, in order to generate additional income.

In this regard, we see that there could be specialized AVs that would provide exactly those services. Yet our study showed that drivers nevertheless shift their core tasks and take over new responsibilities, thereby slowly advancing the mobility services by providing a better experience to the passenger. Even though the introduction of taxi apps had smaller effects in Germany, a change in the work culture was clearly articulated. As a consequence of the direct customer-driver-communication the social bonding between taxi drivers decreased. Especially younger drivers focus more strongly on the logistical task at hand.

Many of these services, such as equipping the vehicle with snacks, adjusting the seats or regulating the temperature, could undoubtedly also be performed automatically by SAVs. It is possible, however, that for some customers it may be a kind of luxury to have a human companion while driving, or that companies may offer their customers the special service of a human attendant, as is the case with elevators in hotels, for example.

10.6.3 Enriching Design through Workers Participation

Taking a step back, what our study also shows is that there are opportunities for HCI research to make a positive impact even on rather technologically-driven innovations such as SAVs. As our research shows, giving drivers a voice as people that are affected or at least threatened by the repercussions of automation of their work can open up interesting implications for the design of better workplaces.

The findings of our study can be interpreted in different ways: on the positive side, it shows that even with advances in automation, the need for having human workers will be further required at least with regard to specific tasks that exceed the mere driving of a vehicle. On the negative side, one could ask though what it will do to the taxi drivers jobs if their work changes in this way, reducing their role to that of an assistant (in the sense of a traditional “doorman”), surely affecting their level of autonomy and work satisfaction. As with other gig economy jobs, the question is who benefits and remains in control of the work: the taxi drivers, or a platform service provider.

Giving taxi drivers a voice in the design of new mobility services thus opens up opportunities for shaping said systems in a way that is more positive for the involved workers, asking questions on how automation can be done in a way that strengthens the role of the workers and not takes away their agency. Engaging with the taxi driver workforce here brings a highly valuable perspective, where coordination, logistics and communication are key to the experiences surrounding taxis. How can taxi drivers be part of the service design of either “self-service” or “personal-service” infrastructures? What are the impacts on the service when there are no people, and does this really matter? And what are the social elements of this type of work, and how can it be supported in a positive way for workers? And if thus changes are implemented, how can we make sure that new types of work provide the same level of satisfaction, or at least preserve the autonomy of the people that are most affected by this type of change. Answering these questions is out of scope for our study, but we think that our findings provide ample insights into opportunities for design, and thus provides first steps towards the design of a more positive future of mobility.

10.7 Limitations and Future Research

The selection of study participants is certainly a limiting factor that determines the generalizability of the results. However, we have tried to select taxi drivers in such a way that they well represent the diversity and composition of taxi drivers in Germany. Contextual qualitative work can contribute in significant ways in HCI, even when grounded in a particular context as it is the case with the study at hand. Further, the region and circumstances addressed in this study are comparable to other metropolitan areas across Europe which make our findings transferable to some extent.

Another limitation is how we tackled the topic of autonomous driving in this study. As we at most provided general information about autonomous driving, pilot projects, or market introduction announcements during the qualitative interviews, the answers of the participants refer very much to their limited knowledge and imagination. Basically, the question of the threat of autonomous driving serves here as a motivation to talk about why or why not autonomous driving is a danger to their profession. From our point of view, it is not absolutely necessary for the participants to have a detailed picture of the technical possibilities of autonomous driving in order to talk about how they as a human being are advantageous to a robot. Nevertheless, this methodological aspect must of course be taken into account when reviewing the results.

In view of the narrow focus of our study and the specific framework conditions, we wish future research to conduct contrasting studies with additional drivers. It would be particularly interesting to include drivers from countries where business models like Uber are already working very successfully. From them one might be able to learn whether and how they position themselves, or what assistance they offer to passengers. In addition to this, further research into specific stakeholders will be needed to get a more detailed picture. For instance, by including other professional taxi drivers, or assistance drivers, we could enrich the picture that we have drawn in this article. As we have also worked out, dispatchers are particularly affected by recent IT-driven changes. It is of particular interest to investigate the future role of dispatchers within the taxi industry and what their stance on SAVs might be. Analyzing their tasks and working practices could as well inform the design of future applications and business models. Further, we have now discussed the perspective of professional taxi drivers and the risk of them becoming obsolete in the age of AVs. However, it will for sure be the customers who will decide between human-driven taxi or automated taxi in the end. Thus, including taxi customers into the analysis is necessary. While many studies have researched taxi und TNC customers in HCI, they have as well not yet discussed the customers preferences in the light of autonomous driving. Investigating customers should thereby cover the range of taxi customers including business customers, healthy customers, but also those with special needs such as patients or elderly [501] and possibly also other service providers such as from the field of care giving. This is in line with recent calls to practice-based research [582] towards a more open, ethically, socially and legally circumspect design practice, which has recently been suggested in other domains and would also be important to consider in the design research on automation in mobility [313].

10.8 Conclusion

Worldwide the gig economy is disrupting the traditional taxi industry [21,27,191,515]. These rather undifferentiated and commoditized jobs are most likely to be automated over time, performed by automated vehicles as some experts predict [311]. Simulations of shared autonomous vehicle (SAV) fleets have shown that the profession of taxi driver could become obsolete in the future [93,95,179,337,492]. The aim of our study was to shed light on the perceptions of taxi drivers towards future forms of mobility such as SAVs to extend the discussion on the future of the gig economy and to whether the profession of taxi driver really becomes obsolete with the advent of autonomous vehicles or how it might adapt in response. For doing so, we interviewed taxi drivers who have so far been underrepresented in the ongoing discourse and who have not actively been involved in research of such innovations in the area of novel mobility concepts – especially in the discussion about SAVs. Since taxi drivers cannot base their views on actual observations, as SAVs are not yet ready for the market, we have expanded the discussion to include the influence of current innovations in the area of mobility apps and services on the drivers' job to approach the topic of the impact of emerging technologies from several perspectives.

Results show that the drivers are already emancipating themselves more and more from regional taxi dispatchers, as e-hailing apps enable them to plan and manage their own travel services. With their common functions (searching, booking, tracking, communicating, paying, rating) current taxi apps support the standard trips from A to B. However, the taxi drivers described that taxi driving exceeds transporting people from A to B, implying opportunities around the support of the social and physical interaction between taxis drivers and passengers in this area.

Since standard trips without required physical assistance or social interaction make up most of the trips, the design of today's apps concentrates on these trips and aligned their functions accordingly. Thus, these needs for supportive services have not yet been met by the design for taxi apps and TNCs. Research on the design of SAVs is also mainly informed by participants who correspond to the clientele of TNCs and taxi apps [279,503], but not to the full clientele of traditional taxi drivers. Thus, it seems reasonable that special trips including additional supportive services that go beyond pure transportation will not be in the core focus in the design of SAV services but that SAVs might rather be designed for standard trips supporting merely getting from A to B. In this respect, our study has shown how important it is to consider taxi drivers in the codesign of future taxis and SAV services. They have tacit and valuable experience and knowledge which, without their involvement, would not be taken into account in the design of future technologies, resulting in disadvantages, especially for vulnerable groups such as the elderly, ill or impaired. Our insights thus open up novel perspectives on the role of physical assistance and social interaction as well as the role of the specific legal and cultural context in which they operate.

Further, our study provides a more differentiated perspective on the potential impacts of SAVs on the transportation sector than former studies that suggest that with the advent of AVs professional drivers will become obsolete [93,179,492,571]. Our results suggest that although many customers could be served with unmanned SAVs, certain customer groups are dependent on human support. Consequently, a division of the market between manned autonomous taxis serving a service-oriented infrastructure and driverless taxis that are aimed at such customers that prefer a self-service infrastructure can be expected, which goes in line with suggestions of some researchers [317,571]. The latter types of journeys currently make up the largest portion of taxi journeys, which shows that even if the profession will not become obsolete, a large proportion of the jobs will be eliminated. Our study has shown that working with those whose work is being disrupted can help to better build systems or services in a responsible way, keeping in mind the workers themselves as their work shifts or becomes obsolete.

11 STUDY 7: TRADITIONAL TAXIS VS. AUTOMATED TAXIS – DOES THE DRIVER MATTER FOR MILLENNIALS?

It is anticipated that autonomous vehicles will have a huge impact on the creation of sustainable smart cities and communities. One of the key concerns regarding autonomous vehicles is how automation may threaten jobs in the transport industry, including the traditional role of taxi drivers. To begin to explore how important an actual taxi driver is to customers and the extent to which they might be happy to have autonomous taxis replace traditional taxis, we conducted qualitative interviews with 34 Millennial-aged participants. These were problem-centered narrative interviews, largely conducted face-to-face, and analyzed using thematic analysis. Millennials were focused upon because, given current figures and likely future projections of use, they form the key market for prospective future autonomous taxis. The results show that the kind of taxi rides Millennials make are particularly suitable for automated taxis because interaction with a human driver is not a high priority for this group, while the prospect of autonomous taxis being cheaper is. Meanwhile the fate of taxi drivers does not play a significant part in how Millennials reason about this. An incidental finding, here, is that, by offering a convenient and affordable alternative, the advent of automated taxis may also pose a threat to public transportation.

11.1 Introduction

In order to realize the visions associated with sustainable cities and communities, the future character of mobility is going to play an important role [408]. A controversial aspect of this that is currently receiving a lot of attention is autonomous driving. Its implementation could have far-reaching consequences for society, people’s mobility and the character of everyday life. While the consequences of this disruptive innovation are potentially far-reaching, they are also very difficult to anticipate because, not only is the technology evolving, but the behavior of users and citizens is also changing in parallel. Many positive outcomes are foreseen as a consequence of vehicle automation and the connected car. These include: increased road safety and fewer accidents through the elimination of human error [176,356]; the construction of lighter vehicles demanding fewer raw materials; improved traffic flow through the exchange of information and, as a result, better energy efficiency, fewer emissions and less noise [79,571]; and, for the passengers, a better or more efficient use of travel time [503]. Some experts are also convinced that automation will strengthen sharing economies and that people will use vehicles on demand instead of owning them permanently – which in turn could significantly reduce the overall number of vehicles on the road [492].

In addition to the various advantages, some experts also see risks in this new technology. These include, in particular, challenges relating to safety. Dependency on the technology may lead to system errors and it is uncertain whether AVs will be able to operate safely under any road and weather conditions [317]. Due to the need to collect and process user data to operate the cars, there are also security and privacy concerns. Vehicle networking may make cars vulnerable to hackers and cyberattacks [18]. Furthermore, the installation of driving automation systems will initially make cars much more expensive [317]. With regard to the ecological impact, some researchers fear rebound effects in the form of increased use of private transportation [402].

Whether autonomous driving will succeed will depend not least on user acceptance. User acceptance has recently been extensively researched and the results show that the intention to buy or use a fully automated vehicle is relatively high [42], even if users share the above concerns [300]. In addition, a large proportion of users are willing to pay an average surcharge of up to USD 7253 for a driving automation system [31,42].

In the spirit of all of this, imagine an automated on-demand vehicle that picks you up and takes you to your destination – an automated taxi without a human driver. Given that automated taxis are likely to be cheaper than taxis with drivers in the long term, it is evident that automation poses a major threat to professional taxi drivers. Indeed, many experts suggest that, in the age of automated vehicles, there will be no more professional drivers [134,317,571]. In order to find out whether this threat is realistic and whether consumers would actually prefer automated taxis to traditional taxis with taxi drivers, we conducted a qualitative study with 34 Millennials (the generation born between the early 1980s and the late 1990s [233]). By addressing so-called Millennials, we focus on a group of people who have grown up in a digital and connected world, who are untroubled by the use of innovative technologies, but who are not yet mature in terms of their mobility behavior [140,371]. This group constitutes about 41.8% of all taxi users in Germany. 40-59 year-olds account for 31.6%, and the over-60s about 26.8% [258]. Millennials, then, represent an important customer group for taxi businesses [197]. Given this background, we have sought to address the following questions:

1) *How important do Millennials think it is to have a human driver in their transportation services?*
2) *Will Millennials prefer autonomous taxis over traditional taxis?*

By addressing these questions, we contribute to a growing body of literature regarding the potential impact of (shared) autonomous vehicles (SAVs/AVs) on mobility behavior and the fate of affected stakeholders such as professional drivers.

11.2 Related Work

11.2.1 Millennials and Their Mobility Behavior

Since we focus in this paper on the important future user group of today's Millennials, we will outline in what respects it differs from previous generations. In this paper, we use the term Millennials to refer to those born between 1980 and 2000 [255,500], although definitions vary [479] with 1974 being the earliest starting age [36] and 2002 being the latest ending age [411,460].

Millennials differ fundamentally from their predecessor generations in terms of both consumer behavior and the demands they make regarding work and lifestyle [511]. They stay longer with their parents, either marry later or not at all, and are slower in setting up their own household. They are very well educated but have little political commitment. Yet they prefer a good work-life balance to a high salary. As Millennials are receptive to comfort and convenience, they appreciate and enjoy the benefits that the digital world offers them [58].

With regard to their mobility, Millennials use new services such as carsharing or ridesharing and use the mobile internet and various routing and ridehailing apps to find their way around in foreign environments more often than representatives of older generations [44,434,478]. In addition, the younger generation is on average fitter than the older generation, so they can move around and manage luggage more easily on their own. Thus, they are more prepared to consider different options than older people when choosing their means of transport [351,385]. To date, the car has been the most important means of transport in the mobility mix for Millennials [385]. However, as in many other developed countries [145], the number of young people in Germany who get a driver's license or buy a car has dropped in recent years, both in real numbers and as a proportion [291,293]. Thus, according to statistics from the Federal Statistical Office and the Federal Motor Transport Authority (KBA), 63.4% of 17-24-year-olds in Germany had a driving license in 2010 compared with 59.7% in 2019.

Shifts in patterns of work and education are another important reason for the change in the mobility behavior of Millennials. The number of young people studying after school has been rising steadily for some years now. While in 2001 the proportion of first-year university students in a generation was 36.1%, by 2018 it had risen to 55.9% [497]. This has had two effects. First, more young people do not earn money until later in life and thus postpone obtaining a driving license or buying a car [472]. Second, many first-year students move to cities, receive a cheap university student ticket for local public transport and do not need a car because of the better mobility opportunities in the cities [469]. In rural areas, the need for a car is still high, even for young people. It is also the case that car-related status and having an emotional connection to a car no longer feature in the same way in the reasoning of Millennials [166,340,487]. The proportion of people who use bicycles, public transport or multimodal transport is significantly higher among those under 29 than among older people [84,242,385].

With regard to taxi use, in all age groups taxis are predominantly used for private purposes. 88.7% among 20-39 year-olds, 85.1% among 40-59 year-olds, and 96.1% among the over 60s, use taxis for private trips. Young adults mainly use taxis for events and leisure activities (74% – for 40-59 year-olds the figure is 61.1%; for over 60s 37.1%). More occasionally they use them for trips to stations/airports, etc. (6.8%; 40-59 year-olds 12.2%; over 60s 17.2%). Unlike older generations, Millennials use taxis much less frequently for medical reasons (4.4%; 40-59 year-olds 8.4%; over 60s 25.9%) [258].

In a generational comparison, Millennials have already been found to be very open to autonomous driving and see it as offering advantages at both an individual and societal level [404,410]. Thus, as a specific user group, Millennials are particularly interesting to look at because they are comparatively likely to adapt their mobility behavior in response to the advent of innovations in the field of automated mobility on demand.

11.2.2 The Taxi Industry

Taxis are an important part of modern transportation systems for the public, in particular with regard to supporting opportunity-based mobility [226]. According to a survey on customer satisfaction with the taxi industry in Germany, the vast majority of customers use taxis for private journeys (90%) [258]. On these private trips, most taxi customers use cabs for getting to and from parties or events (53%). A smaller number use them to get to or from airports and train stations (14%), or for medical reasons (10%) [258]. Taxis are primarily turned to, then, in situations where customers cannot or do not want to drive themselves and there is little or no other choice [132]. A recent study of taxi customers also found that 77% of taxi trips happen in situations where no other means of transportation is available [258]. In Germany 27% of taxi customers are younger than 29, 14% are 30 to 39 years old, 16% are 40 to 49 years old, 15% are 50 to 50 years old, 11% are 60 to 69 years old and the remaining 15% are 70 or older. So almost twice as many people using taxis are under 29 as in any other age group.

The taxi industry is undergoing a worldwide transformation. New technologies have entered the industry, changing the activities of taxi drivers and putting them under pressure from new competition. Taxi drivers use navigation systems that support them in their journeys. E-hailing apps such as mytaxi connect customers directly with taxi drivers – without a classic taxi dispatcher. Customers can use such apps to request a taxi, make cashless payments and rate taxi drivers. At the same time, digitalization and the sharing economy have also created new, disruptive players such as Uber. In its best-known service, Uber brokers trips between private car drivers and customers. These trips are usually cheaper than classic taxi trips, so they have become serious competition for taxi drivers in many cities. A number of studies [66,309,515] have investigated how the market entry of transportation network companies (TNCs) like Uber affect the taxi industry. One study showed that, in San Francisco, the number of journeys by taxi decreased from January 2012 to July 2014 by about 65%, from about 1400 to about 500 per month. In many cities, taxi driver communities have joined forces to protest against those new forms of competition [182].

In the future, the threat to taxi drivers may come from another direction: the development of autonomous driving. With the introduction of AVs to the market, especially shared autonomous vehicles (SAVs), the taxi driver profession risks becoming obsolete [310,512,571]. This has been challenged by other experts, who claim that the professional driver`s role is vastly underestimated [120]. Taking a more differentiated view on the future development of the taxi industry, they suggest that the profession of taxi driver will only be redefined, not disappear completely with the advent of automated taxis [10,116,328,365]. It is conceivable that taxi driving with a human driver will develop into a luxury service – rather like chauffeur services today or that taxi drivers will focus on other niche markets [106,551]

11.2.3 Autonomous Driving and the Impact of Automated Taxis

According to the international standard for full automation (J3016), a vehicle is fully automated when the system dynamically and fully autonomously performs all aspects of the driving tasks under all roadway and environmental conditions without the need for a human driver [458]. Vehicle automation opens up new possibilities for private mobility and enables new ways of using sharing-based transportation concepts. Automated mobility on demand concepts suggest that driverless, automated taxis, will pick up their passengers, chauffeur them to their destination, and then drive on to the next customer [176,179,296,403]. In the literature, SAV is now an established term. However, in this paper we will use the terms automated taxi and SAV synonymously as often done in literature [93,287], even if they are not necessarily the same. The elimination of the driver, whose labor costs make up a large part of the operating costs [203], along with savings resulting from efficiency enhancements, will reduce the cost of such mobility services [95,177,179,236]. Currently, labor costs make up to 57% of the cost in New York [214], 54% in Berlin, Germany and up to 64% in larger taxi companies [295]. With a relatively low cost, and a higher level of convenience and service, automated taxis may be an affordable solution for customers. This alone may encourage a more rapid deployment of SAVs than would otherwise have been the case [400].

A few studies have already investigated people's willingness to adopt SAVs [296,594]. When asking if people would adopt self-driving technology and in what form, [253] found that people`s willingness to use self-driving cars as taxis was not high, with wealthier people being more willing to use a self-driving taxi than those with a lower income. Another study recently focused on SAV preferences and found that younger people with more multimodal travel patterns would be the typical profile of potential SAV users [296]. In a recent study by Moreno et al. [367], 41.5% of the respondents stated they were willing to use an AV as an SAV when asked how they would consider using automated vehicles. Those who were younger than 35, male, did not own a conventional car and made 3 to 4 trips a day had the highest probability of using an SAV.

Experts see great potential in the shared use of AVs and estimate that automated taxis have the potential to reduce the number of private vehicles by more than 90%. To achieve such results, several simulated studies have recently been undertaken relating to fleets of automated taxis. Burns [95] simulated the use of an SAV fleet in a small, a medium and a metropolitan city. He suggested that SAV trips could actually be cheaper than trips by private car or taxi when looking at the cost per mile ($0.41, which currently corresponds to €0.22 per kilometer). He also calculated that all trips could be executed with a fleet of only 15% of the number of privately-owned vehicles. Fagnant and Kockelman [176] and Fagnant et al. [179] have suggested that the amount by which traditional car trips could be replaced is a more modest 3.5% or 1.3%, respectively. On this basis, each SAV could replace around eleven (or nine) conventional vehicles, with a reasonable wait time (one minute or less) and with travel fares less than a third of what a traditional taxi currently charges. Against this, both of these studies found that the mileage traveled might increase, by 10% or 8%, respectively, due to the repositioning of vehicles. Burghout et al. [93] have concluded that it is possible to replace private car commuter trips in a metropolitan area with self-driving on-demand taxis such that there would be a need for less than 5% of the passenger vehicles currently in operation, with the same going for parking places. Spieser et al. [492] simulated the use SAV transportation in Singapore and came to the conclusion that an effective fleet would need to have only one third of today`s private vehicles. Although, as intimated above, these studies show that the total distance traveled by all vehicles will increase [179,492], it is also generally agreed that automated vehicle sharing concepts offer great economic and ecological potential. It is widely assumed in these studies that the operating costs of an SAV will be higher in the early phases of their adoption and that these costs will be offset in the long term through their greater efficiency. Given these possible benefits of SAVs, many experts believe SAVs will have the potential to make mobility more sustainable regarding ecological impacts [177,215]. With regard to the uptake of AVs in general, researchers agree that the shared use instead of the private ownership seems to be the only way in which AVs can contribute to more sustainable and low carbon mobility [68,177,588]. Others are more skeptical, however, and indicate possible rebound effects, such as an increased use of individual mobility. They expect that the shared use of SAVs alone is not sufficient for a positive environmental effect, but that only simultaneous use of such a service can lead to a positive result, e.g. by reducing vehicle miles traveled [304]. This business model – with two or more customers who want to go in to the same direction sharing a ride – is referred to as SAV with dynamic ridesharing [296] or pooled SAV [42,287]. This possibility is also indicated by analyses of existing business models such as Uber, which show that only pooled use can lead to a reduction rather than an increase in vehicles miles travelled [536].

While there has been a major upsurge in studies about autonomous driving in general, and shared autonomous vehicles as a more specific business model, only a few studies have so far addressed the issue of people's willingness to use shared autonomous vehicles in the future. Furthermore, while lots of studies claim that the advent of AVs will put the job of professional drivers, i.e. taxi drivers, at risk [134,317,571], these studies do not reflect upon such consequences in a more differentiated way. They simply make this statement, without further analyzing the possible development of the jobs or otherwise questioning this thesis. Thus, there still is a gap in the automated driving literature regarding the impact of SAVs on other modes of travel or their social consequences, such as job losses, especially from a more deeply rooted empirical perspective.

11.3 Methodology

To address our research questions, we conducted 34 problem-centered narrative interviews with regard to the relevance of having a human taxi driver and, more broadly, the concept of SAV services [578]. The interviews were coded, analyzed thematically and interpreted in relation to the research questions. Qualitative interviews are particularly suitable for exploring more prospective fields of research and for uncovering the subjective perspectives of users [464] and are well-established as a method for analyzing travel behavior [83,180,364,590]. Openness and flexibility in this research process provide space for discovering new, previously unknown phenomena. The interviews were conducted in German, but the excerpts in the paper have been translated into English [81].

11.3.1 Participants and Procedure

To contact and recruit participants, we used a combination of qualitative sampling [126] and snowball sampling [59]. We did not ask for any prior knowledge about AVs and the interviewees took part in the interviews on a voluntary basis and without being compensated. As indicated above, the study focused on so-called “Millennials”, so we only interviewed people born between 1980 and 1999. When selecting the participants, we made sure that at least some of them take a taxi from time to time, some of them even for business. First, a data set of 25 interviews was

Table 11: Socio-demographic data of study participants

NAME (ANONYMIZED)	GENDER	AGE	JOB	MAIN TRAVEL MODE	PLACE OF RESIDENCE
Alex	male	27	Student	PT*	Urban
Tim	male	22	Student	Car	Rural
Lisa	female	23	Medical Assistant	Car	Rural
Luis	male	23	Online Marketing Manager	Car	Rural
Daniel	male	28	Cutting Machine Operator	Car	Rural
Sophie	female	26	Geriatric Nurse	Car	Rural
Fabian	male	34	Engineer	Car	Urban
Tobi	male	22	Student	Car	Rural
Lara	female	22	Student	Car	Rural
Robin	male	21	Student	Car	Rural
Helen	female	26	Automobile Sales Person	Car	Rural
Max	male	26	Student	PT	Urban
Nora	female	34	Architect	Car	Urban
Jonas	male	26	Student	Car	Urban
Oli	male	21	Student	Car/PT	Rural
Leon	male	21	Student	Car	Rural
Philip	male	22	Industrial Mgmt. Assistant	Car	Rural
Sandra	female	20	Apprentice	Car	Rural
Lukas	male	24	Student	PT	Urban
Markus	male	22	Assistant Tax Consultant	Car	Rural
Nina	female	20	Student	PT	Urban
Manuel	male	22	Student	Car	Urban
Stefanie	female	25	Student	PT	Urban
Dennis	male	30	Nurse	Car	Rural
Jan	male	22	Student	PT	Urban
Stefan	male	21	Student	PT	Urban
Julia	female	21	Student	PT	Rural
Emma	female	32	Housewife	Car	Rural
Marie	female	27	Consultant	Car	Urban
Heiko	male	38	Software Engineer	PT	Urban
Anne	female	30	Construction Planner	Car	Rural
Karsten	male	33	Industrial Mechanic	Car	Rural
Selina	female	31	Regional Director (Bank)	PT	Urban
Caroline	female	35	Executive Assistant	Car	Rural

*PT = Public Transportation

analyzed, then the research questions were adapted by including specific questions about interaction with the taxi driver in the interview guide (see 11.3.2), and 9 more interviews were conducted. At this point in time a theoretical saturation was found.

The study was undertaken in Germany, the participants consisted of 14 women and 20 men aged 20 to 38 years (see Table 11). 20 interviewees lived in rural areas, the other 14 in small, medium and large cities with a decent public transport infrastructure. All of the participants held a driver's license and 24 of them owned a private car.

11.3.2 Questionnaire

For the analysis, we evaluated an interview data set (n=25) that originally focused on closely related research questions. These interviews were conducted to find out what requirements the participants have for an SAV service, how they would use it and how their mobility behavior could change as a result. Thus, while the core focus was on questions related to different aspects of service design, other topics such as daily mobility behavior, attitudes towards, experiences with and use of different means of transport (bicycle, car, public transport, taxi, carpooling and carsharing) were also an integral part of the interviews. In this context we also talked with the participants about whether and how often and on what occasions they use taxis, what experiences they have had with taxi services, what they like and dislike about the service and what their relationship is with the taxi driver. Then we talked about the topic of autonomous driving in general, their current knowledge, where they have heard about the topic so far, where they expect benefits and see disadvantages in this context and under what conditions they would use driverless vehicles. However, at the beginning of the interviews, the participants only knew that their mobility behavior, autonomous driving as well as autonomous taxis were the main topics. Up to this point in the interviews, we had not given any background information on AD in order not to influence the respondents. While the idea of driverless vehicles is increasingly becoming well-known in the public domain, we expected the notion of SAVs to be largely unknown. We intended to address this problem and chose a press release on Lyft`s and Uber`s plans on an SAV fleet that served as an envision stimulus. The press release briefly announced the TNC`s plans to develop an automated vehicle that would transport passengers from A to B in the long term without the need of a driver. In addition to the wishes and requirements of the interviewees for a Level 5 SAV like this, we asked them about their possible reasoning for using such a service and attitudes towards it. It was not until the last part of the interviews that we told them the results of the simulation studies and that autonomous taxis could be operated considerably cheaper. We then asked the participants to put themselves in the following situation: In the age of autonomous driving, they are at a party in the evening, have had a drink and want to get a taxi to go home.

We gave them the choice of taking either a conventional taxi with a human driver or an automated driverless taxi that would be 30% cheaper. We then asked them to choose one of the services and justify their decision.

Thus, the dataset provided us with all the content relevant to the research questions at hand. We analyzed the interviews again with regard to the questions we wanted addressed in this study. Based on this set of interviews, we conducted nine more interviews with Millennials. Having learnt from our initial findings, we focused more strongly on the use of conventional taxis and their existing interactions with taxi drivers. The interviews lasted between 20 and 45 minutes.

11.3.3 Data Analysis

The interviews were conducted face-to-face and audio-recorded. They were then fully transcribed and analyzed in-dependently by three researchers (two undergraduate students and one doctorial researcher). For the content analysis of the dataset, we followed a thematic analysis procedure based on Braun and Clarke [73]. Thematic analysis is a method for identifying, analyzing and creating topics from datasets [72], which is used to meaningfully summarize the key aspects of a large amount of data. Thematic analysis highlights similarities and differences between datasets. It also enables unforeseen new insights to be generated. It is often used for the analysis of qualitative data and is flexible because it is not bound to any theoretical framework as e.g. structuration theory conversation analysis is [200].

For our analysis, we first familiarized ourselves with the material. As transcription of the interviews was divided up among the researchers, some familiarization had already been achieved during the transcription, as well as through close reading of the other transcribed interviews. In the next step, we started to code the interviews using MAXQDA software. To do this, we chose a deductive semantic approach. We followed this more theory-driven, rather than inductive, approach. In the context of thematic analysis, theory-driven does not mean that the analysis is based on a superordinate theory, but rather on our specific research questions that had already shaped the structure of the interviews. We knew, for example, that we wanted to extract the advantages and disadvantages of taxi services, which therefore had corresponding codes. Not only were passages coded that were related to our specific interview questions, but also interesting passages such as subordinate clauses explaining other concerns. During the initial coding, we began to assign topics and subtopics by making color mappings. Once we had systematically coded the complete data set, we checked the pre-structured codes, searched for topics and combined them into motifs. We then reorganized the code system by grouping the codes into themes and subtopics before finally sorting the themes. In the next phase, we checked whether the topics were consistent with the elaborated, coded passages and the entire dataset. The coding system was then applied to all of the interviews and iteratively refined, extended and adapted as and when new interviews required it. Finally, we selected meaningful examples of the most relevant topics, representing the diversity and breadth of the interviews, prior to working up the analytic results in text form as findings.

11.4 Findings

In this section we present the results of the interviews. Asking the participants only about their opinions of the SAV concept would have provided us with purely speculative answers. We therefore began by discussing their existing mobility practices. In the findings, we will commence by examining how the participants' currently used taxis and their attitudes to them, illustrating different aspects through quotations and examining the background relevance of having an actual taxi driver, prior to any possible replacement by automated taxis. This will then serve as a backdrop against which to examine the later findings regarding the notion of using SAVs.

11.4.1 Use of Taxis

Most of the participants only used taxis very rarely and for private purposes, although three participants use it occasionally for business trips. There was, however, one female participant – Marie, 27 – who, for professional reasons, used a taxi several times a week that was paid for by her employer. Her taxi use centered upon getting from home to the airport, from the airport to work, and getting to a hotel after business lunches. In everyday life, the other participants used taxis mainly for trips home after events or parties: *“Taxis make sense in that you can order a car if you are no longer able to drive yourself or do not have a suitable means of transport and there are no public transport stops nearby”* (Daniel, 28, Car). However, most of them emphasized that they would only order a taxi if the route could not be covered by alternatives such as public transport, family or friends taking them in the car, using a bicycle or going by foot - i.e. *“only if there is no other way“* (Markus, 22, Car). Some use taxis when PT would, as an alternative, take a comparatively long time and “you just want to get into bed” (Heiko, 38, PT). Selina (31, PT) has *“a higher sense of security at night and late hours”* when she takes a taxi instead of public transport.

The high cost of taxis was repeatedly mentioned as a reason why this comfortable means of transport was not used more frequently: *“Taxis are relatively expensive, especially in Germany, so as a student, if I found another way, I wouldn't spend any money on a taxi now and yes, so I take taxis maybe two or three times a year, that's why”.* These comments in the context of taxi usage show how very price-sensitive Millennials are when it comes to travel mode choices – particularly students, who made a point of mentioning that they had a limited financial budget when discussing the use of taxis.

Outside of their everyday life, Millennials use taxis occasionally during vacations or when they are in foreign cities for other (e.g. professional) reasons: *"On vacation, for example, I always hire taxis, if I don't know my way around at all – because then it's actually quite convenient – you don't have to look at any big train schedules – maybe you don't have the time or the desire to do so – then of course it's also a reason to order a taxi, because you can also get in and the taxi driver will take you from A to B"* (Markus, 22, Car). In these situations, where "*not knowing one`s way around"* plays a role, the taxi driver has the big advantage of being street-smart, so that the customer doesn't have to figure this out for herself or himself and can save a certain amount of effort by not having to study *"bus schedules"*, which can be very complicated in places you don't know.

So, for Millennials, taxis are considered relatively expensive and therefore are used only when you don't want to drive and have no other choice but are a good option when you are somewhere you don't know.

11.4.2 Positive Opinions Regarding Taxi Services

Although taxi services in Germany are officially classified as a form of public transportation, users see clear differences between the use of taxis and buses and trains. Actually, the respondents saw some clear advantages in using taxi services compared to mobility alternatives such as a car or public transport. They consider taxis to be more flexible than buses and trains as they do not follow a fixed timetable and more convenient as they do not have to be shared with other passengers, though they are also considered relatively expensive. Generally, the participants take for granted the fact that 'taxi' is a conflation of a vehicle and the person who drives. Thus, when talking generally about a taxi service, they do not differentiate between the taxi vehicle, the service and the taxi driver. So, we find Lukas saying: *"Yes, the advantages are, of course, that it is very convenient that you have almost no waiting time, because you actually always get to a taxi, most of the time they are standing in front of the discotheques and then you just have to get on and they take you immediately to the location where you want to go, you don't have to go to any bus stop or home from a bus stop"* (Lukas, 24, PT). The comment suggests that for Lukas "*convenient*" means that the service is very quickly available and easy to get to when it is needed, especially compared to PT, which has restrictions because of bus stops and fixed departure times. In addition, many participants mentioned that a great advantage of a taxi is that you do not have to drive it yourself, so it is particularly suitable as a means of transport in situations where the user is no longer roadworthy, for instance, because of drinking alcohol at a party. However, there were other situations the respondents appreciated the aspect of not having to drive themselves: *"Sometimes at super important appointments that follow one another directly, such as an exam, an interview or an apartment inspection, it is practical, because one does not have to drive and* *isn't that stressed"* (Stefanie, 25, PT). So, for Stefanie, not-driving-herself was the main advantage of a taxi, because she often got stressed in situations where she wanted to concentrate on important things. Finally, Leon particularly appreciated the use of taxis for journeys to or from the airport: *"Advantages, especially in comparison to buses and trains, are that it is more flexible – almost like your own car [...] and that you can transport things or luggage in the trunk of your car"* (Leon, 21, Car).

So, Millennials appreciate that taxis are almost as flexible and fast as private vehicles, can also be used for time-critical trips, but offer the advantage of not having to drive yourself.

11.4.3 Orientations to the Driver

When the participants talked about their opinion of taxi services, they also mentioned positive and negative experiences related to the taxi drivers themselves. Jonas (26, Car) appreciated the fact that taxi drivers usually know an area well: *"It's nice to be able to sit in a car and the drivers know their way around and take you where you want to go, even if you don't know anything about a place".* The taxi driver takes the effort of finding all the necessary information one needs to orientate, plan and carry out a journey independently off the customer's shoulders by using his or her knowledge. Caroline (35, Car) had already had nice conversations with some taxi drivers, which caused her to contact the same company via telephone and ask for the same driver again for another trip. Some participants, however, reported unpleasant experiences they had had during taxi rides, related to the behavior of the actual drivers. Heiko and Caroline had experienced that drivers take a longer route than the optimal route to get a higher fare. In Caroline's case, a taxi driver tried to collect the fare, even though it had already been paid in advance by a friend. Some participants check the route in the app during the ride or observe the routing if they know the way. Julia described various occasions where she had ended up having a negative view of the behavior of the driver: *"Of course it takes all sorts of drivers. Some were very unfriendly. There are some who smoke in the car. I don't like that because I don't smoke myself*". For Julia, as a customer, certain kinds of behavior amount to a form of disrespect, taking for granted the right to smoke being one of them. She added: "*What has already happened to me is that drivers were on their mobile phones while they were driving because they received other orders and then I said, 'Could you perhaps put your mobile phone away?' That makes me feel kind of insecure"*. Julia here describes a situation that is known to be risky in road traffic, namely the use of a mobile phone while driving. This is a crime in many countries. Julia felt *"insecure"* because the taxi driver, into whose care she had placed herself, was putting her in danger by breaking the traffic rules. Other respondents also commented that taxi drivers do not always adhere to traffic rules. Jonas (26, Car) considered this to be one of the disadvantages of using a taxi "*that you cannot determine* *your driving style yourself. I have experienced that taxi drivers drive much too fast. Sometimes I feel endangered when driving in a taxi"*. The phrase "*cannot determine your driving style yourself"* shows that Jonas generally preferred to be in control in situations that can be potentially dangerous like driving a car. Marie criticized the attention of drivers in road traffic: *"Recently drivers have overlooked cyclists more frequently"*. The term *"overlooked"* suggests that she feels that the drivers are not concentrating enough on their work and are missing important features of the traffic, potentially endangering the safety of the occupants and other road users. An outcome of this is a reduction of trust in taxi drivers.

To sum up, Millennials value that they can rely on taxi drivers' knowledge of areas and routes. However, they dislike when drivers want to shortchange them, unfriendly and risky behavior, especially when drivers do not obey traffic rules.

11.4.4 Use of the Taxi Driver's Services

By and large, the respondents said that before or during trips they interacted very little with the taxi drivers. Some regularly use an app to order a taxi, others prefer to call the taxi company. They are independent in getting in and out of the car, belting up and communicate their route via app or name it to the taxi driver at the beginning of the journey. Some did say they talked to the taxi driver while driving. Julia (21, PT-user) used taxis or Uber occasionally when on holiday in foreign cities, especially on the way from and to the airport. In this situation she converses with the driver: *"When you are in a foreign city, you can chat like: 'What things can you do here? Which restaurants are good?'"* However, she reflected on this statement afterwards to consider whether this interaction with the driver was really necessary: *"Nowadays, there are so many other possibilities to inform oneself and there is hardly a place where I don't know anyone who has been there before and whom I could ask beforehand, so this is no longer a real advantage of a taxi driver. Especially because many taxi drivers – depending on where you are – don't speak English very well".* Apart from these specific occasions, when she liked to talk to the drivers, Julia, as with many of the other interviewees, did not generally like chatting with taxi drivers: "*It's not like I always talk to taxi drivers. That depends more on my mood or the driver's mood".* Julia and many of the others associated the situation of being in a taxi with a social situation in which it is (culturally) appropriate to talk to each other. This expectation or the fact that the drivers start a conversation (because the driver may also think it is part of his job) was often expressed as the reason why the interviewees talked to the driver. Less often was a conversation motivated by real interest. Marie, who uses a taxi 5-6 times a week for business, even said that it *"bothers"* her when the taxi drivers want to talk to her: *"Because I have no interest in conversations and sometimes simply want to have my peace (...)".* Even though taxi drivers are usually very skilled at having conversations with their passengers and know what kinds of topics may be safely broached between strangers, Marie sometimes disliked the topics that the taxi drivers came up with during a ride: *“Preferably no personal stories. (...) If he starts telling me about his children or their school problems or that they are rejected on apartment inspections because they are foreigners, I don't care”.* Marie personally didn't consider conversations about very private subjects, such as the driver's children or his visits to rental apartments to be appropriate, as she had no close relationship with the driver. She did not want to know private details about the driver, comment on them or reveal anything about herself. Emma (32, Car) even actively tried to avoid such situations because she found them so unpleasant: *“When we are driving in groups, I prefer to sit in the back and think someone else can talk to him in front”.*

Apart from chatting and getting tips, the interviewees only discussed the help they received when loading or unloading luggage. Marie appreciated this service: *“I like that the drivers help me with the suitcases. If you travel a lot, this service makes a difference”.* She found it pleasant that she was helped with her heavy luggage, especially as she took a taxi so often and frequently had heavy luggage with her, not for her private pleasure, but for professional purposes. Notice her emphasis upon *“if you travel a lot”*. This marks out the fact that she needed to account for her interest in this service. So, she did not take it for granted that this was something that just anyone would want or like. Julia, who only used taxis privately, also appreciated this service: “*When you travel and have a lot of luggage, it's pleasant to have a taxi driver who lifts the luggage into the trunk”.* As she already had the topic of autonomous taxis in mind during the conversation, she added: *“But so far I have always tried to make sure that I can carry my luggage myself”.* With this comment she made it clear that she did not assume that she would need the help of a taxi driver and could do without one if necessary. Emma also used taxis during her holidays: *“In Thailand I used taxis a lot with luggage. I don't know if they helped at all – but I think so. But that is not important for me at all”.* She cannot even remember if the drivers helped her with the luggage, which is made clear by the addition *“I don't know [...] I think so”.* This example shows again that some aspects of what taxi drivers do are more or less taken for granted and often do not result in passengers being any more impressed by the service.

However, lots of the participants felt rather independent and like to stow their luggage or pack their purchases into the vehicle by themselves. Although Emma had (probably) made use of luggage services during her holidays, she generally had a very strong need to do things like this on her own: *“I'm not so into services. I also thought it sucked when they introduced an attendant at the gas station who fills up the car for you – I don't like such things and want to do it by myself. That's why I find taking a taxi unpleasant, because it's a person who provides a service for me”.* She even said that it was *"unpleasant”* when describing how she felt when being served. The example of the gas station attendant shows that she did not like to have other people perform such services, which she could do herself or that she actually did by herself. With regard to the specific question of whether the absence of a taxi driver at any stage of the taxi journey could cause difficulties, the participants saw no problems. Rather, they thought that ordering the vehicle, locating the vehicle, communicating the route or destination and paying for the ride could be done via an app even today, or that if you want to have a conversation, you could also "*call someone*" (Selina, 31, PT). They did not see any problems with regard to locating the vehicle which can sometimes be challenging with taxis today. Caroline (35, Car), who often uses rental bikes in the city, says: *"(...) the app shows me where the bikes are and sometimes you have to search for them. Sometimes I couldn't find it, but a car like that is a bit bigger (...), and that's why I think if I had an app with a street map on it and the location of the taxi, I could find my way around. Maybe it would be nice if I could trigger a function in the app, so that it would blink*". Thus, when Caroline abstracted from her experiences with rental bikes, where could not interact with anyone, she was confident that she could carry out all the interactions with the vehicle independently. For the supposedly challenging situation of locating the vehicle, in addition to the typical current solutions (physically searching, using GPS), she suggested that the vehicle might emit a light signal at the push of a button, which would make it easier to find. Heiko suggests the SAV to display an identification number that is shown in the app, too. The only thing that some participants saw as a challenge was spontaneous route changes or stop requests. Here, some participants doubted that the vehicle would be able to process these quickly enough. However, Karsten (33, Car) is confident that control will be possible via a speech assistant.

Thus, some participants like to chat with drivers, and appreciate their assistance with luggage, but these interactions don't seem to be very important. So, Millennials probably wouldn't miss them if travelling in an SAV. However, it is possible that Millennials benefit from other interactions or services that they currently take wholly for granted when using a taxi, hence their failure to mention them. Unpicking the taken-for-granted aspects of taxi travel will require further empirical study in the future.

11.4.5 Choosing Between Traditional and Automated Taxis

When we asked the participants to choose either a traditional taxi with a driver or an automated, driverless taxi given the scenario described in the methodology section, a relatively uniform picture emerged: Most of the Millennials chose the automated, driverless taxi – mainly because of the lower price: *"I would choose the autonomous service because it is cheaper, and I have the same benefit. The only question is whether you trust people or technology. But since I don't find most taxi drivers trustworthy, I would use the automated driving service"* (Stephanie, 25, PT-user).

So, for Stephanie, two points were decisive for her decision in favor of the driverless taxi: first, the lower cost; second, her distrust of taxi drivers. For Max (26, PT-user), too, it was not just the cheaper price that was decisive for his choice: "*I've also experienced far too often that taxi drivers drive very bad, so I'd almost prefer to get into an autonomous taxi than if a driver were sitting in it".* So, Max could imagine doing without a driver because the driver could make him feel his life was at risk. With Alex (27, PT-user), his distrust of taxi drivers was the predominant reason for choosing an automated, driverless taxi: "*I would choose the autonomous service, even if it were more expensive. It would probably bring me home safer than an insane taxi driver who wants to make as much profit as possible".* Alex was very well-informed about autonomous driving and open-minded about the possibilities that autonomous driving offers. He expressed a hope that *"the technology will soon be used nationwide".* Apart from his distrust of taxi drivers, his enthusiasm for autonomous driving was probably one of the reasons why a cost advantage was not relevant to him when making his decision. In his case, he even said he would accept an extra charge for an autonomous taxi. Emma's reasoning needs to be set against the fact that she doesn't like to have services provided for her. She, too, opted for the automated taxi. She justified her choice in the following way: "*I would choose the automated taxi because it is cheaper – I don´t get anything out of a driver".* This statement clearly sums up the fact that she sees no added value in the mere presence of a driver.

Another feature of the findings was that many of those involved initially expressed concerns about the safety of driverless taxis. Sophie (26, car-user), for instance said*: "If it's still something new, I'd say I'd rather take the taxi driver, I can talk to him and say: 'Oh watch out, over there!' With the other one I don't know which button I have to press to intervene and with the taxi driver I can at least grasp the steering wheel. But if that is something that is already totally established and has become normal, then it wouldn't make any difference, then I would order the driverless taxi as well".* Sophie's comment shows clearly that her safety concerns are mainly based on the fact that the technology is not yet available, that it has not yet been tested, that others cannot yet report on their experiences with it and that she did not know how to intervene with a driverless taxi in the case of doubt. This she posed in contrast to an actual driver, where she could at least say something or *"grasp the steering wheel"*). It is, of course, important that not all Millennials have confidence in a driverless technology. However, we do not want to elaborate on concerns about safety and confidence in the technology at this point. In this particular study, the focus was on the importance of the driver.

Interestingly, the prospect of any threat to taxi drivers' jobs posed by autonomous vehicles did not seem to play a role in the choice between the two alternatives. Some respondents raised this issue of job losses on their own when we talked about autonomous driving in general: *"If only* *these cars are used and then no buses, coaches and trains are used anymore and so on, that of course costs a lot of jobs, people will be rationalized and that is of course a critical point"* (Markus, 22, car-user). Like Markus, some participants associated the emergence of AVs and SAVs with a threat to jobs. However, for none of the respondents did this feature in their actual decision-making.

In other words, most participants would opt for a driver-less taxi rather than a human taxi – provided the technology has been established – mainly for reasons of lower cost and their distrust of human drivers.

11.4.6 Use Scenarios

After introducing the topic of automated taxis, we also asked the participants what kind of trips they could imagine with a driverless taxi. We were interested in the question of use scenarios because we wanted to ascertain whether driverless taxis might be used exclusively for certain type of journey. This would have implications, in turn, for whether all taxi journeys might be carried out by driverless taxis in the future, or only some of them. Most of the participants replied that they would mainly undertake the same trips with an autonomous taxi that they are currently using a traditional taxi for: *"For the occasions for which I now use a normal taxi. When I want to go home in the evening and don't come home any other way or when I want to travel and get from the airport to the city. If I want to get from home to the airport, I'm lucky that someone always drives me. But of course, you could also use an automated taxi for that"* (Lisa, 23, car-user).

Interestingly, some participants also mentioned other journeys that they do not currently make by taxi but would consider suitable for an SAV. Alex was so enthusiastic about the idea of an autonomous taxi that he said he would use an SAV for all of his trips: *"I'd use it, so if the price is right, I'd use it to shop, go to work, travel longer distances and visit someone or to drive to the airport or something like that"*. For this, however, he set a condition, namely "*if the price is right"*. At present Alex mostly uses local public transport. He had the following to say about what the right price meant for him: "*I would be satisfied if one kilometer with an autonomous vehicle costs me 20 cents on average. It would definitely have to be cheaper than a taxi. Any cheaper than owning a car – I don't know, I've never calculated it exactly"*. He suggested an amount of 20 cents per kilometer, which is very cheap in comparison to other means of transport. At the same time, he made it clear that he hadn't looked at the cost of other means of transport in detail, making it difficult for him to compare the amounts directly and judge them. It was easier for him to make a clear statement about a taxi because the classic use of a taxi would be similar to an SAV in terms of use-dependent costs. This is different for cars, which have fixed costs in addition to their use-based costs. It turned out that it was also difficult for him to determine the cost of using public transportation per trip, because he had a public transportation ticket for a whole semester and did not pay for the trips individually.

A few of the participants could not imagine using an automated taxi for their daily trips. This was especially true for the participants whose main means of transport was a car. It was hard for them to picture using an SAV instead of their own car. This was either because they were used to the flexibility of having their own vehicle available at all times and its associated private space, or because the use of an SAV would not be practicable for them. For example, for Emma, who is the mother of two children aged 1 and 3, the use of an automated taxi for everyday trips was simply deemed unsuitable: *"With automated taxis it would be very complicated. We need child seats. Currently they always stay in the car, but then they would always be in our house, probably in the basement. Then you have to drag them up, then you install them in the car and hope that it fits, because not every seat fits into every car model. Then you would drive somewhere and then you would have to remove the seats if you didn't have the same car on the way back. And for example, when shopping, you stand there with two seats, that would suck (laughs)"*. She had at least one child with her on most of her trips and therefore needed a lot of things like child seats or toys, which she left in the car all the time. Using an automated taxi instead of her own car would require a lot of additional effort and coordination. However, she foresaw situations in which she could imagine using an automated taxi: *"The only thing I can imagine is when I go out in the evening and return late by train, then I find it super scary to walk down the mountain to my home [10 minutes by foot]. The other day I walked down and then a man walked behind me in 10 meters distance, it was pitch dark and the way goes through the forest. I wet my pants! In such cases, even if it doesn't matter how long the route is, I would order one of those things. I think taxi drivers say it's too short for them, so I never thought about calling a taxi for it"*. So, she thought it made sense to use an automated taxi for a route that she currently did on foot – without children – but where she felt insecure because of the nature of the environment. Using an automated taxi would be a safer option for her, here, as she would be alone in a lockable space and brought to the front door of her house.

So, overall, Millennials would prefer to use automated taxis for the journeys they now make with traditional taxis and, to some extent, they would use them instead of public transportation. Depending on the complexity of their travel organization, some would also use AVs for additional trips.

11.5 Discussion

We now want to discuss some of the implications of these results for the taxi industry. To this end, we will divide this section into four parts that relate to different aspects of the findings, covering the kinds of rides that might be performed by automated taxis, the necessity of interaction with a human driver, the implications for the taxi driving profession, and the implications for other forms of transport. At the end of each sub-section we present implications derived from the findings, which can serve as a starting point for future studies. In addition, Figure 12 summarizes which steps the participants mentioned with regard to the use of taxis, which of them are already represented or supported by a taxi app, and which solutions the participants suggested with regard to the elimination of a human driver.

11.5.1 The Kind of Taxi Rides Millennials Make are Particularly Suitable to be Performed by Automated Taxis

The purposes for which our participants use taxis largely correspond to the results of more extensive surveys: trips to or from events, arrivals and departures at train stations or airports, and trips in foreign environments, especially on holiday [258]. Looking at these three types of trips to judge how well or poorly they could be done with a driverless taxi, we need to ask what an automated and driverless taxi could not cope with. Thus, whether the driver plays a further role apart from just the driving.

Let's first look at the trips to or from events and parties. Millennials use taxis mainly because they drink alcohol and therefore cannot drive themselves. Sometimes you can actually observe that people are so drunk after a party that they can't walk straight or articulate themselves clearly. Based on this situation, an autonomous taxi might find it difficult to understand where the customer wants to go. Here a taxi driver might have an advantage, because he/she could interact more closely with the customer, could have an identity card with the address shown to him or could be shown the way through gestures at intersections. Experienced taxi drivers sometimes also know their customers, so that they re-member where to take them. Here AV viability will depend on things like whether the vehicle will be able to reason in socially nuanced ways and cope with non-verbal communication.

Arrivals and departures at railway stations or airports are often associated with travel where customers take luggage with them. With traditional taxis, the taxi driver usually loads and unloads luggage. It is to be expected that automated taxis would also offer the possibility of stowing luggage. However, a driverless taxi could not physically help its customers to stow luggage in the trunk unless the vehicle was equipped with technical aids such as grab arms, or other lifting mechanisms capable of performing this service, or level access, as is now widely provided for public transportation. We also saw above that even Millennials sometimes appreciate the human aspect of this service.

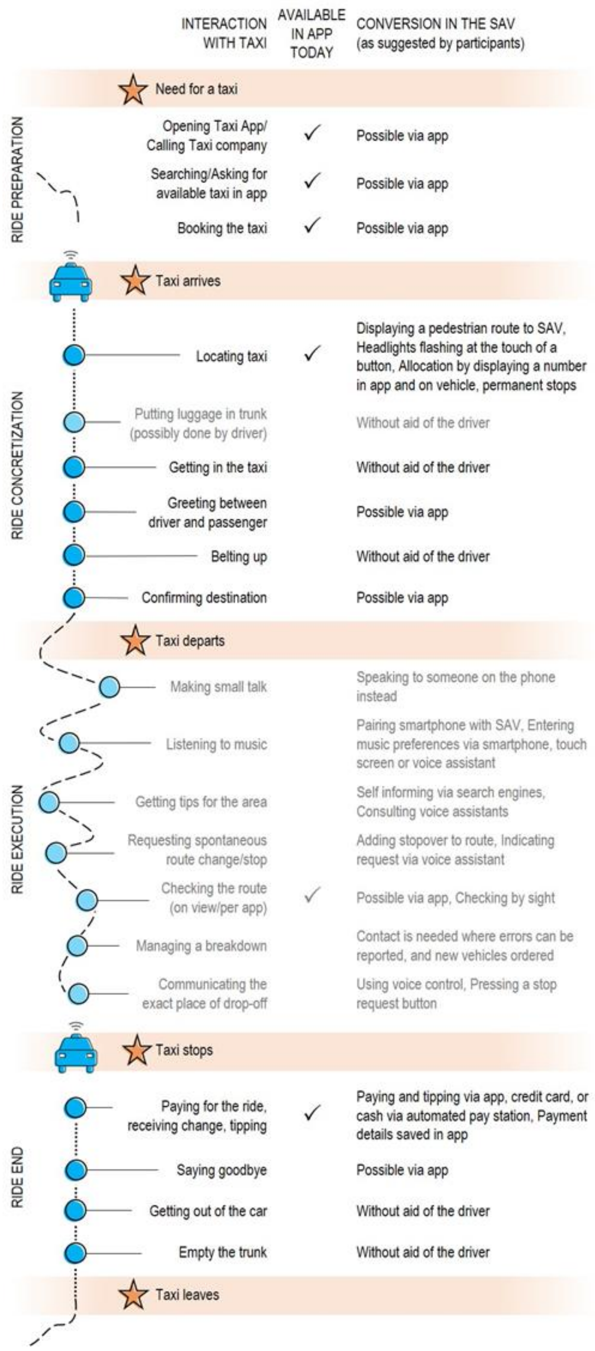

Figure 12: Customer journey of a current taxi ride and possible conversion in an SAV
Interactions that do not occur during every ride are shown in lighter font

Orientation and navigation play a particularly important role with regard to trips in foreign cities or places. Customers appreciate the fact that drivers know their way around and that they can rely on the driver to find the right route. Given that intelligent traffic management systems and GPS navigation already exists, it might be assumed that automated taxis would have the appropriate technological equipment and be capable of intelligent and dynamic routing. However, many taxi drivers are very experienced and know their area very well, so that they know shortcuts or alternative routes that are better and faster than the routes registered in navigation systems. This can be especially important when it comes to sudden changes in traffic circulation resulting from unforeseen events.

Against the background of the results of the interviews and the possible design of driverless taxis, the three types of journeys examined above seem to be suitable for driverless taxis. From a millennium perspective, the interactions involved in these types of rides can also be represented by SAVs and complementary apps, or they can be carried out by the passengers themselves (Figure 12). However, this is only the current view of the participants in relation to a non-existent technology. When there are autonomous taxis at some point, these people will be older, they will probably use taxis for other occasions, and maybe they will value the support that a human person could provide more than they do today. Then a new generation of young adults may constitute the bulk of taxi users, so we can only assume they will have similar attitudes and needs to our participants.

Implication 1: Human taxi drivers have an advantage over SAVs when it comes to difficult-to-understand requests and conversations.

Implication 2a: Millennials appreciate services provided by human taxi drivers, such as loading luggage.

Implication 2b: The Millennials do not mind doing without such services.

Implication 3: Human taxi drivers are superior to SAVs in terms of spontaneous and dynamic route planning.

Implication 4: Most of the millennials prefer SAVs to human driven taxis for their typical taxi trips (events, last mile, unknown places).

11.5.2 Interaction with the Human Driver is not a Valuable Advantage that Justifies the Use of a Traditional Taxi, Especially if the Automated Taxi is Cheaper

Currently, for Millennials, interaction with taxi drivers is mostly limited to organizational matters such as calling a taxi company or searching for available taxis via app, booking an available taxi, communicating the destination or payment. Some of this communication is already done via taxi apps like mytaxi (today: *FREE NOW*; Figure 12). This type of communication and coordination could also be handled via an app for automated taxis. Some participants, however, did talk to taxi drivers. Nonetheless, when analyzing their comments, it was noticeable that most did not usually actively seek conversations, but rather reacted passively to questions and comments from the taxi driver. Some even found such conversations awkward rather than entertaining. In this respect the automated taxi would have no disadvantage. Even if a customer would like to have entertainment or tips on the surroundings, the passenger could always make a call and a language assistant, such as Siri or Alexa, could provide information about the area [323]. To be able to easily locate a taxi before the start of a journey, some participants suggested GPS-positioning displaying a pedestrian route to the taxi, permanent and fixed stops, as well as a feature to trigger the vehicle to flash its lights via the app, or displaying an identical identification number on the app and the vehicle.

However, as we have pointed out already, the social organization of a taxi ride is about much more than just chatting with the driver and loading luggage. Usually, passengers do not experience these activities, because drivers do them as a matter of course and in tacit ways, while other activities are not noticed by the passengers because they accept them as a given. Thus, the participants did not mention these activities and interactions in the interviews. We have in mind here, in particular, things like anticipatory work based on intersubjective reasoning that it is unlikely an automated taxi would be able to replicate. There are forms of interaction that take place before rides and at the ends of rides that are often based upon non-verbal exchanges that it is hard to imagine automated taxis handling. Thus, when arriving at busy terminals with long queues of vehicles waiting to pick up passengers, much of the initial interaction at the moment is handled through mutual gaze and gesture. When arriving at a destination, taxi drivers currently judge just where to drop people and how long to wait for them to exit on the basis of subtle visual monitoring and a mutual exchange of glances. Some of this would be challenging for AVs as they are conceived at present. All of this points to a serious need to engage in further, more thoroughgoing and systematic investigation of how passenger-driver interactions actually proceed, before embarking upon the serious deployment of SAVs. We need to develop a richer understanding of what is actually lost if a real taxi driver is taken out of the equation. Some studies have already been undertaken in this direction (see, for instance [228] and [209]). However, these studies do not focus systematically on the whole course of the ride and are not geared towards providing insights for design.

Implication 5: *Typical communication between Millennials and taxi drivers during rides can be replaced by technology (e.g., voice assistants, touch screens).*

Implication 6: *Communication that takes place before the ride is harder to replace with technology.*

11.5.3 The Fate of Taxi Drivers, Whose Profession is Threatened by Automation, does not Play a Significant Role in How Millennials Make a Choice

Although some participants associated Autonomous Driving with job losses, this aspect did not influence their decision. They clearly have some sympathy for the challenges confronting taxi drivers, but other factors outweighed such considerations, especially cost. At present, to manage this, they accept the disadvantages of other means of transport – such as greater coordination effort or less comfort. Dispassionately, advantages such as a lower price outweigh the disadvantage of possible job losses in their reasoning. The frequently-mentioned issues regarding distrust of taxi drivers may also play a part in this.

Implication 7: *In their decision-making, the fate of drivers plays a subordinate role for millennials compared to factors such as cost.*

11.5.4 The Advent of Automated Taxis also Poses a Threat to Public Transportation

When the participants were considering which routes they might possibly use an automated taxi for, some also mentioned everyday routes, rather than the ones they currently travel in taxis. It was noticeable that public transportation users, in particular, see an advantage in the flexibility and comfort of SAVs when compared to public transportation. Most of the participants insisted, however, that using an automated taxi would hinge upon them being cheaper than a conventional taxi (though some individuals were willing to pay more). Simulation-based studies have shown that journeys using SAVs could be substantially cheaper than journeys by private car or taxi, with costs per mile of as little as $0.41 [95]. This currently translates into €0.22 per kilometer. Costs at this level can compete not only with taxis but with public transport. The amount also comes very close to the concrete proposal of one of the participants regarding the conditions in which he could imagine using an SAV for all of his trips (€0.20 per kilometer). If an alternative means of transport, such as a future automated taxi, could be deployed at these kinds of costs, it would be immediately attractive to many of those who currently use public transportation. Unlike car drivers, public transportation travelers are often not tied to their means of transport because they have made no long-term investment in their provision. Thus, it may not be difficult for them to switch to a new offer like an automated taxi. Clearly, further research is required regarding this topic, but the fact that automated taxis could seem particularly attractive and affordable to public transportation users is important to consider. This is especially important because, even now, AD research is putting a great deal of emphasis upon analyses of how business models can be run profitably [68,179,492] and which factors might increase the attractiveness of autonomous vehicles and autonomous taxis for users [296,387].

To set against this, a shift away from sustainable mass public transportation to individual public transportation could lead to unintended negative environmental impacts. All of this is obviously speculative in nature, but it should nonetheless be considered in the development and regulation of automated taxis.

Implication 8: *SAVs will attract public transportation users to use them for other trips apart from the trips where taxis are currently used.*

Implication 9: *The introduction of SAVs will lead to an unintended shift away from public transportation to SAVs.*

11.6 Conclusion

While many benefits might be attributed to the automation of vehicles, such as a reduction in accidents, better traffic flow or a reduction in the total number of cars, it may threaten the traditional taxi industry. If autonomous vehicles become a reality, the profession of taxi driver could become obsolete as a result [571]. This is despite the fact that representatives of the taxi industry and the taxi driver community currently perceive no threat coming from the introduction of autonomous vehicles [365]. In order to examine the question of whether taxi drivers would still be able to exist in the age of autonomous vehicles, we conducted interviews with 34 Millennials. We found that Millennials could dispense with human taxi drivers and that some even welcomed this (assuming that automated taxis have been established as a safe means of transport).

Millennials are very self-reliant and hardly ever make use of the additional services offered by taxi drivers. As these younger adults are, on average, fitter than older generations, they can manage luggage more easily on their own and are not dependent on the help of a driver, e.g. when getting in or out or when loading or unloading purchases or luggage. The trips for which Millennials use taxi services are particularly suitable for driverless taxis.

The taxi driver as a person offers no added value to Millennials. On the contrary, some people prefer not to talk to the driver and many have had negative experiences with taxi drivers who have been unfriendly or who have ignored traffic rules. Overall, the taxi drivers so far encountered by the participants had not demonstrated a high level of service commitment or customer orientation. Of course, there are many professional and socially aware drivers who are capable of judging accurately whether a passenger is in the mood to chat or not. However, this does not seem to be the rule. Service orientation and customer orientation are of central importance in the taxi driving profession and offer one of the few ways to stand out from automated driving services.

The taxi industry should therefore address the threat posed by automated taxis well in advance. When the majority of trips are no longer carried out by traditional taxis but rather by automated ones, fewer taxi drivers will be needed. This also needs to be considered by politicians and transport planners when issuing taxi concessions. It is important to actively shape this structural change with the involvement of all stakeholders in the taxi industry instead of being caught out by the pace of innovation and shifts in the patterns of customer service consumption.

Of course, this study is not without its limitations. Our sample does not fully capture a representative sample of millennials in terms of age and education. However, it is not the aim of these kinds of qualitative studies to achieve statistical representativeness, but rather to adequately examine complex life worlds and practices [429]. Furthermore, we cannot draw conclusions about the entire taxi clientele from this study. Millennials represent only a specific part of the population and taxi customers. In Germany, however, under 39s account for up to 41% of taxi customers, a significant proportion of the taxi business. If Millennials as a customer group were to completely or even partially shift to using automated and driverless taxis, this would mean a significant loss in sales for traditional taxi companies, driving many out of business. It is also the case that the over-40s use taxis mainly for trips that do not necessarily have to be accompanied and supported by a human driver [258]. Only 10% of trips involve active assistance from a driver, for instance when taking patients to hospital. Clearly there is a need to understand these other groups as well, so future research needs to cover the preferences of other taxi customers.

We also feel there is a need for a more differentiated view when considering the impact on the taxi industry. Analysis of the AD literature and the discussion of its social impact reveals a recurrent claim that drivers will be affected or become obsolete in the advent of driverless vehicles [134,317,370,571]. What is missing is an examination of the taxi industry, the type of work involved, the customers who use the taxi service in different ways, not to mention other possible stakeholders, such that one might be able to make a reliable statement of this kind. So, we need analysis not only of how much of the business (i.e., journeys) will be threatened by automation, but also of how the profession of driver will change and what developments will take place on the way to full automation, during the transitional phases. Against the background of these kinds of research results, there will be a need to discuss how changes in industries with professional drivers can be under-taken in a socially acceptable way.

Beyond all of this, the design of automated vehicles is still in its infancy and deployments are limited and, at best, exploratory. It is therefore pressing that adequate research be conducted now, before the push to deployment outstrips our understanding. For instance, we found that, despite their expressed preferences, Millennials do not necessarily take into account the range of ways in which taxi drivers interact with their customers and the extent to which these interactions may be critical to the provision of an effective service. In addition, only a few of them have addressed issues such as cybersecurity and privacy, even though these may arise as significant concerns in the future against a background of increased networking of vehicles. Nor do we yet know how taxi services may shift to certain niche markets. In short, it is early days to assume the future for taxi drivers is bleak, but we do need to explore the character of future transport provision in a way that more comprehensively examines their current contribution.

12 STUDY 8: THE UNINTENDED SOCIAL CONSEQUENCES OF DRIVERLESS MOBILITY SERVICES – HOW WILL TAXI DRIVERS AND THEIR CUSTOMERS BE AFFECTED?

Social sustainability effects of autonomous vehicles (AVs) are being discussed in a controversial manner. While there are numerous social benefits to be expected with the advent of AVs, some people will face drawbacks of this development. On the one hand for those who earn their living by driving and on the other hand for those customers who are reliant on human assistance to conduct a taxi ride. In order to better anticipate the size of this group and thus how great the threat to the taxi driver's profession is to be replaced, we analyze secondary data on taxi use in Germany. The results show that the proportion of mobility-impaired passengers is 9%, accounting for about 18% of all taxi trips, indicating that there is a small but significant number of customers whose needs probably cannot be met by AVs, and who will potentially continue to rely on human assistance in the future.

12.1 Introduction

Fully automated vehicles have the potential to revolutionize our mobility in a way that is hard to predict [402]. Given that autonomous driving will make vehicle sharing easier and more comfortable, experts hope for a greater shift away from the private car to usage-based mobility services [179,400]. Such shared autonomous vehicles (SAVs) are being controversially discussed with regard to their potential contribution towards a more sustainable mobility.

In the context of Fridays for Future and the omnipresent discussions about climate change, the ecological dimension of sustainability is currently moving into the foreground. This is also reflected in the exploration of possible consequences of autonomous driving. Here, the focus is on the effects on traffic, especially the potential for congestion avoidance and efficiency gains through connected driving and platooning, as well as possible rebound effects and, depending on this, the influence on transport-related emissions [22,215].

The possible social effects of autonomous driving, on the other hand, are discussed to a lesser extent. Experts agree that here, too, major impacts are to be expected both on the individual level and on a societal level. Potential benefits include increased safety for road users, a significant reduction in traffic-related emissions and noise, and improved mobility and autonomy for those who are restricted in their mobility [63,317].

However, the development of unmanned SAVs poses serious threats to two groups of people that shall be considered in this article: firstly, to professional taxi drivers, whose job threatens to become obsolete with the introduction of SAVs, and secondly, to taxi customers with impaired mobility, who are dependent on mobility offers for which a certain level of human support is guaranteed that might get lost with the automation of the taxi service . The SAV concepts envisaged so far hardly take the needs of both groups of people into account. The reason for this is understandable: the average taxi user is rather young and autonomous [258], i.e. not dependent on help. Therefore, it makes sense to design SAV concepts in such a way that most users can make use of them. However, it is not known what relevance the group of potentially support-needy users actually has. Irrespective of a social-ethical necessity to consider these people in need of support in the conception of new mobility services with self-driving cars, this group could also represent an interesting target group for business reasons, depending on its actual size. Quantifying the group of potential taxi users in need of support thus reveals, on the one hand, the potential for assisting taxi drivers, who might also have a right to exist in times of autonomous vehicles, and on the other hand, the potential for the design of SAV concepts focusing on mobility impaired people. With this in mind, we address the following questions in this paper:

1. *What share of the taxi business is accounted for by taxi rides with mobility-impaired customers?*
2. *How can the needs of mobility-impaired people in times of autonomous driving be considered?*

Since there is a lack of reliable figures on the importance of this vulnerable group regarding its taxi use, we evaluate a survey on taxi use conducted in Germany in 2014 [258] with regard to these two questions. Before discussing the results and their implications, the following chapter provides some theoretical and contextualizing information on the automation of the taxi service and the potential social impacts.

12.2 Automating the Taxi Service

12.2.1 Automation of the Taxi Industry

Taxis are nowadays an important part of the public transport system, in particular for addressing opportunity-based mobility [226]. In Germany, taxis are part of the public service, which is under the care of the public authorities. There are more than 28,000 taxi and hired car companies with more than 53,000 vehicles, transporting more than 400 million passengers every year. In 2018, the estimated revenues are around 5.3 billion euros [89]. Most taxi rides were for private reasons (83%), only 17% for professional reasons. More than half of the journeys (53%) are made in connection with events. Taxis are used particularly in metropolitan regions. The passengers are younger than average (up to 29 years) and are above average educated [259]. With the taxi driver as a human person being part of the mobility service, he or she provides certain assistance and support. For example, taxi drivers not only help their passengers with loading and unloading luggage, wheelchairs, walking aids or shopping, but if necessary also pick up customers in need of help in their homes, help them down the stairs, get into the vehicle and fasten their seat belts [398].

There is no doubt that autonomous driving will have a disruptive effect on the taxi industry. The Society of Automotive Engineers defined five stages of vehicle automation, ranging from level 1 (assisted driving) to level 5 (fully automated driving) [458]. According to that taxonomy, vehicles in levels 4 (high driving automation) and 5 (full driving automation) can be operated without human intervention. With level 5 vehicles, taxi services could be fully automated and run unmanned. Considering that the driver accounts for a significant part of the costs for taxi operators [203,317], their elimination seems to be the logical consequence. Of course, the absence of a human driver would change the taxi service in its nature. Then, SAVs could present a flexible and dynamic door-to-door service [353]: the passenger selects the desired vehicle by application and requests a starting location. The vehicle picks up the user at his or her desired location. If several passengers share the same vehicle, the system calculates the optimal route combination automatically [296]. Due to the high level of comfort and flexibility combined with relatively low travel costs, the common use of automated vehicles could become the dominant concept of individual mobility [179]. Thus, SAVs are expected to provide the travel experience of private vehicles including door-to-door service, but at low cost, without the burden of financial investment and ownership of private vehicles.

According to a recent forecast, self-driving cars may become available in many urban areas during the 2020s and 2030s [317]. Overall, the most crucial driving forces are the technology itself (and the speed of its improvements) and the policies depending on how restrictive or supportive they act [356]. Given these advantages of SAVs and the relatively long lifecycles of private cars, experts believe SAVs present a concept that will help autonomous driving to make a breakthrough [375]. Given that SAVs can be offered at relatively low cost, some think it is likely that traditional taxis will be the first transportation mode to be replaced by SAVs in urban areas [179,480].

12.2.2 Social Impacts of Autonomous Vehicles

Regarding social effects, autonomous driving will increase social sustainability in manifold ways. The greatest expected benefit is improved traffic safety. In Germany about 3,000 people get killed in traffic accidents every year, more than 65,000 get seriously injured. With 88.4%, most of these accidents are caused by human error [498]. According to the German Federal Statistical Office, maneuvering errors, disregard for right of way, distance errors, inappropriate speed, and alcohol abuse are the most common causes of accidents [498]. As fully autonomous vehicles take over the driving task completely, they hold the potential to reduce the amount of accidents drastically by avoiding human errors [317].

People would no longer have to focus on driving but could use their time otherwise [317,503]. Further, autonomous driving offers the opportunity to make traffic flow more efficient. Connected driving can prevent, reduce or avoid stop-and-go traffic and congestion [179,400]. In particular, the so-called platooning can be used to optimize traffic flow, since vehicles can exchange data with each other and coordinate driving speed, braking characteristics, and distances between the vehicles. As a consequence, vehicle emissions could be reduced by up to 94% [214]. The resulting reduction in air pollution and noise will have a positive effect on people's health [415].

Autonomous mobility on demand can increase mobility in rural areas that are not or only insufficiently served by regular public transport and thus contribute to equal mobility [390]. Furthermore, the supply of goods and services can be improved through autonomous driving by reducing transport times and increasing the frequency of service intervals. This is also particularly important in rural regions, where the municipal supply of medical care or shopping facilities is often limited.

Furthermore, autonomous driving is expected to increase social sustainability, as it allows for a socially more equitable and self-determined access to and use of mobility [63]. Persons whose ability to drive is temporarily or permanently restricted or not given at all achieve a higher degree of individual mobility. Autonomous driving is thus a great opportunity for people who are too young to drive, for people with disabilities and for the elderly. With the ageing population in industrialized countries, autonomous driving can play an important role in providing access to mobility for elderly people who are losing their ability to drive [352].

So, while autonomous driving offers great potential in terms of social sustainability, there are also some downsides to be expected. These include concerns about data protection and privacy of road users as well as concerns about technology dependence and human immaturity as mobility providers learn much more information about their customers' everyday mobility and know exactly where they live, work and shop [122]. Another much-discussed drawback is the negative impact the introduction of autonomous vehicles could have on the labor market. Some experts argue that there will be no need for professional drivers in the age of autonomous driving [134,317,571]. These include bus drivers, truck drivers, taxi drivers and chauffeurs, sales workers, ambulance drivers. Looking at the large number of people who make a living from those rather low-skilled, undifferentiated jobs, the threat which automation might cause becomes evident.

The way the SAV service is envisioned today, SAVs present an evolutionary development of existing car-oriented mobility services (such as taxi services, ridesharing services, rental cars, and carsharing) towards their full automation [403]. Walker and Marchau among others believe that as a consequence there will be no more employment for taxi drivers [116,571]. However, these researchers and other experts remain quite undifferentiated and vague in making such statements regarding the role of taxi driving in the age of self-driving cars. Others, such as members of the taxi industry are certain that the profession of the taxi driver will rather redefine itself, not disappear [365]. Independent of how exactly the transformation will look like, given that in Germany 255,000 people work as a taxi driver [89], this would mean a large impact on the taxi industry.

Recent studies on the acceptance of autonomous driving and SAVs have indeed confirmed the expert opinion that users have a positive attitude towards the use of such mobility concepts [296,404,508]. If unmanned, fully autonomous taxis were cheaper than manned taxis – as suggested by many simulation studies [177,179] – users would prefer the driverless taxi to the manned taxi [401,405]. In this respect, these empirical studies confirm the potential risk that human taxi drivers face with further automation of vehicles. However, a recent qualitative study by Pakusch et al. [398] with professional taxi drivers showed that they see a right to exist even with the introduction of SAVs. Some of them described their clientele as one that is characterized by regular customers who regularly require assistance from the taxi drivers that goes beyond the normal level of just bringing the customer from A to B. The authors concluded that the nature of the interaction between human driver and passenger is crucial in determining whether a human person is required to be present in self-driving taxis to assist these passengers in using the taxi.

Currently, there are indeed many levels of interaction between taxi driver and passenger. On the one hand, there are interactions of a communicative nature. This includes communication with regard to the processing of the transport order, such as the communication of the destination or other customer needs, or conversations about payment. It also includes the conversations that taxi drivers have with their customers, which range from small talk to information about the region, the city, or regional institutions to confidential or comforting conversations. Taxi drivers also help with loading and unloading luggage, as well as with stowing other items such as wheelchairs or walkers. The taxi drivers go beyond that kind of service whenever they transport passengers in need of special assistance, such as those who are physically impaired or are otherwise restricted in their mobility, when boarding and exiting the vehicle and when fastening their seat belts. They also pick them up at the apartment door, carry their luggage or shopping and physically support them when walking [398]. Regarding this latter group, the human taxi drivers represents a central figure that enables this clientele to be mobile. If, as a result of the automation of the taxi, the aforementioned ways of interacting with a human driver will no longer be possible, some mobility impaired people will be restricted accordingly.

12.2.3 Designing for Passenger-SAV-Interaction

In design-oriented SAV studies, however, this group has so far received little attention. Their relevance with regard to the job of taxi drivers has accordingly been little discussed. Kim et al. [279] analyzed the process of taxi use in order to identify relevant interaction issues that need to be considered in order to replace the human taxi driver. By drafting a customer journey, they map an average taxi ride of a passenger whose only need is to be transported from A to B. While they do identify relevant interaction issues such as “Confirming the destination and route” or “Confirming the exact drop-off location,” their study focuses on the average – thus rather young and fit – users. Other studies focus on the user experience design of (shared) autonomous vehicles with different focuses: special attention is given to interior design, user interface design, and vehicle pedestrian design [416,419,503]. Bass [37], using a method triangulation, concludes in his study that user experience design should address user concerns regarding travel time, comfort, and personal safety. Having participants draw their own designs of SAVs, Stevens et al. consider time use as a starting point for interior design [503]. Pfleging et al. [416] among others, make design proposals depending on the activities that users can imagine doing in AVs and conclude that highly automated cars need to provide a broad range of applications to support these activities.

The vast majority of those studies, thus, has in common, that the needs of mobility impaired people and the interaction of drivers with these people are not being investigated [513]. However, some point out the importance of taking into account the needs of these particular groups of people when designing SAVs, not least because people with disabilities often feel isolated and disadvantaged. Access to mobility is an important aspect of participating in social life and has an impact on the quality of people‘s lives [461].

Taking up this problem, there are a few studies that focus on people with reduced mobility. The focus group study of Brinkley et al. [77] revealed that people with visual impairments consider self-driving vehicles to have a great potential increasing their mobility and independence, but they fear that their specific needs will not be taken into account in the development and design of the respective automated mobility concepts. The comprehensive study by Allu et al. [13] analyzed the needs and requirements that people with different types of disabilities have concerning AVs and makes suggestions for user interfaces adapted to the respective type of disability to facilitate the exchange of information. Lutin [324] demands that the needs of people with mobility impairments must be taken into account when designing autonomous vehicles. Among other things, he recommends the use of robotic assistance to facilitate getting in and out of the vehicle and to secure the people’s equipment on board. Other services that go beyond these and partly take place outside the vehicle, but are nevertheless part of today's taxi service, are not covered by these studies either. However, these represent a need for which a human assistant may still be needed in the future.

12.3 Approximating the Relevance of Needy Customers in the Taxi Industry

12.3.1 Method

Data on the use of taxi services and taxi customers in Germany are rare. For the analysis of the usage data, we use an existing data set, which was collected and published in 2014 [258]. The representative survey on customer satisfaction with taxi companies was commissioned by the German Taxi and Rental Car Association (BZP). The basic population consists of German-speaking persons from the age of 18 who live in Germany and have a telephone connection. The data was collected through Computer Assisted Telephone Interviews (CATI). The sample was randomly selected using the ADM telephone sampling system. Within each household, the target person was selected randomly using the last-birthday method. The net case number is n=1,580, of which 488 were interviews with taxi users and 1,092 were interviews with non-users. The interviews were conducted over a period of 2 weeks from 13 January to 27 January 2014.

The results of the survey have been published in a general report and a tabular report and are not available as raw data but only in aggregated form. The data allow a descriptive analysis. In the analysis we focus on those taxi users who stated in the survey that their mobility is limited due to health problems. We analyze how large this group is and how they differ from the other taxi users in terms of their taxi use. Since the data was partly available in aggregated form (example: when asked how often the participants used a taxi in the last 6 months, the answers were partly clustered in groups: 6-10 times), we calculated conservatively – i.e. with the lower values in each case.

12.3.2 Findings

First of all, the survey showed that about one third of the people occasionally use a taxi (488 of the 1580 respondents). Of these 488 people, 72% used it relatively rarely, only one to three times during the relevant period, a further 18% used it occasionally, i.e. between 4 and 10 times during the half-year period, and 9.4% used the taxi intensively, i.e. more than 11 times. Of the active taxi users, 9.2% (45/488) are restricted in their mobility due to health problems, such as walking difficulties, impaired vision or other restrictions. They form the group that is potentially in need of assistance and dependent on a taxi service. They differ from taxi users who are not restricted in

Table 12: Taxi use of mobility impaired individuals I
(Extract from [267], translated)

		TOTAL	MOBILITY-IMPAIRED			
			Yes		No	
		488	45		444	
Frequency of use	Intensive users	47	10	22%	36	78%
	Occasional users	90	11	13%	79	87%
	Rare user	341	23	7%	328	93%
Last taxi ride alone or together with other people	Alone	150	22	48%	129	29%
	1	120	12	27%	109	24%
	2	74	3	6%	71	16%
	3	74	7	16%	67	15%
	4	39	2	4%	37	8%
	> 5	32	-	-	32	7%
Taxi order	By telephone	359	39	88%	320	72%
	Per app / Internet	2	-	-	2	*
	Taxi stand	70	2	6%	68	15%
	Hailing on street	49	2	4%	47	11%
	Other	4	1	1%	4	1%
	Don' t know	4	*	1%	4	1%
Age	18 to 29	134	5	11%	129	29%
	30 to 39	70	1	1%	70	16%
	40 to 49	80	1	2%	79	18%
	50 to 59	74	7	16%	67	15%
	60 to 69	56	9	21%	47	11%
	> 70	74	22	49%	53	12%
Number of persons in household	1	74	16	36%	58	13%
	2	178	22	49%	156	35%
	3	77	6	14%	71	16%
	4	91	1	2%	90	20%
	> 5	69	-	-	69	16%
Occupation	Fully employed	250	5	11%	245	55%
	Employed part-time	54	3	7%	51	12%
	Unemployed	6	-	-	6	1%
	In training	50	1	1%	49	11%
	Housewife/househusband	16	3	7%	13	3%
	Pensioner	111	33	73%	78	18%

their mobility both in terms of their demographic characteristics and their taxi use behavior. Compared to the non-restricted taxi users, they are characterized by a higher age: While only 22.5% of the non-restricted taxi users are 60 years old or older, the proportion is almost 70% among the mobility impaired. They are more likely to live alone in the household (35.6%) than the non-restricted (13.1%) and are less likely to have a car in the household (62.2% compared to 87.8%). At 73.3%, most of them are pensioners (Table 12).

Compared to other taxi users, mobility-impaired individuals use a taxi service much more often. About 22.7% of them are intensive users, i.e. they use taxis comparatively often, some even several times a week (8.9%), another 25% use them regularly, and about 52.3% rarely use taxis. Among the other taxi users, only 8.1% are intensive users, 17.3% are occasional users, while

Table 13: Taxi use of mobility impaired individuals II
(Extract from [267], translated)

	Total	Mobility-Impaired			
		Yes		No	
	438	**41**		**397**	
Events, parties or other leisure activities	259	4	*11%*	252	*64%*
Arrival / departure to airport / train or bus station	49	3	*8%*	45	*11%*
Private vehicle not available	17	3	*6%*	15	*4%*
Public transport not (no longer) available	11	-	-	11	*3%*
Medical / health reasons / patient trip	50	21	*52%*	29	*7%*
Visiting relatives, friends	29	3	*8%*	26	*7%*
Shopping / procurements / transport of goods or items	9	3	*8%*	6	*1%*
Acute / sudden situations	6	-	-	6	*2%*
Other	9	3	*6%*	6	*2%*

about three quarters use the taxi only rarely. This illustrates the high relevance of taxis for people with limited mobility.

If we look at all taxi users, it is clear that by far the largest proportion (59%) of journeys were made in connection with events, parties or other leisure activities (Table 13). Here, however, the non-restricted individuals are particularly predominant. For them the proportion is as high as 63.6%, while only 10% of the mobility impaired use the taxi for these reasons. In contrast, they use the taxi mainly for health or medical reasons or use it for official patient trips (52.5%) and they also use it more frequently for everyday trips such as shopping or other services.

Nearly every second taxi user with limited mobility uses the taxi on his/her own (48%). This is much less common among users without mobility restrictions (29%). Many of these potentially needy passengers are therefore left on their own during taxi rides and do not receive any assistance from an accompanying person. For those, the presence of the human driver is therefore potentially most significant.

Overall, the survey showed that taxi customers were very satisfied with the taxi service. For the mobility impaired more than for the rest of the population, the positive experience is more due to the punctuality, reliability and helpfulness of the taxi drivers. Overall, people with reduced mobility rated the price-performance ratio of a taxi better (1.9) than people without reduced mobility (2.3). This could be due to the fact that they rely to a certain extent on the taxi and benefit not only from the pure transport but also from other services, such as the helpfulness of the drivers.

With regard to the way in which the taxi is ordered, it is noticeable that passengers with reduced mobility almost always order the taxi by telephone or from the taxi dispatcher (88.6%), while others more often call the taxi spontaneously by going directly to a taxi stand (15.3%) or by hailing a taxi at the side of the road (10.6%). People with limited mobility therefore tend to plan their taxi journey in advance. However, it cannot be ruled out that this effect is alternatively attributable to the higher age.

In total, the respondents used taxi services for 2315 trips during the 6-month period. On the assumption that the journeys of persons with reduced mobility will be relevant in terms of human assistance for taxi rides, it is useful to find out what proportion of the total number of journeys is made by persons with reduced mobility. For this purpose, we analyze how often the mobility-impaired users have used a taxi during the 6-month period. The figures vary between 10 people who used a taxi only once and 7 people who used a taxi more than 15 times. According to a conservative calculation, passengers with restricted mobility account for at least 419 of the 2315 trips. This corresponds to a share of at least 18.1%. Thus, although the mobility-impaired account for only 9.2% of the users, they account for 18.1% of the total number of trips due to the more intensive use of taxis.

12.4 Discussion and Implications

The results suggest that in the age of SAVs there will be mobility consumers who will need human assistance – i.e. some kind of a travel companion – to use autonomous vehicles. These findings are of particular importance for two groups of people that are in the focus of this paper: On the one hand for taxi drivers, whose professional right to exist in an autonomous future depends on whether their human person is needed or offers passengers added value. On the other hand, for the mobility impaired themselves, whose special needs should be taken into account when designing driverless taxis. Both aspects will be discussed in more detail below.

12.4.1 Relevance and Implications for the Taxi Business

A share of 18.1% of the total number of journeys does not constitute a majority, but nevertheless represents a significant quantity for the taxi business. Of course, the share of 18.1% does not automatically mean that even in the age of autonomous vehicles, 18.1% of the trips will be characterized by the fact that these passengers need the kind of support that makes a human person indispensable. Rather, this estimation should be understood as the best possible approximation that is possible on the basis of the data available today.

Some aspects must be taken into account when interpreting this estimation. Firstly, there are reasons why the proportion of journeys where human assistance is required is lower. Not all mobility-impaired individuals per se require assistance when using a taxi. While there are some passengers with reduced mobility who cannot make it to the vehicle alone, cannot get in on their own, cannot stow their luggage on their own and cannot fasten their seatbelts, there are certainly some passengers whose limitations are not so extensive. These passengers could possibly use an SAV, as it is currently being designed for standard journeys [279] or for special activities in the vehicle [419,503], even without human assistance. With regard to the economic importance of these journeys, it must also be added that this figure is the absolute number of journeys – the data do not provide any information on how long the journeys of those individuals with mobility impairments are compared to the average journey, i.e. what proportion of the turnover of the taxi business these journeys represent.

On the other hand, it is known that the demographic structure in western countries like Germany will change in the future. Given the perspective that in these countries people are getting older and therefore more diseases are to be expected [412], it is possible that the number of people who need help with their mobility will increase.

With regard to the taxi business and the importance of human taxi drivers, these figures confirm the statements made by taxi drivers in a recent qualitative study that pointed to the relevance of customers in need of assistance [398]. For example, some professional taxi drivers stated that they not only have a clientele that sometimes requires intensive physical assistance when using the taxi service, but that for some drivers this type of customer forms a significant part of their regular clientele. The calculated figures therefore support the argumentation of these taxi drivers that in the age of autonomous taxis they will not be completely dispensable due to these required supporting services. However, it is questionable whether professional taxi drivers will actually continue to perform this type of task. At present, the supporting services are closely linked to the driving task and in combination form the taxi service. However, it is questionable whether it will actually still be the taxi drivers who will take on the role of a driving companion in a future in which the driving task has been separated from the supporting service. Whether taxi drivers would even like it if their tasks were to concentrate solely on the supporting service is another question. Ultimately, the role of the assisting person could be taken over by different persons, who in turn are commissioned either by the SAV operators or private companies, public institutions or the mobility-impaired people themselves. SAV operators could retrain taxi drivers or train new staff to be used for such journeys requiring assistance, similar to the program Uber and Lyft recently started in some countries (UberAssist, [161]). In addition, nurses for the elderly or nurses for the sick could take over these tasks. It is also conceivable that in future more volunteers will take care of the needs of people in need, for example in the form of a social-oriented gap year or voluntary work, as is common i.e. in Australia [415]. Finally, it is also possible that the support has to be organized by the needy individuals themselves, by assigning assistants or by asking people close to them for support.

We know from examples such as the elevator operator that occupations can remain in a modified form even though they are basically no longer needed. Its primary task of opening and closing elevator doors and directing the elevator to the desired floor has been rendered obsolete by the invention of button operation. As a result, elevator operators have disappeared in most industrialized countries, as elevator passengers could now select the floor themselves and the elevator doors closed and opened automatically. Nowadays, elevator operators are therefore only found where monitoring of elevator operation is necessary for safety reasons. In Europe, they are rarely found in hotels or large department stores, while the so-called elevator girls are still widely found in Japan [357]. A similar development is conceivable in the taxi industry: Some providers could employ taxi drivers or driving attendants in their vehicles in the sense of an exclusive service, regardless of passenger restrictions.

12.4.2 Relevance and Implications for the Traditional Taxi User

In the scenario where the mobility impaired individuals will continue to rely on the traditional taxi service, while others will switch to unmanned SAVs, the density of human assisted taxis will decrease. As a result, manned taxis are expected to have longer journeys to the customer's pick-up location on average, with more empty time and therefore higher costs.

This results in new, unsolved challenges i.e. as to how a nationwide supply of traditional taxis can be ensured, how the increased costs can be passed on to the individual and the community, and how at the same time fair working conditions for taxi drivers can be ensured.

As mentioned, in Germany taxis are part of the public service, which is under the care of the public authorities. In this case, business models are conceivable in which traditional taxi services with human assistants are subsidized by the state. For example, it would be conceivable that taxi drivers would receive a kind of basic salary for providing the taxi service, regardless of whether it is requested by customers. The exact form of a “stand-by fee” would certainly depend on many factors, such as the level of population density (urban/rural), when and how many hours the taxi service is provided, etc.

12.4.3 Considering the Impaired in the Conceptual Design of Shared Autonomous Vehicles

In the development and design of mobility concepts with self-driving vehicles, the focus is currently on the average person or average taxi customer. Experts and scientists generally agree that fully autonomous vehicles have a great potential to help non-drivers, the young and the elderly, as well as people with disabilities to achieve better mobility and greater independence, and thus to create a more equal access to mobility [343]. However, especially the groups of people with different kinds of disabilities currently receive little attention in the design of autonomous vehicles in general and automated taxis in particular. Our results have shown that the number of those who potentially need human assistance in the use of SAVs is considerable.

Some design approaches already take special groups of people and needs into account. In their comprehensive study, Allu et al. [13], for example, have worked out what kind of interfaces for communication are suitable for people with different kinds of limitations. Amanatidis et al. [15] also study user interfaces and formulate different design recommendations to equally meet the needs of all users including the impaired. User interfaces should be able to adapt to the abilities of the individual user. For example, interfaces for people with a visual impairment should be controllable via voice control. In addition, the displays should be adaptable in terms of brightness, contrast, angle and font size, and the user should be able to first, individually enlarge and reduce the size of the contents on the display, and to second, hold the user interface in his hand to adjust the viewing distance individually. Voice control would be equally interesting for people with reduced mobility, as they may not be able to move as freely within the vehicle as unrestricted persons. In addition, the vehicles should offer the possibility of easy access and egress, e.g. in the form of ramps that allow wheelchairs or other walking aids to enter or leave the vehicle. Accordingly, there must be enough space inside the vehicle, or space must be able to be created (e.g. by folding away seats), where a wheelchair can be placed and securely fastened or where other supporting objects can be placed and secured. For those passengers who have very severe physical limitations, there must also be the possibility of automatic seat belt closure. Similar to a roller coaster, these should be able to automatically fasten a seat belt or safety bar and should also be controllable by voice commands. Eye tracking and gesture control are also desirable features for the severely restricted passengers [13,15].

However, such studies and the resulting design approaches usually consider the SAV as a closed entity, i.e. the interior, the interfaces, and the access of the vehicle. Since some passengers require assistance before entering or leaving the vehicle, it is necessary to extend the design of SAVs to additional services and support. Thus, when designing the SAV concept, assisting persons should also be considered to take over such supporting tasks as discussed in the latter section.

Irrespective of the fact that our study has shown that a relevant proportion of all taxi rides are carried out by such people with impairments, there is also a social and moral obligation for scientists, developers and designers to take into account the special needs and requirements of these people. If, on the other hand, this vulnerable group is disregarded, this would result in an increasing isolation and a further deterioration of their already limited mobility, independence and autonomy.

12.5 Limitations

This work does not come without limitations, of course. First of all, the accuracy of the results should be mentioned here. The method of secondary analysis uses existing data, data that were originally collected for a different purpose than the present analysis. In this case, the authors did not have access to the raw data of the primary study, so that they only evaluated the existing partially aggregated values with regard to the present research questions. More detailed and precise data on the dependence of taxi users on human assistance are needed in order to make reliable statements.

Furthermore, the results and implications only have limited validity for other countries in which the use of taxis, especially the servicing of people with restrictions, differs from the conditions in Germany. For Germany, however, the sample is representative, so the findings are at least to some extent transferable to other western countries with a similar age structure.

With regard to the significance of the calculated figures, it must also be critically noted that it remains uncertain what proportion of people with mobility impairments will actually need assistance in using a taxi or, in the future, an SAV.

12.6 Conclusion

Autonomous driving is on the threshold of becoming reality. Different mobility concepts are being developed and some of them are already being tested within the framework of projects. Experts expect that automated taxis in particular – also often referred to as shared autonomous vehicles – could help autonomous driving to gain social acceptance and widespread adoption [375]. While for some people this development may mean easier and more equal access to flexible mobility, for others it poses a threat. On the one hand, for the group of taxi drivers whose job could become obsolete with the introduction of autonomous, unmanned taxis, and on the other hand, for people with impaired mobility who are dependent on human assistance when using mobility services.

While these dangers are generally known and are being debated in the literature, there is a lack of precise knowledge about how large the group of these mobility-impaired people is and what proportion of their trips make up the taxi business. By means of a secondary analysis of a representative customer survey on taxi use from 2014, we calculated that 9.2% of all taxi users in Germany are restricted in their mobility and that these customers are using taxi services more often than the average person [258]. In total, they account for approximately 18.1% of all taxi trips. This relatively high figure shows how important the offer of taxis is for the mobility of these people. At present, people with reduced mobility are only considered to a small extent when designing autonomous taxi services and usually the consideration of their needs is limited to the interior design [13] or the design of user interfaces [77] of autonomous vehicles. However, there remains the danger that consideration of this type of restrictions is not sufficient if, for example, assistance is also required outside the vehicle – such as accompanying passengers from the front door to the vehicle – to use the taxi service. In this respect, it is necessary to check whether SAV services, as they are currently being designed, actually address the needs of all people, or whether there are users who experience a disadvantage due to the absence of a human person in the taxi service.

Whether human taxi drivers will still be needed in a future with autonomous taxis cannot be conclusively assessed. The calculation shows that the proportion of taxi customers whose mobility is restricted is relatively high. Some of the tasks that taxi drivers perform today will probably also be in demand in a future with autonomous taxis. While the driving task will be eliminated, taxi drivers could concentrate on these support-oriented tasks. However, it is also possible that these tasks will be taken over by other people.

While the presented figures should be viewed with caution, they do provide an important indication of how relevant the group of people with mobility impairments is to the taxi industry, and how important it is not only to consider their special needs when designing mobility services with autonomous vehicles, but also to let them participate directly. A further study could therefore investigate this group of people with restricted mobility more closely and ask them whether they can do without human assistance, for what reasons they could not do so, and how an autonomous taxi would have to be designed so that they could use it without human assistance.

13 DISCUSSION AND FINAL REMARKS

Since the advent of the modern sharing economy, its sustainability effects have been the subject of controversial debate [119]. While their potentials were initially discussed as post-ownership development with a view to decentralizing value creation and increasing social capital and environmental relief through better utilization of material goods [243], critics have become increasingly loud in recent years [189,334].

In some areas, the principle of using instead of owning has successfully established itself. Music, films, and computer games in particular are now being consumed flexibly and in a demand-oriented manner instead of being bought [567]. Completely new business models and payment systems have replaced former market mechanisms [569]. In other areas of life, however, the trend has not been as prevalent as in the media world. Many people hoped that carsharing could lead to a development away from ownership towards flexible use and thus more resource-efficient and resource-saving mobility [94,103,336]. However, in the area of mobility, the decisions made by users tend to be oriented towards the long term: The purchase of a car or a subscription to a public transport ticket entail a certain commitment to using this mode of transport frequently [235,485]. Furthermore, established routines and practices that are closely interwoven with other areas of life such as work or leisure make it difficult to switch to other or new modes of transport – such as carsharing [560]. In addition, many people consider carsharing not to be advantageous to the means of transport used to date in terms of cost, flexibility and comfort [124,585]. Despite many further technological and organizational developments and an increase in the number of services on offer in recent years, carsharing remains niche.

One innovation that could elevate carsharing from this niche in the future is autonomous driving. This technology could help shared mobility gain a new boost by overcoming the weaknesses of the present carsharing business model. Flexibility and comfort could be greatly enhanced by SAVs, bridging the private car and taxi, while at the same time offering benefits in terms of low cost and better use of time without the burden of vehicle ownership. It remains questionable, however, whether this concept can make a positive contribution to a more sustainable mobility or whether the use of such SAVs would be at the expense of less polluting means of transport. Transport research has been intensively analyzing the possible economic, social and ecological consequences of autonomous driving for several years.

To contribute to this scientific discourse, this thesis analyzed what behavioral changes SAVs could cause with regard to individual mobility and what this might imply from a sustainability perspective. Therefore, by carrying out mixed-methods analyses of users' attitudes towards SAVs and their expected service attributes in contrast to alternative modes of transport, as well as professional drivers' views of the potential risk of being replaced by SAVs, I provided empirical evidence that may inform future research as well as the design of responsible SAV business models and SAV regulations.

13.1 Summary of Findings

A scenario analysis served as the starting point for our investigation in order to explore the possibilities of the future with autonomous driving. This analysis showed that it is highly likely that private connected and (partially) automated cars will exist in the future. However, it is also possible that SAV will be more widely used in the future if the users' attitude continues to develop towards a demand orientation instead of an ownership orientation. So far, the literature has been very strongly driven by theoretical assumptions. While some studies predicted that with the availability of SAVs, personal ownership of vehicles will be out of fashion [176,492], others focus on a future with private autonomous vehicles [388,410]. Various studies have attempted to model the shares on the basis of expert surveys [47,415,541]. While these studies aim at anticipating the effects of autonomous vehicles, including the mode choice behavior of users, we have tried to empirically capture such effects by including the users themselves. By doing so, we supplement the current discourse with regard to the effects of (shared) autonomous driving. Our empirical studies support the assumption of those who consider it likely that both variants will coexist, with private (autonomous) vehicles likely to be preferred to SAVs. From a user perspective, the SAV proves to be preferable to public transportation and traditional taxis. All three findings are now presented in detail and discussed in contrast to the findings of recent studies. The summarized results as presented in Sections 13.1.1 and 13.1.2 serve to answer the first main research question, on the ecological impacts of SAVs, while the summarized results in Section 13.1.3 serve to answer the second research question, on the social impacts of SAVs.

13.1.1 Users Prefer Private (Autonomous) Vehicles to Shared Autonomous Vehicles

The expectation that SAVs will lead to the hoped-for large-scale modal shift in favor of mobility as a service, as represented by carsharing proponents or other optimists [176,492], does not seem realistic from today's perspective. On the contrary, ownership will continue to play a central role in people's mobility in the future. The majority of participants of the studies at hand would prefer a private vehicle to a shared one. This preference was evident both in the qualitative study (Section 6) and in the quantitative studies (mainly Section 7: 74.2%, to a lesser extent Section 8). This result is in line with the results of the quantitative studies by Moreno et al. [367] and Zmud and Sener [593], which were conducted in Germany and Texas, United States, respectively: Their studies concluded that about 60% of the participants preferred a private autonomic car over a shared autonomic car [367,593]. The study by Haboucha et al. [227] with participants from Israel and North America also showed a similar trend; the preference of users for privately owned cars was strong, at 76%, with conventional cars being preferred over automated cars. Within our studies, users can also imagine both owning a conventional car and owning a fully automated car. In a direct comparison between the two variants, Study 3 showed a clear preference for the conventional car, thus validating the study results of Haboucha et al. [227]. As such, these results are in contrast to those of Stoiber et al. [508], whose study with Swiss participants revealed approximately opposite results (61% of respondents opted for either a pooled-use SAV or an autonomous shuttle/train combination; 39% opted for private autonomous vehicles). These differences may be due to different study designs or differences in traffic systems.

Within the framework of this work, different reasons for these choices could be identified. It became evident that, already known from mobility research, the users' future mobility decisions are strongly influenced by their routines and their current mobility decisions [469,560]. The differentiated analysis of the respondents' decisions (Section 7.5.2) showed that they would adhere to their behavior patterns: Participants who prefer the private vehicle among today's means of transport will continue to do so in the future – be it conventional or automated (Study 3). In this respect, this analysis is consistent with the findings of Krueger et al. [296], who concluded that most respondents adhere to their current mobility option. Meanwhile, the decisions for or against a means of transport also depend on its specific characteristics, as discussed in the travel mode choice theory [433]. The advantages and disadvantages of the different travel modes with regard to their characteristics were captured in the qualitative interviews (Studies 2 and 5) and could then be validated in the quantitative study (Study 4, Section 8). From today's perspective, the perceived advantages of the conventional car dominate in the view of the study participants, especially for the car owners. In particular, the participants rated the availability and flexibility as well as driving pleasure, control, and cost as advantageous for the conventional car. They also appreciate the car as a private space in which they can leave items that they need regularly or occasionally. The desire to create one's own private space according to one's personal needs also became apparent in the study by Stevens et al. [503], in which participants were asked to design the interior of autonomous vehicles. These results further agree with the expectations of other theoretical [317] and empirical studies [168,296] suggesting that some respondents fear that car automation will limit driving pleasure. In fact, users see an advantage in the autonomous variant only with regard to comfort and time utilization in the car, as much theoretical work has already suggested [176,296,316,317] and empirical work such as that by Ashkrof et al. [22] and Kolarova et al. [287] have also supported. Regarding private cars in general (whether conventional or automated), users appreciate their high comfort and the fact that the car is always available, allowing it to be used very flexibly in the shortest possible time and without prior booking. With SAVs, users also expect a loss of control.

With regard to possible modal shift effects, it can be said that the proportion of those who prefer a private car remains quite stable. The majority of users can be expected to remain loyal to the private car, even if new mobility concepts on demand will be added. Some users can only imagine using SAVs as a supplement and reducing the use of their private car; a small proportion of current car owners can even imagine doing without a car (Study 2). In addition, the private autonomous car will also be of interest to a few users who today prefer carsharing or public transportation. Automation makes the private car more attractive for these non-car owners as they do not have to drive the vehicles themselves.

13.1.2 Users Prefer Shared Autonomous Vehicles to Public Transport

Shared autonomous vehicles have the potential to attract a large number of users. Studies showed that users generally see a great benefit in SAVs and that the a priori acceptance is relatively high (Studies 2 and 4). In this respect, these results are in line with those of other studies that have recently investigated the acceptance of SAVs [42,388,410]. Users can imagine using SAVs both for everyday driving and in situations in which they feel unfit, unable to drive, or stressed by traffic conditions (Study 2). Overall, from the user's perspective, the concept of mobility on demand (carsharing) is experiencing a greater increase in benefits than the private car, as revealed in Study 3. This result validates theoretical assumptions that automation addresses and partially levels the weaknesses of traditional carsharing [296,541,571]. In contrast to the private car (40.4%), the majority of users prefer the fully automated version of carsharing over the classic version (58.9%). A comparison with public transportation shows that the preference for carsharing increases significantly due to automation, respectively the preference for public transportation decreases: Without full automation, 40.6% of users prefer traditional carsharing over public transportation, with full automation 53% prefer carsharing over public transportation (Study 3).

The increased attractiveness of carsharing through full automation has the potential to change the minds of some car owners regarding their choice of preferred mode of transport. For example, Study 3 found that for some car owners, automated carsharing took the place of the car as their preferred means of transport in the future. With regard to the different characteristics, the perceived difference between the modes private car and car on demand was reduced or almost levelled out by automation, as other studies have also revealed [296,541,571]. As a consequence, individual car owners expect that they would no longer need their own car, would sell their car, or would forego buying one if there was an attractive offer of SAVs (Study 2, Section 6). This result corresponds to the expectations of some experts [113,318,320] and shows that the hoped-for modal shift away from the private car towards shared mobility through autonomous driving could be realized to a certain extent. However, my studies also show that the modal shift effect could have a much stronger and negative impact on the use of public transport (Studies 3, 2, 4, and 7). With the automation of the private car and carsharing, the preference for public transport decreases significantly, falling from 21.0% to 15.2% (Study 3). While most people remain loyal to public transportation, among future transport modes, users prefer the autonomous private car or autonomous carsharing. Public transportation users are accustomed to using mobility according to their needs, so the hurdle of giving up ownership and the associated advantages do not have to be overcome. Furthermore, SAVs offer the same advantages as public transport but with much higher comfort and flexibility.

The reason for this shift of preference at the expense of public transportation is the many advantages that an SAV has over public transportation, but less so over the private car. Compared to the private car, SAVs can only score points with a better use of time, which results from the fact that the user no longer has to drive the car independently. However, this advantage even disappears with the automation of the private car. For young, cost-sensitive users, SAVs are attractive because using them could be cheaper than owning and maintaining a private car (Study 2). Compared to public transportation, users almost exclusively anticipated advantages for SAVs, as Study 4 revealed. These include the time savings that would result from using SAVs compared to public transportation. Advantages result from benefits such as reduced travel time due to fewer stops, fewer transfers, and that users do not have to travel to and from bus stops or train stations. In addition, SAVs are expected to offer greater availability, flexibility in terms of departure times, easier ways of transporting luggage or other items, and the advantage of not having to be in a vehicle with strangers (Study 4, to a lesser extent Study 2). In this respect, the users' view on the possible benefits of SAVs is in line with the expectations of experts [177,296,317]. So far, the added value of public transport lies mainly in the low cost and good use of time. Furthermore, no driver’s license is required, users do not have to be fit to drive at the time of use, and they can use the driving time for non-driving related activities. All these advantages are reduced by the automation of the car and by automated mobility on demand, if the problem of motion sickness is solved. The only advantage that users see in public transport in the long run is the lower costs. However, if SAVs are affordable, as simulated by some studies [95,179,492], public transportation will lose competitiveness completely. As Studies 3 and 7 have shown, low-cost SAVs could replace not only taxi rides but also public transportation rides. Our results regarding the impact of SAVs on the use of public transportation thus support the concerns of some rather critical experts [296,317]. This would imply that, as a consequence, public transport would be used less, while motorized private transport in the form of private (automated) cars or automated carsharing would increase if no countermeasures are taken by authorities and transport policies. Instead of reducing private transport and the problems associated with it, the widespread introduction of SAVs at an affordable cost would exacerbate these problems.

13.1.3 Users Prefer Autonomous Taxis to Human Driven Taxis

Our studies have shown that it is indeed to be expected that with the introduction of SAVs, a large proportion of traditional human taxi drivers will become obsolete. In the qualitative Studies 2 and 7, most young adults were in favor of using an SAV and against using a human-driven taxi. Young people can imagine using SAVs for journeys for which they have previously used traditional taxis (Studies 2 and 7). This includes in particular journeys in situations in which they have no other mobility alternative and cannot drive or feel unfit to drive, especially journeys to or from events and parties. As such, these findings concerning taxi use correspond to representative data on actual taxi use in Germany [258]. However, users can also imagine making other journeys with the SAV, including everyday trips, running errands, and as a transfer or last mile solution to the station or airport or back. These findings are in line with the results of the study of Bansal and Kockelman [30], who found that most people are interested in using AVs for all types of trips. Individual taxi drivers reported that their clientele consists mainly of young and fit people and confirmed the expectation that this type of customer can do without a human driver (Study 6). From other professional taxi drivers, by contrast, we learned that they do indeed serve a relevant clientele that will continue to rely on a human being present during the taxi ride to assist them. The decisive factor as to whether in the age of autonomous taxis a human being must be present in the vehicle as a driving companion is the role of interaction and assistance between passenger and taxi driver, respectively taxi companion, as was shown in particular by the study with professional taxi drivers (study 6) and the analysis of the taxi use of young taxi customers (Study 7). As Study 8 revealed, the proportion of taxi trips in Germany in which the human driver/accompanying person may continue to play a role in the future is relatively moderate: Of active taxi users, 9.2% are restricted in their mobility due to health problems, such as walking difficulties, impaired vision, or other restrictions. These customers use taxis mainly for health or medical reasons or for official patient trips. They also use taxis more frequently for everyday trips such as shopping or other services compared to non-impaired taxi customers. Human support is probably most likely to be relevant here. The majority of people with reduced mobility are 60 years or older [258]. While this group accounts for a relatively small fraction of all taxi customers in Germany, mobility-impaired individuals use a taxi service much more often than the non-impaired. Around 18.1% of all taxi rides are attributable to this group of the mobility impaired.

When deciding between a traditional human taxi and an SAV, price will play a decisive role. Millennials in particular are very cost sensitive and choose an SAV when it is cheaper than a human driven taxi. Some taxi passengers would prefer an SAV to a traditional taxi, even if it is the same price, and individual ones even if they are more expensive (Studies 2 and 7). Different simulation-based studies [95,179,492] expect autonomous taxis to be cheaper than traditional taxis. The importance of price in the choice of both taxi variants supports the expectations of some experts regarding the use of SAVs [317,571]. The respondents of our study are aware that the automation of the taxi industry will lead to job losses, and they actually feel that it is a disadvantage of such a development. Nevertheless, a cost advantage outweighs this negative aspect when it comes to the concrete decision. What further induces the preference of SAV over human-driven taxis is that the young taxi users do not see any added value in the person of the driver. Some do appreciate the fact that they can talk to the driver, that he or she takes care of navigation and route finding for them and helps them with their luggage. However, they consider these services to be expendable. Some have even had explicitly bad experiences with taxi drivers, including unfriendliness, unwanted conversations, and traffic violations. These person-related disadvantages of taxi rides would disappear with the introduction of SAVs.

Currently, there are many levels of interaction between taxi driver and passenger. On the one hand, interactions of a communicative nature. This includes communication with regard to the processing of the transport order, such as the communication of the destination or other customer needs, or conversations about payment. It also includes the conversations that taxi drivers have with their customers, which range from small talk to information about the region, the city, or regional institutions to confidential or comforting conversations. Taxi drivers also help with loading and unloading luggage, as well as with stowing other items such as wheelchairs or walkers. Taxi drivers also help passengers in need of special assistance, such as those who are physically impaired or are otherwise restricted in their mobility, when boarding and exiting the vehicle and when fastening their seat belts. They also pick them up at the apartment door, carry their luggage or shopping and support them when walking.

Many of these tasks can be taken into account and thus covered when developing SAVs. This is especially true for communication. All information for processing the journey can be transmitted via information and communication technologies, as is already the case with taxi apps or TNC apps. In addition, mobility services such as buses or trains can already be used today without any personal communication, which suggests that this could also work for future autonomous taxis.

Some SAV design studies are dedicated to the interaction between passenger and SAVs and address these aspects of communication [164,581]. In addition to an app and dashboards installed in the SAV, they also propose voice assistants that allow passengers to communicate with the SAV system. This is more difficult, however, if the passenger cannot articulate properly. Shared autonomous vehicles will also offer possible solutions for these situations, such as automatic translations for foreign language speakers and transmission of the destination address via app, smartphone, or ID card. Here, a real person might be superior to a robot, as he or she can try to find out what the passenger wants by using and combining different means of communication. However, this situation seems to occur only rarely and is not particularly relevant. The more sensitive and emotional the communication between taxi driver and passenger, the more likely the human is to be superior to the robot. It is true that chatbots can also have conversations with the passenger, answer questions, or provide information about the region in the manner of a travel guide. However, taxi drivers also reported that some passengers pour out their hearts and talk about personal problems, or that they occasionally transport mourners from a funeral who need comforting. Even if chatbots were to say the same words to the passengers here, the question remains of whether the passengers receive the communication equally or prefer the human being. It is to be expected that the loading and unloading of luggage, as well as easy access for people with wheelchairs, walkers, or strollers will be taken into account when designing SAVs. This is suggested by initial design-oriented studies and was implemented in concept cars that add grab arms or an even access to the vehicle [324]. It will, however, be a challenge to map the assistance in securing people in need of help, such as fastening seat belts. Additionally, assistance that takes place outside the vehicle but that is nowadays part of the taxi service such as seeing passengers from the door to the vehicle might be difficult to address. These could be other tasks in which a human companion will be needed in the future.

According to some taxi drivers, a substantial proportion of their clientele is made up of customers who require intensive assistance on a journey and who are loyal regular customers. This view is well supported by statistics: Customers who use taxis for patient trips or who are mobility impaired use taxis more intensively, that is, several times a month, compared to than other customers (see study 8; [258]). Against this background, it is to be expected that the taxi market will differentiate itself in the age of autonomous driving. While a large proportion of journeys could be executed by SAVs, a certain proportion of customers have special needs or require assistance, meaning that a human driver or driving companion may still be needed in the future. As a consequence, this means that although the taxi driver profession is not expected to become completely obsolete, significantly fewer taxi drivers will be needed. In this respect, our study validates to a large extent the theoretical claim of many previous studies that the profession of taxi driver is becoming obsolete [46,63,134,571]. However, our analysis has shown that such an un-reflected and undifferentiated consideration and sweeping statement is probably not justified. In this respect, my studies make an important contribution to the existing literature dealing with the consequences of autonomous driving.

13.2 Implications for the Design of SAVs

The studies have shown that SAVs basically have the potential to attract car drivers. These could subsequently do without a car and shift their mobility to alternative on-demand services. From an individual point of view, SAVs should therefore be designed in such a way that they are particularly attractive to car drivers, so that the desired modal shift can be achieved. Our studies have shown that, from today's perspective, users prefer the private car over SAVs, mainly due to better availability, flexibility, greater control and driving pleasure, reduced waiting times and costs, and greater ease transporting things (Section 8.4.1). These characteristics must therefore be addressed in the development of SAVs. In order to be able to compete with the private (autonomous) car, such development places correspondingly high demands on the design and service level of SAVs.

Our studies revealed that SAVs should be significantly cheaper than private cars in order to attract former car owners. In this respect, they are consistent with the findings of other studies that have shown that the price of SAVs is the decisive factor in their successful adoption [227,296]. Few participants were willing to pay a surcharge for an SAV due to their greater convenience. According to the various SAV studies [179,492], these expectations are basically feasible. Simulation studies, such as that conducted by Burns et al. [95], show that this cost expectation can generally be realized. In these studies, SAV costs vary between USD 0.25 and 0.62 per kilometer, indicating that SAV trips could actually be cheaper than trips by private cars or taxis, depending on the fleet size and capacity utilization. However, the authors assume that the operating costs of SAVs will be higher in the early phases of SAVs and that these costs will only fall in the long term due to efficiency advantages. The providers who want to offer SAVs on the market will therefore be faced with high investments and initial losses. They therefore need a sufficient nest egg to survive until SAVs are widely accepted, and they can benefit from the cost-winning phase. Some comments have revealed that study participants are not aware of the true costs of mobility. This phenomenon has also been observed in previous studies [196,491]. Nevertheless, participants state that costs are an essential factor. There seems to be a discrepancy between actual and perceived facts: In this case, the users' subjectively perceived costs is the factor relevant to decision-making. If a driver thinks that his or her car is cheap, because he or she only thinks of fuel costs, but not of depreciation, insurance, and other costs, then this lower amount and not the actual total cost of ownership is decisive for the comparison between mobility alternatives and the resulting decision (see 2.2). The reason for this is that once an investment decision, for example, to purchase a car, has been made, the (one-time) investment is often treated as a sunk cost and is not included in the individual calculation and decision-making [248]. It is therefore not relevant for the user when comparing mobility alternatives.

In addition to costs, availability and waiting time are crucial factors to be taken into account when designing SAVs for an intended modal shift. For private cars, the waiting time until the start of the journey is almost zero, as a journey can basically be started at any time. The availability is also very high, as the car is exclusively available for its owner. Various SAV simulations have calculated waiting time. According to these studies, the high demands on the availability and waiting time of our respondents can be met. The study by Burns et al. [95] shows that, with a fleet of 3,500, 18,000, or 9,000 shared driverless vehicles, an average waiting time of less than one minute could be achieved in small, medium-sized, and metropolitan cities. The simulation results for the model region Singapore from Spieser et al. [492] promise maximum waiting times of approximately 30 minutes during peak hours for a fleet of 250,000 vehicles. If the number of vehicles is increased to 300,000, the maximum waiting time is reduced to 15 minutes. Fagnant and Kockelman [177] calculate an average waiting time of 0.295 minutes, with less than 0.5% of users needing to wait five minutes or longer for an SAV. In a further study, Fagnant et al. [179] simulate the average waiting time at one minute, with 94.3% of travelers waiting less than 5 minutes, 98.8% of travelers waiting under 10 minutes, and just 0.10% of travelers waiting 15–29 minutes. Fagnant and Kockelman [178] also included the option of dynamic ridesharing in their calculation and concluded that dynamic ridesharing reduces the average waiting time from 9 to 4.5 minutes in peak hours (5 p.m.–6 p.m.). The daily average waiting time is 1.18 minutes, with 98.6% of travelers waiting 10 minutes or less. Thus, given a large fleet of SAVs, the average waiting time and availability can meet the user's requirements.

If correspondingly low costs and short waiting times can be achieved, as suggested by these calculations, user requirements for high flexibility can also be met. The flexibility of an SAV would hardly be inferior to the flexibility of a private car. However, there is always the risk for the users that they will not benefit from the average low waiting time but will have to wait much longer – even if the probability for this case is very low. In this respect, the flexibility of an SAV may converge very closely to the flexibility of a private car, but in the end the private car will remain slightly advantageous.

As other studies also revealed, for some users, vehicle control is essential [241,445]. Some wish to be able to switch between fully automatic control and self-control or to have the possibility to influence the vehicle's driving style and directions. Control is related both to the feeling of safety and to driving fun. Including an optional takeover request is a problem, since the takeover time can take up to 30 seconds [262]. Especially when thinking of dynamic ridesharing, this variant is hardly feasible; as soon as more than one person was a passenger of the SAV, the question arose as to whether and which of them should take over control and whether the other passengers would agree. It is questionable whether SAVs – especially with dynamic ridesharing – will be perceived in the long term not as private individual traffic but as public individual traffic. In the latter case, it might not be as important for passengers to be able to drive the vehicle themselves, similar to the current attitude towards public transport or taxis. Positive user experiences and an increased sense of safety could also reduce the desire for control takeovers in the long term. It is thus conceivable that the market will become more differentiated in this area and that vehicles will be offered in which it is possible to switch to human control, while in others only technological control will be provided.

With regard to the transportation of goods, SAVs could be equipped with technology to facilitate the loading and unloading of objects, purchases, or luggage. For example, grab arms could assist passengers in loading or unloading personal items. In order to make it easier for people with restricted mobility or wheelchair users to enter the vehicle, SAVs would have to be equipped with a level access or with ramps that compensate for a difference in height. Renault, for example, has come up with corresponding design proposals [324].

13.3 Implications for a Responsible Transition to the Automated Era Considering Driver-Related Jobs

With the prospect that the tasks of the taxi drivers and thus their importance will decrease with increasing automation, it becomes necessary to arrange this development in a responsible manner. Experts assume that SAVs will become widely accepted on the market even before private autonomous vehicles [62,296]. If policy makers do not intervene in the design and regulation of SAV services, it can be expected that there will be similar developments as in industries in which people have stuck to old systems for (too) long, although change was inevitable. The coal industry can be cited as an example here. Although it has been known for decades that generating energy from coal is highly harmful to the environment, and it has now been decided that coal-fired power plants are to be gradually shut down, further investment in the coal industry has been made in recent years. As a result, the state will have to make enormous compensation payments and structural aid payments. In terms of the taxi industry, this would mean the further issue of taxi concessions by the cities and municipalities, as well as the further training and employment of new taxi drivers. In order to avoid this scenario, the issue of taxi licenses and the training and employment of human taxi drivers should be successively reduced in line with the spread of SAVs.

Until the large-scale introduction of SAVs, the preparation period should be at least 10 years [317]. This time window accordingly offers sufficient opportunities for drivers to withdraw from the profession, for example, to retire or retrain for other positions. If their vacant positions are then not re-staffed in line with the market penetration of SAVs, the number of human taxi drivers will automatically shrink as a result. In this way, the taxi drivers who are already established in the profession could be deployed in the manned taxis, while no or significantly fewer new taxi drivers would enter the job market. The decisive factor is appropriate communication of the expected progress and changes, so that retraining and reorganization processes can be initiated in time [415].

In Studies 6 and 7, we found that taxi driving without a human driver is possible and sometimes even preferable for a large number of users, but we were also able to identify the clientele of taxi drivers who would probably not be able to use an SAV if they were on their own. Therefore, it is to be expected that there will be a certain need for human accompaniment for taxi driving in the future with autonomous vehicles. The taxi drivers have stated that the performance of such tasks related to assisting these passengers is inextricably linked to their role as taxi drivers. If the automation of the vehicles means that the driving task is no longer necessary, these two tasks will be unlinked from one another. The tasks related to the support of the needy and mobility-impaired clientele could then still be performed by a taxi driver, whose profession would subsequently change to that of a travel companion. However, it would also be possible for a completely different person to take over these tasks. Either SAV operators could offer accompanying persons as an additional service, who would be in the vehicle and assist if the customer's needs required it. Alternatively, the tasks could also be performed by persons who are completely detached from the services offered by the SAV, such as nurses for the elderly or the sick.

In addition to assisting activities, taxi drivers today perform tasks such as car maintenance, including washing, cleaning, and refueling, as well as planning routes and coordinating their driving tasks. Some self-employed taxi drivers also have tasks related to operational management, such as coordinating employees and settling accounts with head offices, health insurance companies, and other clients. It therefore stands to reason that taxi drivers could specialize in their activities according to their interests and abilities. In any case, it makes sense to involve the taxi drivers themselves in the further development of SAVs and the new services related to the use of SAVs. Studies such as that conducted by Kim et al. [279] have tried to illustrate the process of a taxi ride including all tasks without the involvement of drivers and to analyze it with regard to execution by SAVs. However, the result is a standard process that does not reflect these additional tasks that go beyond the usual ride. Thus, the authors were able to identify which interaction issues and tasks must be addressed in the development of SAVs to replace the taxi driver in a standard ride. However, the SAVs based on this approach would not be able to cover the entire taxi business including all additional tasks.

13.4 Implications for the Design of Regulations

The analyses of the interviews and survey data (Studies 2 and 3) have shown that the availability of SAVs could lead to partly desirable modal shifts (waiving one's own car for the benefits of SAVs), but undesirable changes with SAVs must also be expected (reduction of low-emission vehicles, walking, bicycling, and public transport use due to the benefits of SAVs). These results are consistent with the theoretical expectations of other studies [219,296]. Consequently, it must be assumed that the availability of SAVs does not lead to fewer journeys but rather to rebound effects due to the high convenience and competitiveness of SAVs. If SAV journeys characterized by a very high level of comfort were financially affordable in the future, it is to be expected that users would prefer to use SAVs as a means of transport and might be willing to travel longer distances, as they can make good use of the time in the SAV [134]. The rebound effects would then lead to the replacement of existing (partly lower-emission) modes of transport or to SAVs being used in addition to existing modes of transport. In the latter case, the total number of kilometers travelled would increase.

These implications are of particular importance for state and environmental policy, public transport operators, and planning authorities. The future operators of SAVs are interested in achieving the greatest possible user demand with SAVs in order to generate profits. Accordingly, they will design and offer SAVs in such a way that they are as attractive as possible for potential users. In this case, the suppliers' objectives do not coincide with environmental policy objectives. While the providers want users to make intensive use of SAV, it is in the interest of environmental policy to reduce the number of routes traveled using an emission-intensive means of transport.

Thus, while it is desirable from an individual point of view for SAVs to be offered with a high level of service at a low cost, it is not desirable from a societal and environmental point of view if this results in the intensive use of SAVs at the expense of lower-emission means of transport. Such a negative effect should therefore be counteracted in the interest of the general good. It is not to be expected that the market will regulate itself towards sustainable transport behavior. The market does not do that today, as current traffic problems show. Therefore, regulation that maintains or reinforces the positive effects while counteracting the negative effects is needed.

The design implications as outlined in Section 13.2 address interests on an *individual* level, in particular those of car drivers, who are to be induced to a modal shift. A modal shift in this direction is to be encouraged in order to contribute to transport-related ecological goals. Further positive effects at the individual level, which are to be strengthened by regulation, are the creation of autonomy and independence through equal access to flexible and comfortable mobility, even for people who have had no or only limited access to it up until now [18,317]. These include children, the elderly, the disabled, and other persons with impaired mobility [584], who constitute a significant demand of travel (Study 8).

In addition, on a societal level, positive effects are to be strengthened through regulation. This includes, in particular, increasing road safety and reducing the number of accidents through the use of intelligent connected-car technology [176,356,415]. Furthermore, the positive ecological effects should be supported. Intelligent routing, driving in platoons, and dynamic ridesharing can contribute to this, resulting in more efficient traffic flows, which can reduce emissions, air pollution, and noise and save energy, which in turn benefits people's quality of life and health. In addition, a reduced need for driving space and parking space could contribute to better land use for residential or leisure purposes. The supply of mobility in rural areas should be improved and thus lead to an increased attractiveness.

The negative consequences of SAVs should be counteracted by targeted regulation. Particular emphasis should be placed on rebound effects, which include direct rebound effects in the form of an increased use of individual motorized mobility, which could result from cost and time savings on the one hand and increased comfort on the other [114,237,356,566], as well as migration rebound effects in the form of unintended modal shifts, as Studies 3 and 4 have demonstrated, since both effects would lead to increased energy consumption and increased emissions, as some assumptions and calculations show [215,317]. Aside from the rebound effects, regulation should also address the social impacts on the labor market as outlined in Section 5.3.

Assuming that in a future with autonomous driving, public transportation will continue to be the most environmentally friendly means of transport, followed by pooled SAV, non-pooled SAV, and the private car, the aim of transport policy can be formulated as follows with regard to the creation of sustainable mobility. As in the past, drivers should primarily be motivated to make a modal shift towards public transportation (first priority), and secondly to make a modal shift towards pooled SAVs (second priority); at the same time, the aim must be to persuade public transportation users to also opt for public transportation in an autonomous driving future (first priority) and to persuade those public transportation users who are latent (later) car drivers to opt for pooled SAVs (second priority). Therefore, a key starting point for transport policy is to promote the use of more environmentally friendly means of transport, in particular by making public transportation attractive and, if necessary, by making the use of individual motorized mobility less attractive.

Preference should be given to the first approach, especially since the latter requires rather unpopular measures that politicians often do not want to implement for electoral reasons. Ultimately, however, it is the effectiveness of the measures that is decisive. In principle, the aim should be to make use of the so-called windows of opportunity, that is, those periods of time in which actors are open to innovation and to adapting their behavior. When developing autonomous vehicles, such windows of opportunity can be addressed both to consumers and to operators or suppliers of (S)AVs. If the course is set at an early stage, before routines and habits have become established among consumers and before lobbyists have established themselves on the supplier side, steering instruments and measures can have a better effect. With a regard to concrete recommendations to action, a major step in this process would be to follow the proposals of the EU Commission, which have been formulated with regard to today's mobility. A key demand is to base charging systems for transport on the polluter-pays principle, according to which all users of transport infrastructure should pay for the costs they cause, including external costs, as close as possible to the place of use. Such external costs include costs paid by others, such as the free provision of public parking spaces, uncovered infrastructure costs, uncovered accident costs, uncovered ecological costs (e.g., caused by noise disturbance or air pollution), uncovered health costs caused by such external effects, and time costs imposed on others [173]. If these costs were taken into account, the use of high-emission and polluting transport modes would become more expensive. Against the background of market prices as a decisive factor for users in their travel mode choice, a directing effect is likely [174,248]. However, if market prices do not reflect existing scarcities (clean air, environmental absorption capacity, infrastructure, etc.), the individual choices of consumers and producers no longer lead to a result that provides the greatest possible benefit to society as a whole [174]. Only if the external effects are internalized, that is, if each user bears the full social costs that can be attributed to his or her journey, does the price serve as an incentive for an intended modal shift towards environmentally friendly means of transport. In this respect, the measures proposed for current modal shifts can be transferred to the planning of SAVs. However, costs are only one – albeit important – adjusting lever in a directive transport policy. In concrete terms, a number of measures can be implemented and also applied in combination; these are presented and discussed further below (see Table 14). These include pull measures to encourage users to use (automated) public transportation (APT) or at least (pooled) SAVs (reducing APT/SAV costs, reducing APT/SAV travel time, increasing APT/SAV

Table 14: Possible pull and push measures to encourage sustainable mobility behavior in the age of SAVs

DIRECTION	MEASURE	SPECIFICATION	EXAMPLES
Pull measures (encouraging APT /SAV use)	Reduced Cost	Reduced APT cost	– APT cheaper than PT
		Reduced SAV subscription cost	– SAVs cost less than car owning but more than APT
	Reduced Time	Reduced APT time	– Improved driving time APT – Decreased waiting time APT – Priority to road transport for more environmentally modes
		Reduced SAV time	– Improved driving time SAV – Decreased waiting time SAV – Reduced parking time SAV
	Increased comfort	Increased APT comfort	– Improved walking distances to unboarding – Improved flexibility through dynamic routing and times
		Increased SAV comfort	– SAVs used non-pooled – SAVs with privacy-seperation – Availability similar to PAV
Push measures (discouraging PAV use)	Increased cost	Increased PAV cost	– Increased parking cost for cars – Kilometer dependent car taxes – Emission dependent car taxes – Differentiated fuel taxes – Differentiated road tolls
	Increased time	Increased PAV time	– Reduced speed limit for cars – Reduced parking for cars
	Reduce Comfort	Reduced PAV comfort	– Reduced parking for cars

comfort), and push measures to discourage users from using a private (autonomous) car (increasing car costs, increasing car time, reducing car comfort).

As we learned from Study 4, public transportation needs to improve in terms of travel and waiting time, comfort in general, flexibility, and transport options in order to become attractive for all users (pull instruments). A stronger cost advantage for public transportation compared to the car could favor a modal shift. For public transportation, this is likely to mean a higher level of subsidization. Shared autonomous vehicles should also be cheaper than a private car to attract car users, but they should still be more expensive than public transportation. The automation of public transportation can possibly address the challenges of time and flexibility. As Study 5 revealed, the attitude towards automated public transportation and the willingness to use automated public transportation is generally very high among the young generation that is experienced in using public transportation. With rail-bound public transportation the barrier of accepting automation is easier to overcome than with non-rail-bound transport modes such as private AVs and SAVs. Some research projects aim to make public transportation more flexible through dynamic routing, which could reduce driving and waiting time [273,543]. In addition, smaller units are already being discussed and tested, for example, in the form of autonomous shuttle buses, which could also operate more flexibly and could serve less busy routes on demand [389,423]. The journey time itself should also be reduced by intelligent and dynamic routing as well as by efficient traffic flow and infrastructure management and by giving priority to more environmentally friendly travel modes in road traffic. With regard to general comfort, two approaches emerge: Either the components in which public transportation is inferior to the car must be improved, or new quality components in public transport that a car does not or cannot offer must be specifically created [210]. Solutions for the first approach are difficult in that the car sets a standard that is difficult for public transportation to meet or exceed. With regard to better privacy in private cars, increased privacy would also be achievable in public transportation, but even more so in pooled SAVs, by allowing passengers to separate their seats with controllable flexible partitions on request [155]. The un-pooled use of an SAV also represents a comfort advantage in contrast to pooled use.

In order to reduce car use or the use of an AV as a private car (push measures), increases in the costs associated with driving the respective means of transport are suitable. Here, the fuel or energy costs, the travel costs in the form of taxes or road tolls, or the parking costs can be addressed in the sense of cost internalization [219,227]. Private AV users could avoid high parking costs by letting the vehicle maneuver independently to more distant, cheaper parking spaces (valet parking) or by letting the car drive around until the next use (valet cruising). Such avoidance tactics should be countered by pricing automated valet parking/cruising. As mentioned above, besides the favorable price, the driving time is also a decisive reason for choosing a car. The study by de Witte et al. [143] showed that among Belgian commuters, car drivers choose a car mainly because of speed. Reducing the possible driving time of the car can therefore also be an effective tool. This can be achieved, for example, by lowering speed limits, giving priority to more environmentally friendly traffic on the roads, or reducing parking spaces. Reduced parking areas can also be effective in terms of reduced comfort: If the car cannot be parked directly at the destination, an additional journey is required. Here too, any valet parking/cruising must be counteracted.

The study by Stoiber et al. [508] tested some of these instruments with regard to the use of SAVs using a stated choice experiment. The results showed that for a short-term mobility decision, besides a kilometer-based tax, the reduction of parking spaces is an effective means to reduce the preference for private autonomous vehicles. In order to encourage users to use pooled SAVs, according to this study, price-reduced tickets for pooled SAVs and public transportation as well as a reduced waiting time are suitable. Overall, the greatest modal shift potential towards public transportation could be identified when all pull instruments (better comfort, time, and cost in public transportation) are combined with push instruments (worse comfort, time, and cost in cars).

13.5 Limitations

Limitations of this work arise on the one hand from the fact that within the studies, my colleagues and I tried to estimate the consequences of a new, not-yet-existing technology and on the other hand from the fact that we chose a user-oriented, empirical approach as a basis for our analysis.

Focusing on SAVs – a future technology and business model – as a research object, I cannot avoid a relatively high degree of speculative interpretation, which subsequently also influences the recommendations for action. Assessing the impacts of the not-yet-existing generally comes with great uncertainty. Technology assessment regularly analyses and assesses the expected impacts of technologies that are not yet sufficiently developed and – as in the case of AVs and SAVs – not yet accessible to users, making their impact difficult to predict. There is no doubt that the research questions at hand cannot be answered today but can only be answered conclusively when driverless vehicles have become part of everyday life. Until then, research results will naturally remain vague and only of a preliminary nature – rather than being able to draw a realistic picture, it can only reflect the current perspective of the respondents on the unknown future, with all its assumptions and imponderables [577]. Nevertheless, there are many reasons to investigate these questions today. Undoubtedly, the more advanced the technology of automated vehicles is and the better known the usage contexts are, the better the prospects for safe knowledge of the technology's consequences [223]. If, however, we wait until this point before estimating the consequences of the advent of driverless cars, there is no longer any possibility of influencing the technology or its consequences [220]. By then, the development will have progressed so far, and use will have become so established in people's behavior, that, for economic reasons, it will be hardly possible or no longer possible to change course [121,221]. In the context of technology assessment, this problem is known as the Collingridge dilemma [121,312]. However, despite these weaknesses, research that accompanies and influences the progressing development is indispensable if social and environmental compatibility is to be guaranteed.

Choosing a user-oriented, participatory approach limits the results of this work, too. In contrast to experts, non-experts or laypeople have a much lower level of knowledge about new technologies. Therefore, they often find it difficult to imagine and assess the possibilities as well as the consequences of a new technology. The empirical studies showed that although the majority of participants had already heard of autonomous driving, only a very small proportion had already dealt with the topic in depth (Sections 6, 7, 8, 10, and 11). In order to judge the topic and answer the survey questions, participants must thus rely on their imagination. Within some studies, we have addressed this problem by presenting a short video on SAVs (Section 7) or a press release (Sections 6 and 11) to provide them some information about the technology and possible use cases. However, even such brief glimpses bear the risk of influencing the participants in their responses. Experts, by contrast, know more about their field of expertise, making it easier for them to assess future scenarios. However, there is also no evidence that the findings of experts go beyond the normal level [208]. By introducing the user's perspective, we further enrich the discourse on the possible impacts of SAVs.

From a methodological perspective, differences between user assessments regarding potential use and users' actual use limit the validity of the studies' results. Although users' preferences and their intentions regarding the use of modes of transport are a predictor of actual use [135], it must be considered that there regularly is an intention-action gap. The preference or intention to use expressed in user studies may differ significantly from actual use [8]. In addition, there may be biases in the response behavior of users if they subject their responses to unconscious social desirability [297]. This type of bias should be taken into account when reading the results.

Further, the results of this study are not representative for the German and other populations. Some characteristics of the study samples deviate from the characteristics of the German population (especially age, education level, and income). However, particularly in the qualitative studies, we did not aim for representativeness and statistical generalizability, but rather to obtain the greatest possible variety of answers. Therefore, we tried to represent the broadest possible spectrum of participants in the sense of a theoretical sampling [126]. In this respect, the composition of the respective sample should be taken into account when interpreting the results.

14 CONCLUSION AND OUTLOOK

With the aim to inform politics, industry, society, and science, my colleagues and I conducted several empirical studies to assess possible ecological and social consequences of SAVs. We applied a user-oriented approach that is meant to complement technology assessment studies on autonomous driving that have so far been dominated by scenario analyses and simulations that are shaped by the experts who conduct them. Only rarely has the user of the technology itself been included in empirical research on the potential impacts of SAVs. Addressing this gap, we focused on contributing to assess the ecological consequences of SAVs in terms of potential modal shifts induced by SAVs as well as social consequences of SAVs in terms of potential job losses in the taxi industry induced by SAVs. In view of the first aspect, the empirical studies presented in this work provide evidence that the automation of mobility services such as carsharing fosters a shift from the private vehicle towards mobility as a service to a small extent. However, findings also indicate that twice as many users are expected to be moving away from the more sustainable public transportation, leading to an overcompensation of the positive migration effects by the negative migration effects. Concerning the second aspect about the potential risk of the taxi driver profession becoming obsolete with the advent of SAVs, our qualitative interviews with taxi drivers and taxi users showed that in fact a large proportion of the taxi trips carried out can be replaced by SAVs, making the profession of taxi driver in fact somewhat obsolete. However, the interviews with those affected additionally indicated that, depending on the purpose of the journey or the customer group, the services provided by the drivers go beyond mere transport, so that even in the age of SAVs the need for human assistance will continue to exist. While the driving task will be eliminated, taxi drivers could concentrate on these support-oriented tasks. However, it is also possible that these tasks will be taken over by people other than taxi drivers such as nurses for the elderly or nurses for the sick, volunteers, or family members.

With regard to the social consequences of the AV technology, this means that policy makers will have to address the question of putting thousands of jobs at risk by opening the taxi sector to SAV operators or how a change in the industry can be initiated in a socially responsible way. In contrast to Germany, a welfare state and protective country, taxi entrepreneurs and unions in more liberal countries such as the United States will have to face this question in the near future.

Based on our empirical studies, we see action potential at different levels: users, mobility service providers, and policymakers. Regarding environmental and social impacts resulting from the use of SAVs, there is a strong conflict of objectives between users, potential SAV operators and sustainable environmental and social policies. As people are not always intrinsically motivated to behave in a sustainable manner [276] and as there is evidence that not-environmental-related criteria such as comfort and reliability are decisive for travel mode choice [352,501], users will choose the most convenient mobility option they can afford. If the cost of SAVs is to actually be in line with users' price expectations – as suggested by the comparison of current simulations with the latest studies – it must be expected that these users who see added value of the SAV compared to their existing means of transport switch to SAVs. Shared autonomous vehicle operators will also contribute to making SAVs as attractive as possible to meet their revenue and profit targets. If environmental and economic policy does not set a course at this point, aspects of sustainability will be neglected – as has been the case in the past. Policymakers will have to intervene to prevent a worsening of the existing traffic problems. The government and public research and development must put more effort into their transportation policy by making sustainable public transportation more attractive for people and providing incentives for private companies to offer sustainable mobility. The users' wish for and the operators' aim to offer comfortable and affordable SAVs is simultaneously in conflict with the aim of preserving jobs and bears the threat of overlooking people in need of human assistance. Here, taxi companies and trade unions are faced with the challenges of opening up to the developments of the future and focusing on service orientation – because this is the only unique selling point of drivers compared to automated technology. Thus, my thesis finally shows how research in technology assessment can methodologically be embedded in a regulative process to inform both technology and legislation.

Further research is needed to validate the results of the studies at hand. There is no question that first of all, technological research is required to find out whether a realization of SAVs as currently planned is feasible or whether AVs, for example, will only be usable to a very limited extent. This is because the results of these studies and studies based on them or supplementary studies are only interesting in the event that Level 4 or Level 5 vehicles are realized for use by private individuals. In this case, however, further studies are needed to explore the possible consequences of the introduction of SAVs with regard to changes in the mobility behavior of users. For example, further quantitative studies designed to be representative should demonstrate whether the present results can be generalized. Comparative studies should also be carried out with users from other countries in which the transport system and mobility behavior of users differ from those in Germany. In this way, differences and similarities could be identified and it could be assessed whether regulations should be established on a cross-national basis. With regard to the travel mode choices investigated here, the participants' choice was limited to some current and future means of transport. For example, hybrid mobility concepts such as automated shuttle buses or other forms of automated public transport (with the exception of Study 5) were not considered in the selection. How new automated forms of public transportation, such as automated minibuses for the last mile, will affect users' future preferences should thus be analyzed.

Second, further studies are needed to investigate possible social impacts of SAVs, particularly with regard to job losses. It would be of particular interest to carry out contrasting studies, asking professional taxi drivers from other countries as well as TNC drivers about their future prospects and to compare these results with those presented here. In addition to this, further research into specific stakeholders is needed to gain a more detailed picture. For instance, by including other assistance drivers, dispatchers, and further customer groups. For the group of millennial aged customers, it would be of value to validate the results of Study 7 using a quantitative approach and also to identify cross-country differences. Further, these studies should also be extended to other customer groups, and in particular address the needs of people with reduced mobility. The group of people with restricted mobility should be considered more closely in future research investigating whether they could do without human assistance, for what reasons they could not do so, and how an autonomous taxi would have to be designed so that they could use it without human assistance.

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