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The Path to Sustainable Mobility Systems
8 Theses on a digital mobility transition

A study commissioned by
Huawei Technologies Germany GmbH

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Executive Summary

The transport sector will be key to the success of Germany's climate protection plans. However, in no other sector are climate-neutrality goals so far adrift from the actual situation. In 2019, the transport sector in Germany emitted 146 million tonnes of CO2, equal to emissions in 1990. Any sustainable reduction in greenhouse gas emissions requires integrated "EcoMobility" initiatives that focus on walking, cycling, and public transport combined with innovative Mobility-as-a-Service (MaaS). Such initiatives would drive a move away from internal combustion engines, and fundamentally change mobility routines. This is where digitalization can play a central role.

Digitalization works on the three levels of ***Improve - Convert - Transform***, which together form the framework of our "Shaping Digital Transformation - Digital solution systems for the transition to sustainability" project. These three levels establish concrete starting points for digitalization to achieve the climate targets in the transport sector, as outlined below:

- **Improve**

  Digitalization improves the usability of environmentally-friendly mobility services: Smartphones and apps offer constant access to mobility services, including route planning and booking. Digital systems, supported by AI, optimize the availability of such services and provide tailor-made offers from different providers.

  Mobility data enables real-time traffic planning and optimization: Currently, it is still far too common for traffic planning to be conducted based on outdated survey data or incomplete traffic measurements. Therefore, big data and AI should be consistently used for traffic optimization, which will prevent additional emissions from being generated through traffic congestion or searches for parking spaces.

  Virtual mobility reduces traffic: Mobile working and video conferencing can replace daily commutes and long business trips to help limit climate-damaging emissions.

- **Convert**

  Shared data and digitally-networked systems enable sustainable EcoMobility through walking, cycling, public transport, and MaaS services: Today's mobility services are characterized by local and regional tariffs, inconsistent booking systems, and fragmented data structures. Seamless booking must become a reality to truly offer an alternative to private cars.

  Standardization realises tailor-made mobility solutions: Standards for data structures, data streams, and data interfaces are the basic prerequisite for providing sustainable door-to-door mobility to all.

  Never take a wrong turn: All new solutions must be critically analysed with a view to their potential effects. Autonomous cars and on-demand driving services should be used first and foremost for MaaS offerings, as they substantially increase the occupancy of vehicles.

- **Transform**

  Digitalization coordinates a transport transition: The comprehensive transformation towards sustainable EcoMobility must be planned over the long term and controlled dynamically. This requires up-to-date and detailed data, the ability to analyse and develop models, the capacity to assess and forecast the effects of related measures, and the agility to promptly manage changes to complex mobility systems in smart cities.

  The transition to digital transport requires both fundamental changes to EcoMobility financing and an opposition to the use of private cars: Ultimately, utilizing the potential of digitalization to transition to sustainable digital transport depends on political framework conditions. Financing for sustainable mobility must be strengthened, while subsidies must part with the current small-scale and fragmented approach they have to public transport. Aside from providing an attractive alternative, concrete measures must be taken to reduce the existing privileges enjoyed by private car traffic and allocate road space and financing to the transition to sustainable transport.

The positive effects of digitalization within the "Improve" level are already being seen in many individual cases, however, consistent scaling is required to unlock its full potential. The "Convert" level showcases much potential that can be unleashed through the networking, integration, and standardization of mobility offers. There is still considerable demand regarding this level, but only the consistent support of political entities will lead to the systemic effects of digitalization developing into new offers, business models, and standards. It is crucial that the financial and regulatory guidelines for ramping up EcoMobility align with simultaneous and gradual restrictions on private car traffic. To eventually achieve profound changes at the "Transform" level, a fundamental rethink will be required in terms of both politics and society. Digitalization is also a prerequisite for politicians to define strategies and establish a new culture of mobility that questions routines and status symbols.

Development prospects are noticeable, and the tasks that the new federal government needs to tackle are clearly defined. The agreement between the three parties of the so-called traffic light coalition, presented on 24.11.2021, rises to new challenges and notes the need to "...use the 2020s to usher in a new start for mobility policies and enable sustainable, efficient, barrier-free, intelligent, innovative, and affordable mobility for all." Some key points of this study are specifically named, such as the provisioning of mobility data, further development of the mobility data space, promotion of digital mobility services, and intermodal links, as well as long-term strategies for autonomous and connected driving in regards to public transport.

To ensure the successful and comprehensive transition of transport to sustainable mobility, the coalition agreement must contain measures that are specifically developed, correctly supplemented, and actively implemented. This report aims to provide impetus for this transition and for a climate-friendly and sustainable transport transformation in Germany.

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Abbreviations

AI	Artificial Intelligence
MaaS	Mobility-as-a-Service
MDM	Mobility Data Marketplace
MPT	Motorized private transport
NFC	Near Field Communication
OPEX	Operating Expenses

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Introduction

The European Union has set the ambitious target of achieving climate neutrality by 2050. In April 2021, Germany's Federal Constitutional Court called for politicians and the new Federal Government to more effectively and quickly work to achieve this goal, making it their chief focus. Climate protection and the search for paths to a climate-neutral future will be central topics in the coming years.

This is overshadowed by strict time constraints, meaning that efforts to reduce greenhouse gas emissions must be significantly accelerated to achieve Germany's individual target of climate neutrality by 2045. Profound changes to the ecological system are on the horizon for all key areas of the economy and society – the so-called "transformation arenas".

Digitalization is a precondition for the success of these changes. Digital technologies and applications will make it possible to improve current procedures, processes, and structures **(Improve)** and take the first steps towards the new orientation of business models and framework conditions **(Convert)**. Meanwhile, digitalization must be used to further transform the economy and create value, while supporting the ecological reorientation of society and lifestyles **(Transform)** (Figure 1). As the last of these three levels is vital to the success of ecological change, it must be a point of focus within debates. The three levels of impact are interlinked, influence each other, and must be addressed through a holistic approach.

It is vital to tap into the short-term potential of optimization today, while beginning to shape the conditions for deeper change in the structures and framework of the economy and society.

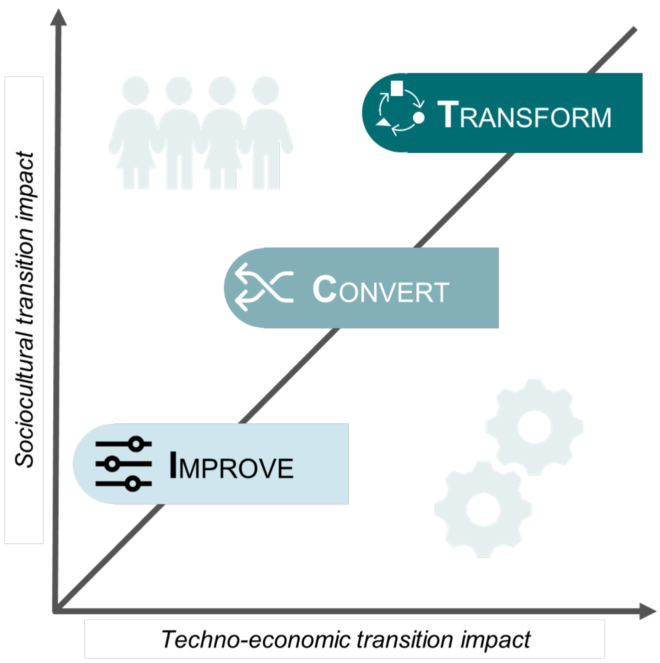

Figure 1: Impact levels of digitalization on sustainability transformation (Source: own illustration)

This is where the "Shaping Digitalization - Enabling Transformation to Sustainability" project comes in on behalf of Huawei Technologies Germany. Within this project, we aim to highlight and discuss the opportunities that digitalisation can bring to Germany. In particular, we will discuss three exemplary areas of ecological transformation where action is necessary: mobility, circular economy, agriculture and food (Wuppertal Institute, 2021).

This report addresses the first action field (mobility) which is considered a "transformation arena" with special challenges. In the transport sector, there is a particularly large gap between the stagnating status quo of greenhouse gas emissions, foreseeable trends, and the politically-defined sustainability goals. In the following text, the tasks required to achieve the climate-friendly transformation of passenger transport are outlined and translated into a target picture of intelligent, networked, attractive, and climate-friendly EcoMobility.

This target is only attainable with the help of digitalization. Digital technologies, new business models, and social innovations must be combined, supported by a transport policy that sets the framework conditions and incentives required to achieve this goal and creates conditions for digital solutions to be effective. Action must be taken.

The current report aims to provide an impetus to pursue this path and provide new stimuli for a climate-friendly and sustainable mobility transition in Germany. The report is based on the results of an interdisciplinary workshop entitled "Digital Transformation for a Mobility Transition" that was joined by experts from the research, civil society, and public authority domains, as well as from private companies (see Acknowledgements). The workshop discussion focused on current research findings regarding the political, organizational, and technical framework conditions for an ecologically-effective and socially-balanced mobility transition.

Background and challenge

Currently, the transport sector is responsible for around 20% of Germany's greenhouse gas emissions. This share has increased slightly in recent years because, unlike other sectors, the transport sector has not contributed to climate change since 1990. This needs to change. The updated Climate Protection Act defines a clear pathway for this sector to reduce its greenhouse gas emissions from the 164 million tonnes seen in 2019[1] (UBA, 2021) to 85 million tonnes in 2030 (BMU, 2021), and then towards carbon neutrality in 2045.

The unique effects of the COVID-19 pandemic meant that the sector temporarily met its targets in 2020. However, the current projection report commissioned by the German government, based on an EU regulation on the development of greenhouse gas emissions in individual sectors, offers little hope for the coming years. Based on the measures adopted in the summer of 2021, CO2 emissions are only expected to fall by 23 percent by 2030, compared to 1990 (Repenning et al., 2021). This indicates that currently planned and implemented measures will not even be enough to achieve half of the target set out in the Climate Protection Act. In contrast to this gap between the target and projections in the transport sector (52% of the target will be achieved), other sectors like energy (75% target fulfilment), industry (82%), building (84%), and agriculture (89%) delivered much better performance (own calculations based on UBA, 2021 and Repenning et al., 2021).

In short, no other sector is further from achieving its objectives than the transport sector. The interim goal of almost halving emissions within a decade highlights the scale of the challenge, which will be achievable only through the fundamental transformation of the transport system.

Within this transformation, the key focus will be on passenger transport, which accounts for the largest share of transport-related greenhouse gas emissions in Germany, at over 60% (Sach et al., 2021). In addition, roads and vehicles require land and resources that have further environmental consequences.

Therefore, achieving climate protection targets will largely depend on the success of our endeavour to set the course for significant emission reductions in road transport over the coming years. This task is becoming increasingly urgent, as the level of CO2 emissions remains worryingly stable: extensive improvements to engines and exhaust gas cleaning in recent years that would reduce emissions have been more than offset by a trend towards larger vehicles and increases in traffic. As a consequence, CO2 emissions from the transport sector were 146 million tonnes in 2019, exactly the same as in 1990 (BMU, 2021), while absolute CO2 emissions from passenger transport increased by as much as 5.1 % between 1995 and 2019 (UBA, 2021). Within the transport sector, passenger transport accounts for almost two-thirds of emissions, while freight transport accounts for around one-third. Therefore, this report focuses on the challenges and solutions related to passenger transport.

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[1] In 2020, emissions from the transport sector were 145 million tonnes, slightly below the target of 150 million tonnes (Federal Government, 2021). However, 2020 figures were strongly curbed by traffic restrictions brought about by the COVID-19 pandemic. Therefore, 2019 emissions are used in this report for reference.

The ultimate goal is a comprehensive mobility transition (Hochfeld et al., 2017; Hennicke et al. 2021) that is based on three strategic pillars:

- First, it is necessary to **reduce total traffic**, meaning that the number and length of traffic routes must also be reduced. This can be achieved by using space more efficiently and utilising virtual mobility. For example, by replacing rush-hour traffic and business trips with home offices and digital meetings.
- Second, it will be necessary **to shift from modes of transport that harm the environment to EcoMobility**, such as walking, cycling, public transport, and flexible sharing solutions. Achieving this will require increasing the attractiveness of EcoMobility, particularly compared with private cars, and taking actions to improve its user-friendliness such as providing digital services for easy travel planning and booking.
- Third, it is vital to **improve modes of transport**. In addition to increasing efficiency, changing the way that vehicles operate will be indispensable. In the passenger transport sector, for example, this can be achieved by switching to battery electric vehicles and ensuring their intelligent integration into power systems. Smart grids are the basic prerequisite for this.[2]

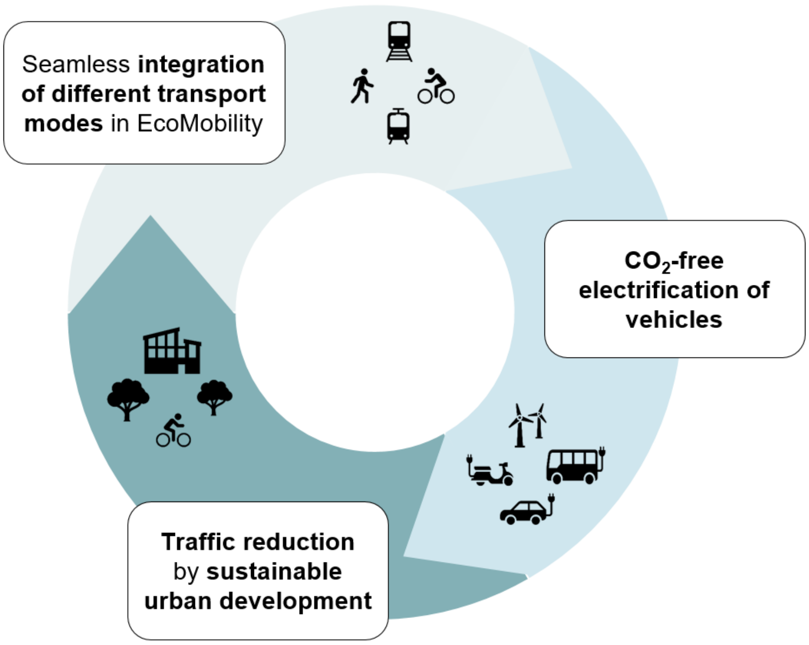

Figure 2: Key points for sustainable mobility in passenger transport (Source: own illustration)

A mobility transition that aims to achieve climate targets, within the framework of short implementation deadlines, will need to fundamentally transform mobility systems that, so far, have been highly automotive-centric. Achieving this will require a combination of the aforementioned strategies. Therefore, a mobility transition is a major economic and social undertaking, as more than 1 million people work in the transport sector in Germany. Many jobs are linked to the automotive industry, and large numbers of people currently still rely on cars.

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2 Switching to electric mobility will not solve the problem alone. This is because the energy requirements of approximately 18.4% of current net electricity generation would substantially prolong the need to use fossil fuels and increase political dependence on gas supplies (Schmidt, 2020).

It should be noted that the situation differs greatly between rural and urban areas. In urban areas, there is often easy access to public long-distance transport, sharing services, and MaaS services that are provided by private actors. However, such alternatives are still in their infancy in the countryside. The rural population is significantly disadvantaged by its current dependence on private cars. In rural areas, people without cars, children and adolescents, and visually impaired people can all experience substantially restricted freedom of movement due to a system that is designed around private cars. Cyclists and walkers are both at a disadvantage compared to those who use cars, as they have less available space and often have to deal with patchy and unsafe cycle paths and footpaths. Therefore, they are particularly at risk of accidents, often making cycling and walking even more unattractive. In addition, the health of socially- and economically-disadvantaged populations living in residential areas is commonly damaged by particulate matter and noise pollution (UBA, 2020). A sustainable mobility transition promises to improve quality of life and mobility for all in these areas.

Vision for the future

The transformation task is clear: we need **an intelligent transport system that provides climate-friendly transport services**. In addition to traffic prevention and a shift to electric, it is vital that motorized private transport (MPT) with private cars, is shifted as far as possible towards EcoMobility through climate-friendly mobility offers. For example, improved and better-developed interactions for walking and bicycle traffic, more punctual public passenger transport, and high-performance long-distance rail.

Such transport services require flexible support that can cover the "last mile" of routes where public transport is not available. This can be achieved either with tailor-made sharing offers for various vehicles, including e-scooters and (cargo) bicycles, or through flexible on-demand ride pooling offers. Both combine the advantages of individual and collective mobility by offering the convenience of short-distance journeys or, depending on the design, door-to-door services and reducing the negative effects related to the use of vehicles (Bauer et al., 2020; Purr et al., 2020).

Such digitally networked services can fulfil various functions that can currently often only be provided by one's own car due to a number of factors. For example, ride pooling services commonly only cover routes in sparsely populated areas or on the outskirts of cities, and buses and trains can run sporadically, particularly late in the evenings or at weekends. However, new services will allow comfortable transport to be quickly and easily arranged, even making it suitable for travelling with small children. Sharing offers will help to reliably manage occasional trips without your car, such as going to the store, visiting relatives, or journeying to the local park. It will be simple to use a rental bike in the evening to travel home or to a train station, or use a shared cargo bike for bulk purchases.

To make all these means of transport feasible and attractive, it will be necessary to have seamless travel chains "from a single source". After all, a key perceived advantage of private cars is that they do not need to abide by timetables, complicated transfers, or waiting times to get from A to B. For transport services to offer a comparable experience, mobile stations should serve as mobility hubs that provide transfer options between modes of transport, as well as integrated apps and booking platforms. This will ensure the user receives simple information and that booking a route is a smooth process, regardless of the number of respective individual providers.

Digitally condensed and integrated "EcoMobility" will make it possible to travel in both cities and rural areas without owning a car, by creating a transport system that matches the experience and efficiency of private cars.

The public transport system, which currently offers only basic mobility, in the sense of basic services that cater to general interest, will become a fully-fledged alternative to owning a car and thus encourage people to move away from private cars. Therefore, the key is not just to offer services like school buses in the morning and afternoon, but to provide mobility services throughout the day with tailor-made routes, timetables, and frequencies. Once the foundation is laid for this comprehensive alternative, it will be possible to negate the advantages of private cars. Only through a push-pull strategy that highlights the attractiveness of sustainable transport and undesirability of non-sustainable transport, can a mobility transition be implemented effectively.

A key challenge is the quick, reliable, coordinated, and low-cost construction of new mobility systems, while accounting for the needs of different groups within the population, such as old and young, urban and rural, with and without children, and high and low income.

This is where digitalization must begin. In concrete terms, the digitalization of the transport sector needs to enable environmentally-friendly offers and solutions that are on a whole new level, and match or even surpass the experience offered by private cars. The goal is to create new mobility offers that are functionally equivalent and socially accepted. This is the only way to achieve the necessary dissemination and scaling of the offers. In addition to novel on-demand and sharing offers, it is crucial that various offers from public and private mobility service providers can be comprehensively combined into the systems and are designed to be user-friendly.

In the spirit of the integrated approach ***Improve*** – ***Convert*** – ***Transform***, the following chapters outline the possibilities and obstacles related to the use of digitalization for a comprehensive mobility transition.

Improve: Digital applications can enhance mobility systems

Today, the prevalence of smartphones and the mobile Internet is enabling the improvement of many mobility-related processes. These improvements are laying the foundation upon which new business models and framework conditions, as well as comprehensive social change, can be built on. The following three theses detail how much digitalization has already changed the mobility sector. Each thesis also examines options for improvement that remain unexplored but can be quickly turned to an advantage as so-called "low-hanging-fruit".

The following information focuses first on the optimization of existing mobility systems, then considers planning processes, which are fundamental to the structure of the supply side of these systems. Finally, the need for travel –the demand side – is discussed, as well as how the efficient use of travel time is being transformed by digital developments.

Thesis 1: Digitalization can improve the accessibility and quality of existing transport systems

Publicly accessible mobility services are already greatly benefiting from the spread of smartphones, the mobile internet, public Wi-Fi, and easy-to-use apps. Compared to when travel was planned mainly through analogue timetables or visits to travel agencies, the mobile Internet and digital user interfaces offer incomparably better information and booking options. It is easier than ever to plan, book, or reschedule trips in advance, and the number of people taking advantage of this is always on the rise. For example, in recent years the number of train tickets booked via mobile phone in Germany has increased exponentially (Figure 3). New technologies are breaking down barriers to the use of traditional public transport and enabling easier handling of changes to planned itineraries caused by factors such as delays or cancellations.

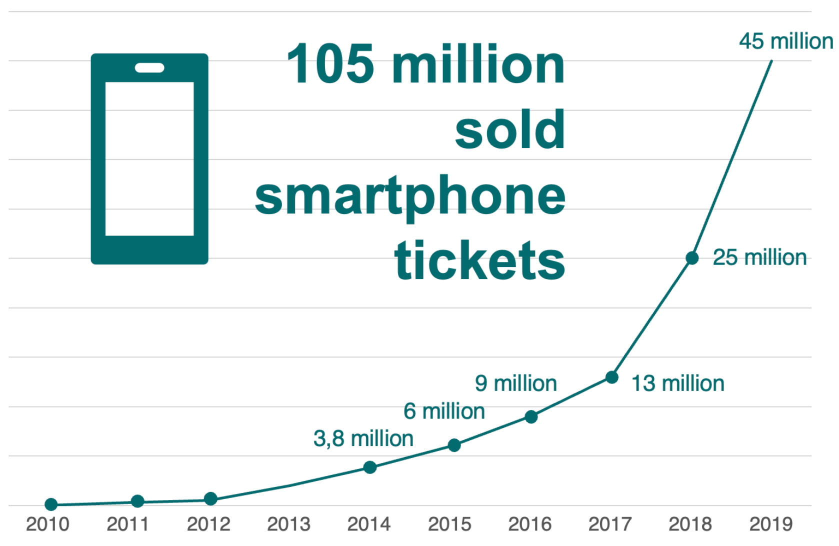

Figure 3: Ticket sales via mobile phone at Deutsche Bahn. (Source: Deutsche Bahn, 2019)

In addition, information systems have been introduced in parallel by numerous mobility providers, which utilize data exchanges based on API interfaces and Open Data, enabling intermodal travel chains. This is possible because real-time information acquisition from different routes as a whole, regardless of location, is now a reality. Some mobile service providers are more effective than others in implementing such systems. It is easily conceivable to make improvements to such systems. This is particularly true regarding information offered by transport associations, as they usually exclusively provide services to certain areas and are commonly owned by local authorities, and therefore are not in competition.

Booking and access systems have also now been digitized in some cases. With car sharing, for example, digital access is now commonplace, opposed to the complex analogue technology such as keys and safes used previously. In the cases of bike and e-scooter sharing systems, neither could have been established without user-friendly access through smartphones. Further development potential for low-threshold solutions lies in technologies like QR or NFC codes.

Improving the accessibility and quality of these transport systems is already possible in a number of ways. For example, the convenience of using digitized routing apps and timetable information can be further increased based on individual user profiles. This would mean accounting for factors like individual speeds when walking or cycling and routine stops at certain locations. Such considerations can then drive the further optimization of travel chains and enable even more convenient services.

Therefore, data can improve offers. However, it must be remembered that not all potential users are currently covered by such offers or data. Currently, MaaS services are mainly used by younger, male people who have moved to urban areas (Rambol Mobility, 2021). This is not primarily down to the divergent use of modern technology by gender, but due to different user profiles (e.g. transporting children) and different perceptions of social and physical risks (ibid.). The use of new technology, which is perceived by many as complex, varies in terms of age and milieu. Therefore, making such technology easier to access and use would help reduce barriers faced by many people and reach wider social groups. This means that as new products and infrastructures are developed, existing database must be critically questioned and enriched with information from underrepresented social groups.

The key task is to create incentives for the development of inclusive MaaS services and offers that are suited to the broader population, such as discount rail tickets. Broader integration of payment options will also make digital mobility services more accessible for people without credit cards, PayPal accounts, and so on.

Accessibility must therefore be broadly considered. Currently, numerous physical and digital systems are not yet accessible to people with disabilities. Digitalization can help to alleviate this by informing people with limited mobility about the accessibility of physical systems (e.g. the existence of functioning elevators). To this end, image recognition, voice assistance, Easy speech, and text-to-speech systems can make such information more readily available.

Another key aspect for improving the accessibility of EcoMobility is minimizing necessary cognitive effort. The use of public mobility should be intuitive and simple, meaning the fault tolerance of the digital systems is crucial. Searching for destinations can be simplified by including places of public interest within destination databases, while error corrections and the ability to search for nearby or previously-selected destinations should also be integrated. Easier usability also leads to self-reinforcement, as the more often systems are used, the simpler and more standardized the tools, such as QR codes, will become. In addition, as users become more familiar with the processes, barriers are lowered, making it more likely that systems will be used in the future.

Digitalization also enables improvements to foot and bicycle traffic. For example, introducing digital reporting for traffic obstructions caused by incorrectly parked cars would be a step towards increasing safety for pedestrian and bicycle traffic. Some municipalities have already started down this path. Even road defects, damaged public transport stops, or damaged vehicles can be detected and eliminated more quickly through digital reporting systems. Digitally-supported process automation is key to ensuring that requests can be quickly processed without overloading the administration.

Guaranteeing the efficiency of these services, particularly regarding rail passenger transport, is essential for the switch from private cars to public transport. The use of digitized control systems, such as ETCS 3.0 in rail transport, can greatly improve the utilization of existing infrastructure. For example, regarding rail, the digital control and communication of rail vehicles and infrastructure allows trains to operate closer together and more quickly be assigned different roles. This significantly increases the capacity of rail networks and reduces delays, thus improving the overall quality of public transport. At the same time, additional capacity is freed up in the short term to enable supply consolidation and meet rising demands. Within this context, projects that require no or few infrastructural upgrades are particularly interesting, as the lengthy, expensive, and problem-prone construction of additional rail infrastructure can be minimized. These improvements are not imagined, but already a reality. However, this is only currently true in individual successful applications and pilot projects. Therefore, it is clear that the diffusion of successful digital solutions should be encouraged and, where necessary, codified by standards. Thus "low-hanging-fruit" improvements in relation to the accessibility and quality of existing transport systems can be exploited through digitalization.

Thesis 2: Mobility data can facilitate traffic planning and control

Digital devices and the increasing number of sensors in vehicles provide more high-quality and spatially-precise mobility data than ever before. The navigation services of large digital companies already offer access to real-time data and forecasts of upcoming traffic conditions. However, such data is often not yet being utilized for transport planning. The planning of new traffic routes or comprehensive mobility concepts is still typically based on traffic counts, which are generated based on count stations or surveys that are often years out of date.

Digitalization facilitates higher-quality traffic data in terms of topicality, forecasting, granularity, and analysis. The potential of this must be carefully considered and used far more consistently during traffic planning. For example, it is possible to conduct small-scale and situational evaluations through more focused planning (such as Modal shares). This will enable more demand-oriented planning and more precise evaluations of the implemented changes. In addition, the use of real-time data will allow for dynamic adjustments based on changes in demand (e.g. due to key events or weather conditions). Further optimization of traffic flow, for example by introducing dynamic, EcoMobility-oriented traffic light schedules, is also conceivable within this context.

The advantages are clear, but numerous barriers stand in the way of implementing such solutions. In many cases, municipalities simply lack the personnel and competence to conduct independent data analyses or use the data correctly, even if centralized services are available. In addition, the prices that digital companies, mobile phone providers, or app providers charge for such data is a hurdle for financially weaker municipalities. Ultimately, preparing the data can be incredibly time-consuming and a high-level of caution is required regarding data quality, meaningfulness, and protection (EBP 2017: III). Open-source-data generated by publicly-operated apps or data that is made available by all operators through appropriate regulations could present a solution.

The optimization of traffic flows represents another valuable method of applying real-time data. Through the continuous evaluation of traffic flows, and communication between vehicles and infrastructure, traffic control systems can support the efficient utilization of existing resources and reduce congestion. A number of approaches are suitable for this purpose, such as situationally changing the direction of lanes, dynamically changing traffic lights, recommending diversions, and temporarily closing roads, some of which are already in use. It is also conceivable that future vehicle-to-vehicle communication will better support smooth traffic flows and enable denser traffic over short periods without causing congestion. In addition, the amount of traffic searching for parking can be reduced by digital parking management systems, which can control available parking spaces through apps or navigation.

However, these optimization measures represent a double-edged sword – by increasing the capacity of transport infrastructure in the short term, thus reducing the cost of space, additional traffic will be induced in the medium and long term. Therefore, traffic flow optimization has the potential to trigger a rebound effect, similar to how the expansion of roads further increases the attractiveness of automobiles, leading to the larger roads once again becoming plagued by congestion. However, traffic flow optimization could have even farther-reaching effects. In light of this, the key to productively applying the optimization of traffic flows, within a traffic transition, is to ensure it is accompanied by a redistribution of road space at the expense of traffic. Such optimizations will mean fewer lanes and parking spaces and more room for cycling and walking traffic, without disrupting vehicle traffic (cf. Thesis 8).

Thesis 3: Virtual mobility can reduce traffic volume

Referring to a common saying of energy policy, it could be stated that "the best mobility is that which does not cause traffic." Therefore, this third thesis on improvements in mobility through digitalization focuses on reducing traffic volume, which, considering the triad of Avoiding – Relocating – Improving (Hennicke et al., 2021:233), should always be carefully considered.

Both our mobility needs and how they are met are highly dependent on social conditions. For example, commuting was a very normal part of working life up until the COVID-19 pandemic. Following this, many workers were given more freedom when it came to commuting to and from work. Digital technologies have been enabling increasing spatial and temporal flexibility of work for a number of years, and some groups and companies have long been exploring the related opportunities. However, it took the COVID-19 pandemic to catalyse the dissemination of the skills, technologies, and organizational requirements needed to make mobile work possible on a large scale, such as company agreements and working time regulations. The ways in which these changes benefit a mobility transition are manifold. The most obvious of these is as significant decrease in work-related traffic (Lambrecht et al., 2021). In addition, the conscious use of teleworking during morning or afternoon hours can effectively combat rush hours by gradually reducing and shifting commuter flows over time. Aside from reducing congestion-related emissions, these changes would help mitigate potential capacity bottlenecks in public transport, which are likely in the event of a broad shift from MPT to EcoMobility. In addition, increasing the temporal flexibility of work will better support commuting by bike, as cyclists who can avoid bad weather with the help of forecasts and telework will not feel the need to travel by car. All related approaches can be promoted under the framework of both operational and municipal mobility management. Within operational mobility, business trips that previously may have been deemed necessary can be replaced by virtual meetings and online conferences, saving on required travel and working time.

However, the potential of digitalization to prevent traffic still extends far beyond work travel. Digital technologies enable day-to-day tasks to be carried out from any location, such as downloading digital prescriptions instead of going to the doctor or conducting administrative procedures over the Internet. These services often require the transfer of intimate data, and so the identification of authorized persons, high levels of data protection, and secure authentication mechanisms, coupled with low-threshold technical access, will be critically important for the success of MaaS offerings. Whether a public service, family physician, employer or providers and users with necessary digital technologies can actively determine traffic reductions and use the results to their benefit, for example, in the context of operational sustainability management or marketing.

Greater attention should also be paid to how time can be used during journeys, which have been transformed by digitalization. In addition to more traditional activities, such as relaxing or listening to music, other activities like working, surfing the Internet, and talking on the phone are all common during travel today. If equipment (fast and secure internet), interiors (power sockets and luggage storage) and atmosphere (calm and private) are all at a certain standard, then the spatial and temporal limitations of working on public transport can be mitigated. This could be a huge advantage for a mobility transition in a number of ways. For example, workers and employers may accept longer journeys via public transport if they know work can be done effectively during travel.

However, the same is true of autonomous vehicles, which do not need to be actively controlled. Therefore, the broad introduction of autonomous vehicles to the private sector is likely to have substantial rebound effects. On the one hand, the advantages of autonomous vehicles could lead to a preference for digitized individual transport over public transport. On the other hand, further applications for private cars will be conceived. For example, there may be scenarios where autonomous vehicles drive around close to their owners' locations for hours just to ensure their availability when parking spaces are scarce. Such rebound effects should be considered in the future during the potential approval of autonomous vehicles. Consideration should also be given to prioritizing autonomous vehicles for use in public transport and ride sharing, in order to achieve the goals of a mobility transition (cf. Thesis 6).

Convert: The framework for new development must focus on integration, specialization, and framework conditions

Specific improvements to transport and mobility, through digital applications, will not be sufficient to realize a comprehensive mobility transition. Instead, digital solutions must be used to develop new mobility offers, business models, and framework conditions that can help existing mobility systems take on new qualities and create an attractive alternative to private cars.

The overarching goal is to use the potential of digital applications to establish EcoMobility as being functionally equivalent to motorized individual transport. If a combination of walking, bikes, public transport, ride sharing, and on-demand mobility services can offer quick and efficient journeys, and connections are secure and search times are short, then going from A to B will be simple and comfortable for everyone. This is how EcoMobility can become a genuine alternative to private cars.

In terms of Convert, previously discussed optimization potential is supplemented by new approaches that create conditions for integrated solutions to be introduced to EcoMobility. Digitalization makes it easier to seamlessly link existing modes of transport, paving the way for intermodal travel chains that either could not exist previously or were too unattractive when compared to automobiles. Digitalization also enables new mobility offers, such as open sharing systems and on-demand transport, which are important building blocks for convenient EcoMobility.

The prerequisite for any such integrated and digital mobility solution is the use of data. While it is not essential for mobility and traffic planning to process sensitive personal data, individually-tailored offers and solutions benefit greatly from having access to such information, like daily routines, walking speeds, and preferred routes. Therefore, the development of new mobility concepts must exploit the potential of data-based services while weighing the costs and benefits of using personal data securely and responsibly. Recent technical developments related to algorithmic methods for anonymization or decentralized solutions of AI can contribute greatly to data protection and service quality. According to concepts of federated learning, data analyses should be carried out on users' end devices. This would make the advantages of AI-based services available without transferring sensitive data.

The following text presents three central solution approaches that integrate individual building blocks to form a qualitatively new and ecologically more sustainable system.

Thesis 4: Integrated, cross-domain services will enable full EcoMobility

Digital innovation undoubtedly makes the lives of individuals more convenient. However, individuals are unlikely to change their mobility habits and adopt new mobility offerings without a significant cognitive change. The key barrier preventing this change continues to be how difficult it is for individuals to search for information, make plans, and deal with unfamiliar offerings, tools, and procedures. While new technologies like navigation and parking assistance have made private car use easier, the implementation of MaaS requires significant organizational efforts as the systems are not sufficiently integrated. For example, if a consumer wanted to take an intermodal route to their destination, each leg of the journey could very likely have to be booked in its own respective app. Many users are also uncomfortable with the time-consuming process that requires the comparison of all their available options and prices on different websites. Users want to travel flexibly and spontaneously without needing to link various means of transportation or compare pricing by themselves.

Creating an intuitive, one-stop system that integrates all individual solutions will require integration in the following four areas:

- **Data and data access:** Unifying standards for data feeds, booking system access methods, and real-time information about available mobility options will reduce costs. These cost reductions will be large enough that even smaller providers will be able to offer competitive services. Politics is already playing a supporting role here.

  According to EU law, mobility providers must initially provide static and, in the future, dynamic travel and traffic data. The Mobility Data Ordinance adopted in September 2021 (BMVi, 2021) also requires data on timetables, routes, and ticket prices throughout Germany be made available on a single platform – the Mobility Data Marketplace (MDM). These regulations should be further developed to enable better use of the data and level the playing field for all mobility providers. For example, data analysis and aggregation rights must be granted and mandatory quality standards for provided data must be created so that all providers will be able to use timeliness and provision without delayed data.

- **Portals for information and booking:** Integrating information services to provide information of all relevant and available means of transportation for single trips on a single information platform increases the attractiveness of the entire mobility system. While data bundling makes it possible to create panoramic mobility information that includes public transport and MaaS services, users typically still need to access multiple portals to book a single route. Real experience enhancement will not be possible until there is a single booking platform for multiple link services.

  Beyond the provision of data, requirements must be made for the integration of the booking platforms. Such requirements will have to balance the losses mobility providers would encounter in customer loyalty against the public interest in an easy-to-use integrated booking system. Ideally, shared data and digital solutions such as booking and payment services will create secure, barrier-free, and intuitive platforms that can be used nationwide, bundle all existing mobility options, and enable cross-modal booking processes. Beyond the obvious advantages in user experience, these platforms can also level the playing field for smaller businesses and bolster market competition.

- **Ticket and fare systems:** Standardizing ticket and fare systems will similarly improve user experience by making fare structures, regardless of the method of transportation or destination, and reduce purchase errors. An ideal standardized fare system would apply across multiple mobility services and across multiple cities, regions, and nations.

  However, while a standardized fare system would increase bookability, user preferences in this area are diverse. Any standardized fare system created would need "mobility packages" that include, for example, monthly available mileage for different services as well as for on-demand public transport. Some users would need pay-per-use systems that avoid ongoing costs, while others prefer season tickets or subscription models that accommodate spontaneous or regular use.

- **Physically linked mobility options:** In addition to digitally linking mobility services so that travel information across multiple modes of transport can accessed more easily, better physical links between these transport modes will also be needed. EcoMobility solutions are made more attractive by increased access to transit information, such as track and stop details, map views, route suggestions, and augmented reality directions through mobile apps. But ultimately, in mobility, time is more often than not the deciding factor.

  For EcoMobility to be an attractive alternative to private cars, door-to-door travel time must be kept as short as possible and transits must be short and uncomplicated. This makes the physical links between mobility services very important. One example of better links would be "mobile stations" at recognizable locations that can bundle transportation with daily life services, such as smart lockers or parcel stations. This will attract and retain more users for EcoMobility services.

Digitalisation not only enables further development in mobility services themselves, but also offers new ways to link and integrate these services. Service integration offers two distinct advantages: First, it allows sporadic improvements in a single service to improve experiences across multiple services or areas; and second, it eases the transition from private cars to alternative mobility options.

Users tend to have a low tolerance for system errors when working with new mobility options due to their lack of experience and familiarity with the systems. Such errors are not uncommon in systems that rely on automobile traffic and classic public transport options, so users often give up on alternative mobility options easily. This means successful digitalization can play an important role in making user interfaces more intuitive and reducing the complex of registration, information and booking processes. The transition from old to new mobility routines will require new programs such as trial packages that will give interested individuals a sense of what is on offer. For instance, new services can be promoted through incentives such as free rides and allowances to take on extra passengers on weekends.

Thesis 5: Nationwide MaaS rollout must be based on clear standards

Today, the range of public transport and sharing mobility offerings differs massively between urban and rural areas. Most large cities already have attractive public mobility offerings. The primary function of MaaS is to supplement conventional public transport during times or in areas where there is low demand. This often means it is responsible for first- and last-mile links. This makes MaaS particularly useful in urban areas with week public transportation. Consumer demand in most urban areas is also high enough to make MaaS and sharing services commercially viable. They are therefore the most lucrative spaces to develop, test, and optimize MaaS offerings in. However, here is also a risk new mobility services could cannibalize EcoMobility if they are targeted at users who are already public transport users or cyclists instead of car drivers. In cities, MaaS services must supplement existing mobility services and seamlessly integrated so that a functional equivalence to private cars becomes omnipresent.

Conversely, in rural areas, development, testing, and optimisation of MaaS is significantly more difficult. Public transportation companies already struggle to provide basic lines and connections in these areas and users are often scarce, meaning privately-operated mobility services are not commercially viable. Therefore, public funding for MaaS that can serve as a basic public service must be secured before we can achieve any substantial transition of the mobility system. The situation in suburban areas or in small and medium-sized cities is often the same.

Mobility system transitions must be implemented consistently across entire nations, and not just in individual, pioneering cities. Innovative solutions must therefore be standardized and compatible so that they can be scaled and disseminated effectively.

Typically, innovations are developed, optimized, and established in niche markets. Experiments, trials, pilot projects are necessary to develop innovative, individual solutions, and so must be encouraged.

At a certain point though, individual solutions must be converted into an overall system that can be rapidly scaled. This makes compatibility between individual solutions essential. Ideally, individual solutions will support and reinforce each other from the beginning, leading to further integration of more and more system parts. However, this scaling depends on the compatibility of the individual solutions, and our ability to integrate them into the overall system.

At present, the incompatibility of individual solutions is slowing down nationwide mobility transitions and creating market barriers for individual, regional systems. Challenges to integration include the strong competitive mind-set found in private mobility service providers as well as established fare and billing structures. Transition won't occur if we rely solely on cooperation between mobility providers and transport companies, so centralized guidance and standardization by policymakers will be needed.

Goals that will likely only be accomplished with such centralized guidance on standardization include:

- **Mobility-to-the-home and mobility guarantees:** Current mobility service standards on minimum service and use frequency do not do enough to establish a functional equivalence to private cars.

  Service standards need to create a sufficient supply of EcoMobility services for every region. Standards must be defined for public transport, for MaaS offerings, and for selected sharing services (such as car and bike sharing), ideally on a nationwide basis. Standards must also be adapted regionally to ensure EcoMobility services provide a real alternative to private cars in both urban and rural areas. Adequate alternatives must be provided to users at no additional cost if services cannot be used due to disruptions or delays. This is the only way to create a "mobility-to-the-home" transport system (Schwedes & Daubnitz, 2011) or a "mobility guarantee" (Ministry for Transport of Baden-Württemberg, 2021).

- **Standardization of interfaces:** There is currently no one-size-fits-all solution for widespread deployment of MaaS offerings. Different solutions are needed for different contexts and regions.

  Developing each of these offerings separately is wasteful though, so sample solutions for different spatial structures and for particular challenges should be provided in a kind of modular system. Making their interfaces standardized and interoperable also improves their implementation and networking, ultimately resulting in easier to use and more broadly accepted offerings.

- **Standardization of coordination bodies:** Stakeholder trust will depend on data exchange. Clearly defined processes and responsibilities will be needed to facilitate such exchanges.

  Several coordinating bodies are currently well positioned to help to pool the data. BaSt (the Federal Highway Research Institute), for example, could be expanded as such a coordinating body.

There are already a variety of individualized solutions in different stages of development where we could test the effects of such standardization. The upcoming implementation of new, digital mobility solutions and traffic systems offers a window of opportunity to network these individual solutions and trial a single comprehensive system.

To this end, politics and administration should intensify exchanges and planning on the decision-making level. Action strategy implementation should be harmonized both vertically in individual municipalities and horizontally on higher levels. There are already approaches that can be used to bundle research and development projects for data-based Mobility 4.0 applications, such as the German Federal Ministry of Transport's mFUND innovation initiative framework. Holistic system design and networking though will require a further inventory of all activities and their interfaces.

The accessibility and scalability of digital services for the mobility transition will increase significantly if we can enable nationwide interoperability between simple processes and data interfaces for users, providers, and other responsible parties. Digitization will play a particularly important role here as the marginal cost of scaling up digital systems is quite low.

Thesis 6: Poorly directed digital applications can undermine mobility transitions

Digitalisation undoubtedly offers great opportunities for a mobility transition. However, blind support of innovative solutions could have unintended impacts, such as an increase in the attractiveness of private cars or in traffic overall. Early identification and interference in these development paths could stop the unfavourable results and ensure mobility transitions are not jeopardized. Potentially problematic development paths include:

- **Private sector autonomous driving:** Autonomous driving is being continuously pushed as "the future" of mobility. It offers numerous advantages to users: Drivers become passengers, giving them more free time; traffic flow can be better optimized, reducing overall travel times; and parking processes can be completely reformed. These advantages increase the attractiveness of MPT and make it much more comfortable than, for example, public transport.

  However, the increased comfort provided by autonomous driving could encourage more people to commute alone and possibly even journey alone for longer distances. Autonomous vehicles could even start searching for their own parking space even after the driver has disembarked at their destination. This would unfortunately increase traffic (Agora Verkehrswende (transport transition) 2020). Such a development cannot be reconciled with the goals of a necessary mobility transition.

  However, autonomous driving is not intrinsically harmful in and of itself. It offers enormous opportunities for transition by supporting public transport in intelligently bundling journeys, reducing per capita emissions, and maximizing the use of existing road space. Removing drivers also reduces the cost of new mobility services, enabling the public sector to achieve a significantly higher level of service with the same amount of investment. Autonomous driving presents both opportunities and risks, and so applications must be guided from the earliest stages to prioritize supporting mobility transition.

- **On-demand transport:** Similarly to autonomous driving, on-demand transport should also be primarily used to increase occupancy rates. Current "ride hailing" services that use private vehicles to carry individual passengers unfortunately lead to a significant increase in inner-city traffic (Baltic et al., 2019). They also threaten to cannibalize the public transit user base as users could shift from preferring public transport to ride hailing. In addition, ride hailing services often have vehicles driving to and possibly returning from a drop-off point, generating a significant number of empty runs (Schaller, 2021). This increases overall motorized traffic.

  The opportunity for on-demand services for the mobility transition therefore lies in two areas: First, in the shared use of on-demand services, for example in the form of small minibuses or cabs that pick up several passengers along a single route; and second, in on-demand services that are integrated into and supplement existing mobility offerings in low-demand areas or during off-peak periods.

Transform: Comprehensive external support will be needed to facilitate transition

The theses proposed in the **Improve** and **Convert** sections of this report explain how existing transport systems can either be optimized or expanded with new mobility services, business models and frameworks to drive a gradual change in mobility. This change will need to proceed in a targeted manner and achieve greenhouse gas neutral mobility for all (cf. Hennicke et al., 2021) to achieve a comprehensive transformation of everyday mobility, in both cities and rural areas. Digitalisation-based improvements and new framework conditions and business models will play important roles in this process.

New MaaS offerings and the networking of these offerings will create an attractive, seamless mobility system that does not require private cars. Such services can be scaled to densely interconnected and closely meshed systems together with public transport and rolled out to areas beyond the major cities so that it can be available to almost everyone. Furthermore, we could completely transform our current car-centric mobility patterns by additionally eliminating certain privileges granted to users of climate-damaging forms of mobility such as individually used cars. Creating a new mobility culture and new mobility routines will not completely eliminate individually used cars as they still provide advantages on some routes and individually used cars will likely continue to function as a status symbol for some. But the number of privately used cars will likely decline significantly.

Below is a brief illustrative story about what new mobility could look like in 2035.

Elma, 65, lives in a suburb of Munich. To get some gardening soil, she must travel to the local hardware store. She uses a mobility token (stored in an app on her smartphone or a transponder) to rent an e-bike, which she can get at one of five rental stations in town, which she rides to the store. After she purchases the soil, Elma uses her favourite app to either call an on-demand vehicle with the appropriate transport capacity or, depending on how big the bag of soil is, swaps her e-bike for an e-cargo bike. She doesn't have to look far to do this - various shared transport options on every street corner. Later, she sets off to visit friends. The carpooling service she books with an app picks her up at the street corner within 10 minutes and takes her to the S-Bahn station a few kilometres away, where a train leaves every quarter of an hour thanks to the newly expanded service schedule. She doesn't need to buy a ticket - the train recognizes her mobility token and bills her account automatically according to the mobility package Elma has subscribed to. The fare here is low thanks to the high density of users and the public subsidies for sustainable mobility services.

Whether Elma decides to take a cargo bike, an on-call bus, or a train, she is able to access and pay for the services using a single platform that runs on either physical or digital mobility tokens. When the tokens are issued, Elma can decide to only allow her mobility service provider to access her data (to guarantee compensation claims and law enforcement) or she can allow some or all of her personal data and mobility routines to be shared with other providers in exchange for discounted ticket prices. Similarly, Elma can decide to share her data for personalized travel suggestions. The platform she uses also allows her to customize her mobility preferences for preferred modes of transportation, minimum transfer times, and more to ensure she isn't overwhelmed by route options.

Her son Hamsa, on the other hand, goes one step further. He decides to have his previous mobility behaviour automatically analysed. An algorithm determines exactly how long Hamsa needs to get to the next train station and also that he likes to sprint to catch the train.

Hamsa and Elma's everyday mobility is fast, comfortable, forward-looking, and sustainable. They don't understand why Uncle Joseph still owns a car. Joseph himself is also beginning to wonder why the blind date he went on the other day looked at his car in disbelief. His date might have assumed that Joseph had an unusual obsession with cars since he did not take the train for their day trip to Usedom and therefore preferred driving the highway to toasting relaxed in the train.

An app and a token can be all it takes to use mobility services. Whether in the city or in the countryside, on-demand vehicles and sharing services have brought mobility hubs and rail lines within reach. These new benefits of Eco-Mobility make it easy to say goodbye to private cars and introduce unfamiliar mobility for people who were previously excluded from social interaction and participation due to automobile dependency. By levelling the playing field with open interfaces and integrated mobility platforms, competition between different mobility providers has taken off. Although not all services will be available on every platform, but it will be possible for MaaS providers to provide users with an overview of all services.

In order to realize this vision of a sustainable digital mobility system, a framework that extends beyond individual transport subsystems to cover all forms transport must be established. This will require structural changes in other system outside of transport. Changes must also be made to our urban and regional planning systems and the competency division and financial allocation among governance levels of municipalities, states, federal governments, and the EU. These framework conditions are outlined in the final two theses.

Together, the theses of this paper will clearly describe the necessary changes required to drive a profound transformation of the status quo. This comprehensive process requires both innovations directly related to digitalisation (Theses 1-6) and changes to the regulatory framework (Theses 7 and 8). Even if regulatory changes are primarily the subject of social negotiation, the strategies are always based on assumptions and estimations on the effects of the decisions to be made. The mobility transition, like the tasks in other transformation arenas, is a complex transformation process that will be repeatedly promoted and readjusted over an extended period of time. This requires a new type of political action that is enabled and strengthened by digitalisation, in particular:

1. The acquisition, connection and analysis of large data sets facilitate political and planning decisions by monitoring implementation efficacy continuously and in real-time (e.g., the effects of congestion charges or changes in the use of the rail system);
2. Simulations enhance the forecasting capabilities of policy consultations so that measures can be planned with greater foresight (e.g., realistic testing of the impact of potential measures, like infrastructure expansion, using agent-based modelling); and
3. Real-time data enables timely intervention in smart-city traffic processes so that undesirable conditions and developments can be detected, addressed, or quickly remedied as they arise.

These kinds of digital solutions can foster a better understanding of the changes needed for complex mobility systems and thus strengthen the ability of policymakers and public actors to develop strategies and act. These solutions, together with the framework conditions listed below, will be prerequisite for the success of EcoMobility.

Thesis 7: EcoMobility will require restructured financing models

A mobility transition that goes beyond sporadic improvements and creates EcoMobility offerings that are functionally equivalent to private cars will require a high-level of investment, especially in regions with moderate or poor starting conditions. Investment will be needed to expand the existing public transport system; to purchase buses, trains, shuttles, and shared vehicles; to upgrade existing transportation hubs into more attractive, multifunctional ones; to build mobile transfer stations; and, last but not least, to build digital infrastructure including mobile networks, smart transport infrastructures, and data platforms. At the same time, the operating cost of high-quality, dense public transport services, sharing services, and on-demand transport are also extremely high. A new public transport system will only be attractive enough to function as an alternative to private cars if sufficient investments are allocated for development and OPEX. However, the demand for subsidies will eventually decrease as usage increases.

For new service financing, a distinction must be made between partially profitable urban areas and the far greater number of situations that will not be economically viable - most notably areas with low demand. It will not be possible to establish the mobility services needed for the mobility transition if we solely rely on the private sector. Instead public funding will be needed in varying degrees depending on profitability and spatial context of each service.

Currently, public transport in Germany is financed by federal, state, and local governments as part of a complex grant system. In most cases, the purpose of these grants is to guarantee the provision of basic public mobility services. This is considered a responsibility of all municipalities. However, not every part of the country counts mobility as a mandatory part of basic public services. In addition, establishing a functional equivalent to private transport will require a considerable increase in expenditure, since, in most cases, initial revenue won't be able to cover short-term costs. So, concrete goals and funds separate from those set aside for basic public services must be defined and anchored in law. Provisions must be made for the integration of on-demand transport and sharing services in particular.

Simultaneously, the current public funding system must be reformed. Only additional federal subsidies for both initial investment and OPEX will make it possible for states and municipalities to create nationwide services that guarantee the desired service quality. A transport generation levy could also be a sensible way to supplement traffic avoidance and modal shift efforts. For example, employers whose employees have to drive long distances should pay higher levy than those whose employees commute less or those who have successfully guided employees to choose bicycles and public transport.

New compulsory tasks for a mobility transition should also be made a binding part of financing reform.

It should be noted that, from a business perspective, MaaS systems are characterized by the interaction of several stakeholders that may previously have been competitors. These stakeholders include municipalities as clients or purchasers, public transport operators, MaaS service operators, data and service providers. As a result, MaaS services are "multi-stakeholder ventures" whose new and sometimes challenging business models make it necessary to rethink financing channels. In addition to models that are operated and financed exclusively by the private sector, public-private cooperation and privately-operated models should also be considered.

Thesis 8: Regulatory support will be needed to encourage individual transitions away from private car ownership

The current transportation system is centred on individual motorized traffic. Its evolution has also evolved in a path-dependent manner. New roads, parking lots and discounts for cars have favoured private ownership. Roads and parking resources have in turn shaped mobility routines and guided the decisions people make about where to live, where to work, and where to go to school or university. These mobility routines and decisions will only change when we substantially shake the foundations of established mobility behaviour (Rid et al., 2018: 25).

Such disruptive momentum rarely results from market forces alone. Even the ambitious goal of functional equivalence between private and public transport cannot – without accompanying push and pull measures – ensure a broad transformation of the mobility system. Car drivers enjoy a number of privileges. Road space is primarily designed to meet their needs, parking spaces for residents are – completely or almost – free of charge, the majority of transport investments is devoted to road traffic, and a number of subsidies – from the commuter allowance to the company car privilege to the diesel subsidy – are designed to benefit car traffic. The expansion of EcoMobility therefore needs to be accompanied by changes in the regulatory framework, in price incentives for private cars, and in spatial, urban and transport planning. In addition, the symbolic and emotional aspects attached to car ownership must also be addressed.

The foundations for local action are typically laid at the federal or state level. Reorganizing road space will require binding quality standards for bicycle and pedestrian paths, simplified planning requirements for bicycle paths, and more restrictions on motor vehicle traffic. Changes in the Road Traffic Order would make it easier to convert on-street parking spaces into bicycle parking facilities, green spaces and rest areas, or mobility hubs. A standard speed of 30 km/h in cities will make cycling more accessible and ease traffic flow. Nationwide rules will also be needed for MaaS offerings, like obligations for mobility service providers to enable cross-provider ticket bookings and service standard requirements. In addition, municipalities should be entitled to regulate car traffic through a price mechanism, such as increasing parking fees and introducing congestion charges. Any successful approaches trialled by one municipality could then be made mandatory for similar municipalities. It is important to keep in mind that approaches for rural and urban areas can differ greatly. Parking space management will be less critical than communal busses (volunteer-run public and community transport) in rural areas. Therefore, the regulatory framework should be reviewed with different spatial situations in mind.

An overall framework will be needed to ensure that these complex changes in regulatory law, transportation planning, and pricing incentives work together in a meaningful way and do not create conflicting incentives. The development of new mobility options and the retirement of old transportation systems should be coordinated for maximum impact. This overall framework should be created within federal mobility law via a roadmap for mobility system transition.

A comprehensive mobility transition toward sustainable mobility for all segments of the population is a far-reaching change for which the necessary structural prerequisites and framework conditions must be created. Theses 8 and 9 are key starting points for this. For a successful transformation of our mobility system, however, we must think even more broadly - our behaviour and attitudes toward mobility must also be realigned.

Mobility behaviour is shaped by more than just spatial structures, transport modes, costs, and time expenditures. The mind-set of individuals is also shaped by socio-cultural influences and the symbolic and emotional values assigned to different forms of mobility. Different means of transport are often used to project social status. The importance and possibility of physical exercise, perceived behavioural control, and the inclination to use digital interfaces are also factors that influence individual choices. Most of these factors are sub-consciously enforced by media role models and advertising. Therefore, we can and must start to transform our mobility system by addressing these attitudes and social norms.

This task touches on psychological, social, and cultural aspects that go beyond pure mobility issues and cannot be discussed further within the scope of this study. However, it is obvious that digitalisation can also help to address challenges and opportunities for communication, information transfer, and targeted impetus for behaviour change through transparent and value-based nudging, and mobilization of target groups through challenges or gamification.

Changing mobility routines is not an easy task and the need for action is huge. It will require target group-specific strategies as well as persistence. "Hard" technical and infrastructure strategies must be accompanied with "soft" communication and interaction-related measures. Only together will they be able to drive changes in behaviour and routine in our everyday lives.

Conclusion

A fundamental mobility transition is essential to tackling our current climate crisis. We must consider all available strategies to make our transport system greenhouse-gas-neutral and to cut the enormous energy requirements of our mobility system. We must consider reducing traffic; shifting to a new, expanded EcoMobility; and optimizing our means of transport by increasing the efficiency of renewable energies.

For this mobility transition to be successful, we will need to abandon our current car-centric transport system.

And so, we will need a sustainable alternative to the current system: a new mobility system that enables the same mobility with less traffic. It must be supported by virtual mobility and a new EcoMobility that seamlessly combines new mobility services with bus, rail, walking, and cycling. Carpooling services, shared vehicles, and mobile stations must be networked to form modular building blocks that can be booked from a single platform, making travel reliable, comfortable, and inclusive. This is the only way for EcoMobility to outperform private cars.

However, this system will only be possible if the right framework conditions are put in place.

The transformation and design of a networked system requires coordinated, networked policy approaches and a smart policy mix. This report has described the approaches that can be used to Improve, Convert and Transform our mobility system while focusing on how digitalisation can contribute to the process. A comprehensive transformation (**Transform**) of our current mobility system will be necessary, but the path towards that transformation will consists of many small steps (**Improve**), which, in turn, must support and complement each other and lead to a qualitative change (**Convert**) in the transport system. Coordinated public support from legal frameworks, standards, and financing will also be needed during the structural upheavals that will result from this transformation process.

Over the past decade, a multitude of digitalisation-based innovations have become deeply rooted in our everyday lives. The challenge we face now is figuring out how to connect them and make them easier to use. To this end, a common data space will be crucial. While conventional business models are often based on the exclusive use of data by individual players, data on mobility supply and demand must be available to all mobility service providers. In this context, interoperability should become mandatory so that users will be able to access information about and book a wide range of offers on one platform. This will create the basis for a competitive mobility market, increase user convenience through uniform access and payment system, and prevent monopolization.

Coordinated development of new public transport systems and MaaS will only happen with nationwide service standards that guarantee viable offerings in both cities and rural areas. Players in this space will include the public sector and conventional transport companies as well as new mobility providers. To this end, we will need efficient and financially viable business and cooperation models that will enable the development of these services in this decade.

This requires financing models in which both private and public funds are used specifically for the mobility transition. We must start to develop and implement these models now in order to navigate the tangle of interests between various political levels and mobility providers.

The mobility transition outlined here is an orchestrated change that needs to involve both public and private actors. It will require new entrepreneurial initiatives that rely on publicly provided infrastructure and preparatory efforts to provide their services. Within this, the exploitation of digital innovation potentials will be critical for both the upscaling of environmentally friendly mobility alternatives and for the gradual curtailment of motorized individual transport.

The opportunities for development though are clearly visible. It is also clear which tasks the new federal government must first accomplish. The agreement for the future so-called traffic light coalition, presented on November 24, 2021, addresses these challenges and claims it will, "... use the 2020s for a breakthrough in mobility policy and enable sustainable, efficient, barrier-free, intelligent, innovative mobility that is affordable for all." Some of the cornerstones of this study are specifically named in the coalition agreement, such as the provision of mobility data, the further development of a mobility data space, and the promotion of digital mobility services or intermodal links, as well as a long-term strategy for autonomous and connected driving in public transport.

For the success of a comprehensive transition into sustainable mobility, the measures outlined in the coalition agreement must be concretely elaborated, supplemented and implemented. We hope this report will similarly serve as an impetus for this path and drive a climate-friendly and sustainable mobility transition in Germany.

Bibliography

Agora Traffic Transition (2020). The automation of the automobile and its consequences. Opportunities and *Risks of self-driving vehicles for sustainable mobility*.https://www.agora-verkehrswende.de/veroeffentlichungen/die-automatisierung-des-automobils-und-ihre-folgen/

Baltic, T., Cappy, A., Hensley, R., & Pfaff, N. (2019). How to transform the road: McKinsey, Germany.https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-sharing-the-road-is-likely-to-transform-american-mobility

Federal Government (2021). Greenhouse gas balance - Germany remains on track in climate protection. Website.https://www.bundesregierung.de/breg-de/aktuelles/klimaschutzziel-2020-erreicht-1876954

Bauer, U., Bracher, T., & Gies, J. (2020). Another city traffic is possible. New opportunities for crisis-proof and climate-friendly mobility. Agora traffic turnaround.https://www.agora-verkehrswende.de/fileadmin/Projekte/2020/Covid19_Stadtverkehr/Agora-Verkehrswende_Ein-anderer-Stadtverkehr-ist-moeglich_1-1.pdf

BMU (2021). Greenhouse gas emissions in Germany continue to fall - BMU infographic. Website.https://www.bmu.de/MD1485

BMVI (2021). Mobility data regulation, opinions of the associations.https://www.bmvi.de/SharedDocs/DE/Gesetze-19/mobilitaetsdaten-verordnung.html?nn=382740

Deutsche Bahn (2019). 10 years DB Navigator: 105 million mobile phone tickets. Website.https://www.deutschebahn.com/de/presse/pressestart_zentrales_uebersicht/10-Jahre-DB-Navigator-105-Millionen-Handy-Tickets--4714210

EBP (2017). Big Data and Crowd Data for Berlin Urban Development Planning. Report commissioned by the Senate Department for Urban Development and Housing of the City of Berlin. Zurich/Berlin: EBP Switzerland AG/EBP Deutschland GmbH https://stadtentwicklung.berlin.de/planen/basisdaten_stadtentwicklung/big-data/downloads/big-data_crowd-data_berlin.pdf

Koska, T., Rasch, J., Reutter, O., & Seifried, D. (2021). Sustainable mobility for all. A plea for more traffic justice. New York: Oekom Verlag.https://doi.org/10.14512/9783962388072

Hochfeld, C., Jung, A., Klein-Hitpass, A., Maier, U., Meyer, K., & Vorholz, F. (2017). 12 Theses on the transport transition (short version). Agora Traffic Transition.https://www.agora-verkehrswende.de/fileadmin/Projekte/2017/12_Thesen/Agora-Verkehrswende-12-Thesen-Kurzfassung_WEB.pdf

Lambrecht, Udo, Kräck, Jan & Dünnebeil, Frank (2021). Home office and replacement of business and business trips with video conferencing. Potentials for reducing greenhouse gas emissions, taking into account the experiences of the corona crisis. ifeu paper 04/2021.https://www.ifeu.de/fileadmin/uploads/IFEU-Workingpaper_4-_21_-__Mobiles_Arbeiten_und_Videokonferenzen.pdf

Ministry of Transport Baden-Württemberg (2021). Public transport strategy 2030 for Baden-Württemberg Together to double the number of passengers on public transport. Draft, as of September 29, 2021.https://vm.baden-wuerttemberg.de/fileadmin/redaktion/m-mvi/intern/Dateien/PDF/2109_29_Entwurf_%C3%96PNV-Strategie2030_Anh%C3%B6rung.pdf

Mommens, K., Buldeo Rai, H., van Lier, T., & Macharis, C. (2021). Delivery to Homes or Collection Points? A Sustainability Analysis for Urban, Urbanised and Rural Areas in Belgium. Journal of Transport Geography, vol. 94.https://doi.org/10.1016/j.jtrangeo.2021.103095

Purr, K., Guenther, J., Lehmann, H., & Nuss, P. (2019). Pathways to resource-efficient greenhouse gas neutrality. RESCUE Study No. 36. Federal Environment Agency.http://www.umweltbundesamt.de/publikationen

Rambol mobility (2021). Gender and (Smart) Mobility. Green Paper 2021. Rambol.https://ramboll.com/-/media/files/rgr/documents/markets/transport/g/gender-and-mobility_report.pdf?la=en

Repenning, J., Harthan, R.O., Blanck, R., Boettcher, H., Braungardt, S., Östermann, V., Emele, L., et al. a. (2021). Projection report 2021 for Germany in accordance with the requirements of Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the governance system for the Energy Union and for climate protection. Berlin, Karlsruhe, Braunschweig, Eberswalde, Hamburg: Eco Institute, Frauenhofer ISI, IREES GmbH, Thünen Institute.https://www.oeko.de/fileadmin/oekodoc/projektionsbericht_2021_bf.pdf

Rid, W., Parzinger, G., Grissam, M., Müller, U., & Herdtle, C. (2018). Potentials of (e-)carsharing. In: Rid, W., Parzinger, G., Grausam, M., Müller, U., & Herdtle, C. (ed.): Carsharing in Germany: Potentials and Challenges, Business Models and Electromobility, pp. 21-44. New York: Springer Journal of International Journals.https://doi.org/10.1007/978-3-658-15906-1_4

Sach, T., Breischlag, L., Bruhin, L., Kerres, P., Lotz, B., & Oppermann, L. (2021). Climate protection in figures: facts, trends and impulses of German climate policy. Issue 2021. BMU https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/klimaschutz_zahlen_2021_bf.pdf

Sounder, B. (2021). Can sharing a ride make for less traffic? Evidence from Uber and Lyft and transportation for cities. Transport Policy.https://doi.org/10.1016/j.tranpol.2020.12.015

Schmidt, U. (2020). Electromobility and Climate Protection: The Great Miscalculation. Kiel Policy Brief 143. Kiel Institute for the World Economy (ifw)https://www.ifw-kiel.de/fileadmin/Dateiverwaltung/IfW-Publications/-ifw/Kiel_Policy_Brief/2020/KPB_143.pdf.

Swedes, O. & Daubnitz, S. (2011). The role of the physiology of the physiology of the physiology. German Consumer Association (VZBV).https://www.vzbv.de/sites/default/files/downloads/Hausanschluss_Mobilitaet_vzbv_2012.pdf

UBA (2020). Environmental Justice – Environment, Health and Social Situation. Website https://www.umweltbundesamt.de/themen/gesundheit/umwelteinfluesse-auf-den-menschen/umweltgerechtigkeit-umwelt-gesundheit-soziale-lage

UBA (2021). Development of greenhouse gas emissions in Germany in delimitation of the sectors of the Climate Protection Act. Excel data volume.https://www.umweltbundesamt.de/sites/default/files/medien/361/dokumente/2021_03_10_trendtabellen_thg_nach_sektoren_v1.0.xlsx

Wuppertal Institute (2021). Shaping digitalisation – enabling transformation to sustainability. Study in the framework of the project Shaping the Digital Transformation. Wuppertal Institute for Climate, Environment and Energy.https://wupperinst.org/fa/redaktion/downloads/projects/ShapingDIT_de.pdf