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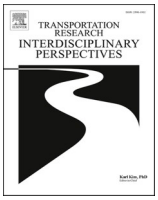

Potential impacts of institutional dynamics on the development of automated vehicles: Towards sustainable mobility?

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ABSTRACT

Most experts agree that automated vehicles (AV) will be commercialized sooner or later and that this will lead to far-reaching changes in the mobility system. However, it is still open whether these developments will lead to more sustainable transport systems. AVs may render private car ownership more attractive and therefore intensify car-oriented mobility patterns, or may increase the attractiveness of public transport when mostly used as robo-taxis. Once development has started to move in a specific direction, self-reinforcing dynamics and path-dependencies may unfold. Therefore, it is important to analyze which factors may influence the direction of path-dependencies. We argue that understanding emerging path-dependencies requires an understanding of the interrelated technical, economic and societal dynamics. We draw on recent insights into societal dynamics in sociotechnical regimes, drawn from sustainability transition research, to identify potential development trajectories of automated driving due to changes in what is conceptualized as normative-cognitive institutions. We introduce an approach to map such institutional dynamics based on recent data from developments in the German mobility sector. Results demonstrate that the direction of future AV pathways may depend on such institutional developments. Both a reinforcing and a disruptive pathway are plausible. Governance strategies that aim to tap the potential of AVs in supporting sustainable urban mobility should consider institutional dynamics more explicitly.

1. Introduction

There is broad agreement that automated vehicles (AV) will become commercialized sooner or later and that this will lead to far-reaching changes in the mobility system – and beyond. However, it is unclear and contested whether AVs will support or hamper a transition towards more sustainable transport systems (Haugland and Skjølsvold, 2020; Hopkins and Schwanen, 2018a; Transport & Environment, 2019). Some experts argue that AVs will lead to a significant decline in private car ownership and to a rise of a regime of seamlessly intermodal mobility options that are used "on-demand" but not owned (Docherty et al., 2018; UITP, 2017). This trajectory is supposed to result in a reduction of current negative externalities of the transport sector. Others argue that AVs could push developments in the opposite direction of a dramatic decline in public transport and of an intensification of personal car-based mobility behavior, and therefore further reinforce negative impacts on health, the environment and waste of space, since driverless cars will offer highly efficient and extremely convenient personal transport (Fagnant and Kockelman, 2015).

It is difficult to predict the exact course of development of AVs and to understand which factors are relevant for setting the course in one or the other direction. The impacts in terms of sustainability may be substantial. Policymakers should be able to ensure that AVs develop in line with societal goals and expectations. The governance of AVs should therefore be based on a solid understanding of factors that reinforce one or another trajectory, to be able to prepare effective policy measures early on. Insights into the starting points of emerging path-dependencies are required in order to prevent non-sustainable path-dependencies unfolding at an early stage of developments. In this paper, we aim at a better understanding of those moments when alternative directions of transformative change are shaping up. We will do this by drawing on recent insights from transition studies.

The high degree of uncertainty about the future of AVs is a challenge for disciplines such as technology assessment or foresight, which aim to

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provide guidance in technology policy (Grunwald, 2018). Reasons why anticipation may be difficult may be easily understandable from the point of view of transition research. This research field has demonstrated that transformative change depends on a broad set of factors, beyond technical and economic performance. Rather, these factors can only be understood in their interaction with social and institutional conditions, which co-evolve with a new technology (Truffer et al., 2017). Therefore the development of new technical options needs to be analysed on par with changes in regulations or policies, but also "informal" factors such as routinized practices, societal perceptions or beliefs of what is "normal", or taken-for-granted etc. (Geels, 2004; Geels and Schot, 2007; Rip & Kemp, 1998). Based on institutional theory (Scott, 2008), these informal conditions are usually subdivided as cognitive and normative institutions, which complement the more formal regulative institutions (Fuenfschilling & Truffer, 2014; Geels, 2004).

Transition research has repeatedly shown how social and technical factors co-evolve and align to form stable "configurations that work" (Rip & Kemp, 1998). The coherence of these configurations depends on whether and how actors agree on the core rule set the so-called socio-technical regime. The socio-technical regime shapes the selection environment for innovations, i.e. once established, technologies typically progress along rather narrowly-defined paths. It is therefore important to understand how socio-technical regimes weaken, allowing new radical options to develop and mature. Cognitive and normative institutions, or cultural settings, play a key role in the stabilization of these regimes and therefore shape the directionality of new technologies (Fuenfschilling & Truffer, 2014; Wirth et al., 2013; Yap and Truffer, 2019). Significant change in sociotechnical systems will therefore not only depend on the superiority of a technical design or its cost-competitiveness. New mobility options have to be perceived as legitimate by users, citizens, policymakers and other societal actors in order to be adopted in everyday mobility practices (Binz et al., 2016). Deep structural changes therefore occur when the regime-rules start to allow for solutions beyond the business-as-usual, and lead to hopefully more sustainable new products and practices.

Generally, the relevance of societal preferences and norms for development and stabilisation has repeatedly been emphasised by authors from the field of transitions research and social science-oriented mobility research (Cohen et al., 2020; Dennis and Urry, 2009; Geels et al., 2012; Milakis and Müller, 2021; Sheller, 2012; Urry, 2004). However, to our knowledge, these insights have not explicitly addressed emerging changes in directionality. This appears surprising in view of the manifold fundamental changes that are expected due to the digitalization of the transport sector. In recent years, a broad range of foresight and scenario studies on the future of AVs have been published (Faisal et al., 2019; May et al., 2020; Meyer et al., 2017; Milakis et al., 2020; Schippl and Truffer, 2020). Often, these studies start with a selection of technical designs of AV-based mobility options. Institutional dynamics are mostly considered to be of subordinated nature; context conditions for the scenarios, of sorts. Quantitative, model-based approaches usually assume that specific forms of private or collective AVs will be introduced to (mostly urban) mobility systems (Friedrich and Hartl, 2016; Meyer et al., 2017; Winter et al., 2021). The subsequent focus is then on calculating the impacts of these AV-based mobility systems on transport flows, capacities, and costs, as well as on the environment, and sometimes also on urban development. These studies however, do not problematize how new development trajectories come into being. Other approaches, often of a more qualitative nature (ifmo, 2016), consider aspects of varying institutional configurations as framework conditions but do not use them as key-variables to build-up the scenarios. Closer to our ideas is the approach of Fraedrich et al. 2015, which draws on concepts from transition research to analyse potential future development pathways of AVs. However, also in this case, a systematic analysis of cognitive-normative institutional variations that may trigger new path-dependencies is not in the scope of the study.

In this paper, we focus on how to systematically assess early dynamics in cognitive-normative institutions in the emerging AV technology field. We consider this as important, since it is here where directionalities of AV-developments are co-determined, as will be shown in the analyses. The contribution of the paper is therefore twofold: First, we highlight the relevance of cognitive and normative institutions for the future development of AV technologies. Second, we apply an approach for mapping indicators for dynamics in institutional settings, based on concepts and insights from transitions research (Truffer et al., 2017). We relate the expected shifts in cognitive and normative institutions, to investigate whether and how the regime core of the transport sector may show changes in the directionality of AV-based innovations. More specifically, we focus on changes in the relationship between citizens and car-mobility, since this is at the heart of recent debates about the sustainability of future trajectories of AV-based mobility. We will show that some observable dynamics work towards change, however the development of others works towards stabilisation.

The paper proceeds as follows. Recent developments in the field of AVs are summarised in section 2. In section 3 we develop our conceptual approach based on insights from transitions research. In section 4 we map different indicators of institutional dynamics in the mobility regime. In section 5, we show that very different path dependencies may take effect depending on which institutional configurations become dominant. Conclusion are drawn in section 6.

2. Automated driving – More or less sustainable futures?

In line with the general digitalisation trend, automated (or even "autonomous") driving has become one of the most debated topics in the transport sector, over the past few years. The huge transformative potential of these innovations is widely acknowledged, but there are also widely different opinions and a high degree of uncertainty regarding when, where, and to which degree automation will become commercially available. The Society of Automotive Engineers (SAE) International (SAE International, 2016) defines five levels of vehicle automation. In levels 1 and 2 the human driver still monitors the driving environment and is assisted by various types and combinations of driver assistance systems. In levels 3 to 5 an automated driving system monitors the driving process. At level 3 ("conditional driving automation") the human driver is expected to respond appropriately to specific intervention requests. At level 4 the vehicle operates autonomously in predefined contexts and the human driver is not expected to respond immediately to an intervention request. Only at level 5 is fully autonomous driving possible: Here the automated driving system provides full-time performance under any roadway and environmental conditions that a human driver would also handle.

Significant technical progress has been made in the field of AVs in recent years. However, it remains contested when and in what way higher levels of automation will be commercialised (Haugland and Skjølsvold, 2020; Rebalski et al., 2022). There is an argument that high degrees of automation will be achieved for highway applications first, long before cars will be able to navigate themselves though extremely complex urban traffic situations (Sigal, 2019). The car industry in general promises a continuous evolution of driver assistance systems to lead step-by-step towards level 4 and level 5 automation. So far, advanced driver assistance systems do not go beyond level 2. Recently, it seems as if the first car companies will bring level 3 assistance systems for traffic jams on highways onto the market in due time. The more revolutionary perspective, usually linked with robo-taxis in urban agglomerations, sees a rapid introduction of driverless cars as the most promising and likely pathway. Advocates for this pathway can be found in the field of Tech-companies such as Waymo or Zoox. These companies carry out respective field trials in the USA. In Arizona, Waymo is running a publicly accessible, fully autonomous shuttle without a security driver, in a predefined area.

Discussions about the potential societal and environmental impacts of AVs are no less controversial. Many optimistic expectations are linked in particular to levels 4 and 5, when cars are able to be operated in self-driving or even driverless modes (see for example Skinner and Bidwell, 2016). Amongst the expected benefits are a reduction in the number of traffic accidents, better transport flows, more efficient use of infrastructures, more energy-efficient driving, new options for use of travel time, improved mobility for disabled persons, and also competitive advantages for the automotive sector. It is generally assumed that AVs will be electrically-powered and that this will reduce emissions of pollutants and greenhouse gases (Alsalman et al., 2021). On the other hand, there are also concerns related to the ambivalence the general public has in interacting with "robots", and related to safety and security issues, data protection and cybersecurity (Fleischer and Schippl, 2018). In particular, when it comes to a transition towards a more sustainable transport system, it is contested whether AVs will be a blessing or a curse (Hopkins and Schwanen, 2018b; Legêne et al., 2020; Nikitas et al., 2021; Salas Gironés et al., 2020; Thomopoulos and Givoni, 2015). Fraedrich et al., 2017 argue that AVs can drive public transport either into a virtuous cycle or into a vicious cycle. One of the major concerns relates to the overall increase in car traffic, because AVs may make car use more attractive. As a consequence, public transport trips may decline for longer distance journeys, since users of AVs do not have to drive, but can use the time to do other things such as working, sleeping or playing games. AVs could therefore displace public transport, in particular in smaller cities and rural areas, which could result in a reduction of public transport services and thus further weaken its competitiveness ("Vicious Cycle" of public transport, Fraedrich et al., 2017). In contrast, other experts envision driverless robo-taxis and smaller busses as flexible, efficient and affordable complements to public transport (Canzler and Knie, 2016; UITP, 2017). They see AVs as an opportunity to strengthen the attractiveness of public transport and related services, which would lead to a reduction in individual car transport (virtuous cycle, Fraedrich et al. 2017). So, the extent to which AV-technology will support a transition to a more sustainable transport system strongly depends on which of the sketched development trajectories will dominate in the future. We now introduce an approach to analyze the potential influence of institutional dynamics on the emergence phase of these development trajectories.

3. Putting institutional dynamics center stage

3.1. Conceptual background: Approaches from transition research and institutional theory

Our approach draws on concepts and findings from transitions research, institutional theory and technology assessment. Transitions research aims at understanding the development of innovation processes in socio-technical systems, i.e. it analyzes technical and non-technical factors in their co-evolutionary interdependence. The core rule set of a sociotechnical system is conceptualized as a socio-technical regime, a rather stable configuration of technological principles, regulations, ways of thinking, routinized practices, skills and procedures, or ways of handling relevant artefacts and actors (Rip and Kemp, 1998). According to Rip and Kemp, a sociotechnical regime can be understood as a stable, deeply institutionalized "configuration that works". Transitions are, in this logic, understood as fundamental restructurings of regimes (Geels, 2004).

Institutions are therefore central to studies on socio-technical transitions (see Geels, 2004). Fuenfschilling and Truffer (2014) argue that the strength of a regime can be described by the degrees of institutionalization of its core elements. A configuration is stable if the different institutional elements are coherently aligned and exert a high degree of structuration for the actions of different actors. Institutions may be differentiated as representing regulative, normative, and cognitive pillars, "providing the elastic fibers that guide behavior and resist change" (Scott, 2008). Scott describes these elements as follows:

- Regulative institutions: rules fixed in laws, directives, standards etc.
- Normative institutions: "normative rules that introduce a prescriptive, evaluative and obligatory dimension into social life. Values and norms play a central role. It is about normative expectations of how specific actors are supposed to behave.
- Cognitive institutions: taken-for-grantedness, shared logics or understandings, perception of what is "normal"

According to Hoffmann (1997 quoted in Scott 2008), the three elements form a continuum, moving "from the conscious to the unconscious, from the legally enforced to the taken for granted". The differentiation between the three pillars is particularly interesting to us, in going beyond the formal laws, standards and regulations. It is needless to say that regulative elements such as policies, regulations or standards are usually highly important for developments in the transport sector. However, changes in meanings, in perception of what is "normal", in taken-for-granted assumptions or established routines may be even more relevant for setting the course of a new technology. There are at least two reasons for this focus: First, normative-cognitive dimensions are often not adequately considered in the assessment of the transformative potential of innovations in the transport sector, because they are more difficult to study and less visible than technologies, costs and polices (see Wirth et al., 2013). Second, cognitive and normative institutions have a significant influence on mobility patterns and on future development trajectories in the mobility sector. This holds in particular for car use, as illustrated by various studies (see Dennis and Urry, 2009; Freudendal-Pedersen, 2009; Gössling, 2018; Truffer et al., 2017). Sheller (2012) puts it as follows: "Car use is never simply about rational choice but is as well about aesthetic, emotional and sensory responses to driving, as well as patterns of built environment, political process, sociability, habitation, family and work".

Against this background, we posit that the way automobility is perceived and used, and its importance to social life, are core components of the sociotechnical mobility regime. Thus, it is not only technical and regulatory aspects that determine whether and how the diffusion of AV technology will change the regime. Cognitive-normative institutions also affect the relationship between citizens and automobility, and thus the initial conditions that AVs encounter in the mobility regime. This relationship is also part of the strongly institutionalized rules of the regime, which need to change in order to enable significant changes in transport mode choice (Sheller, 2012). We therefore propose to focus on dynamics in the realm of cognitive and normative institutions that affect the relationship between citizens and automobility, in order to identify potential future development directions for AVs.

3.2. Methodological approach

As shown above, the potential development of AVs is strongly related to how car-based mobility will be used in the future, how it will be perceived, and how it will be socially embedded. In one potential development trajectory, cars play an even more central role than today, while in the other they reduce significantly in importance. We therefore propose to have a closer look at the institutional dynamics which shape the practices of private car use. The point of reference is whether cars and car use will continue, or even increase, to be seen as a core component of modern mobility systems. But if citizens tend to change car-related perceptions and mobility behaviour, this would mean that the societal relevance of private car use is decreasing. This is one of the most important questions in the debates on sustainable mobility transitions (Banister, 2008). We see three dimensions of cognitive-normative institutions related to car-mobility that are likely to undergo fundamental change in the near future: These dimensions are interrelated, but sufficiently distinct to use for mapping indicators for upcoming changes in the mobility regime.

- The first dimension relates to the established form and intensity of user commitment that is required to get access to a car; the degree to which buying and maintaining cars is considered as normal and desirable practice;
- The second dimension relates to the routines and practices of car use that are perceived as normal, the relevance and the symbolic meaning of car use for personal mobility patterns and for the organization of daily life.
- The third dimension relates to the common social embedding of cars, including expectations towards car-oriented planning and policies.

We want to highlight that opposing tendencies in the three institutional dimensions are currently at play, which will co-determine whether AVs will contribute to a disruptive development or to a reinforcement of the car-dominated mobility regime. However, changes in cognitive-normative institutions are not directly visible or measurable. We therefore draw on a set of indicators of institutional dynamics to see whether specific institutional configurations might gain influence and lead to either a more or a less car-dominated mobility system. As a consequence, AVs could lead to very different development trajectories depending on which institutional configuration will become dominant. We briefly sketch these potentially self-reinforcing path-dependent dynamics in the qualitative scenarios in section 5.

Through the scenarios, we aim to show that variations in cognitive-normative institutions can be very important for the future design and sustainability of the mobility sector, especially for the case of automated driving. Quantitative and qualitative scenarios represent a well-established methodology in future-oriented approaches such as technology assessment (Grunwald, 2018). The idea is not to predict the future, but to illustrate that different future development trajectories are possible, depending on different assumptions about initial conditions and cause-effect relationships. We do not intend to sketch the full range of potential future development trajectories; here, we illustrate that very different trajectories are plausible from today's point of view.

4. Dynamics in user-related institutional dimensions

We start with mapping indicators for changes in the three user-related institutional dimensions of car mobility. As a geographical frame for our analysis we take Germany, a country where the car industry has a long-standing tradition and where national economic welfare depends to a substantial degree on producing and selling cars. We draw on recent data from the mobility sector and pick out indicators that can be considered as relevant for one of the three institutional dynamics. We do not aim to provide an exhaustive overview of all the data that might be relevant for mapping institutional dynamics. This would go beyond the scope of this article. However, our line of reasoning can be a basis for such broader analysis. The main source for our analysis is the large-scale survey "Mobilität in Deutschland" [Mobility in Germany] that was carried out in 2017 (Nobis and Kuhnimhof, 2018). This is supplemented by additional data from other surveys, and evidence from literature, which can be related to the three institutional dimensions. We will show that indicators pointing at changes in institutional settings can be found. However, we also see evidence for stabilization of established regime structures. This implies that it is not yet determined in which direction the three institutional dimensions will develop. Nevertheless, for the future of AVs, and for the mobility sector in general, institutional dynamics can become a highly relevant factor (see section 5).

4.1. Institutional dimension 1: Commitment required to get access to (car) mobility

This dimension refers to the established and routinized form of getting access to cars (see Table 1). It is about the extent to which the level of knowledge and effort (in terms of time and money) to gain access to a car is considered normal or acceptable to the user. Driving licenses are needed, and cars have to be purchased and maintained. Under these aspects, cars also compete with other modes of transport. Cycling needs certain skills and access to a bicycle, and also specific skills are required to use public transport, for instance to know how to read timetables of trains and buses.

Table 1
Institutional dimension 1: Commitment required to get access to cars.

Institutional dimension 1: Commitment required to get access to cars		
Characteristics of specific institutions	Indicators for institutional change - towards less car orientation	Indicators for institutional change - Towards stabilisation or intensification of car orientation
- willingness to invest in driving license	- slight decline in interest in access to car mobility amongst younger adults	- increase in driving licences of elderlies
- willingness to invest time and money in cars (e.g. maintenance)	- cars compete with other household items such as gadgets (phones, tablets etc.)	- car fleet grew by 10% between 2010 and 2017
- perception of access to other means of transport (access to public transport considered complicated)	- increases in cycling because of e-bikes, physical fitness less relevant to use cycles - digitalisation and integration of public transport and related services facilitates access to these modes	- access to cars still simple - critical discussion about privacy may hamper the usage of data-intensive mobility platforms
- established mode of car ownership	- increasing options for publicly accessible fleets (different scheme of car-sharing and bike-sharing)	– 24.000 car-sharing cars but 46 million private/ business cars - increasing share in company cars handed over to private persons

In 2017, 87% of Germans older than 17 years held a driving license (Nobis and Kuhnimhof, 2018). Investing in a driving license is still taken for granted for most Germans as soon as they reach the eligible age. However, recently the relevance of cars seems to have declined slightly amongst younger people in urban areas (Nobis and Kuhnimhof, 2018; Puhe and Schippl, 2014). This development is often interpreted as a decreasing commitment to car transport. However, amongst elderly people the degree of car ownership is growing, alongside the share of driving license holders (Nobis and Kuhnimhof, 2018).

In the current regime, most users are willing to invest considerable amounts of time and money in their privately-owned car. Between 2011 and 2021 the total number of registered cars grew by 14% in Germany (KBA, 2021).

According to Nobis and Kuhnimhof (2018) there were about 43 million cars in private households in 2017. Beyond urban areas, more than 90% of households had at least one car. The rate of car ownership is still much lower in urban areas. In large metropolitan areas, 40% of households do not have a car. It is usually considered normal that cars block a high share of a household's budget and that users are confronted with high opportunity costs, as operating a car requires a high investment in the form of time for learning and dealing with maintenance tasks. The situation is somewhat moderated in the case of privately-used company cars, where large parts of the cost of operation and maintenance are covered by the employer and not by the user. On the other hand, cars increasingly compete with items such as phones and tablets in household budgets. Owning a smart phone is increasingly 'mandatory', especially for younger people. In 2009, 29% of 14–29 year-olds indicated that they could not imagine life without a cell phone. Only 64% of this group could not imagine life without a car (Bitkom, 2009).

Alternative use forms such as car-sharing, taxi-sharing or also bike-sharing have experienced impressive growth rates, but in term of modal shift they still operate at very low levels. The number of car-sharing cars in Germany comes close to 24.000 (BCS, 2020), but this

is still of minor relevance compared to the 43 million private cars.

Digitalization seems to increasingly influence mobility behavior. Mobility-related apps and online platforms offer new kinds of access to mobility services. In particular public transport, car-sharing and also bike-sharing schemes offer significantly more user-friendly access to information, purchase of tickets and billing (Canzler and Knie, 2016). Apps such as the DB Navigator are widely used to get access to the German railway system. Services such as ShareNow or MOIA are only accessible via Apps. In a Eurobarometer (2020, p57) it was asked, "For the future of your personal mobility, which of the following would you find most useful?". In Germany, 49%answered "a single-ticket tool for all your urban journeys" (33% in EU average). This indicates that a stronger digital integration of alternatives to the private car would be greatly appreciated.

4.2. Institutional dimension 2: Common patterns of car use and modal choice

This dimension refers to how cars (compared to other modes of transport) are normally used and interwoven with the activities of daily life; it refers to the established and deeply-sedimented routines of car use in the context of daily activity patterns, which motivate modal choices, and in this sense also influence the perceived performance of car alternatives (see Table 2). In particular in urban mobility, decisions are usually made as a choice amongst different alternatives.

To a certain extent, virtual mobility is replacing or supplementing physical mobility. There is an increasing social pressure to be present in social networks, to invest time and to provide personal information for virtual contacts. However, for many Germans, cars are still perceived as normal or even as unavoidable for the organization of daily life. Mobility volumes in general increased from 1099 billion person kilometres in 2006 to 1205 billion person kilometres in 2016. About 80 % of all km travelled are done by car (BMVI, 2017). Regarding transport volumes, there is a slight increase in using cars as a driver, and a remarkable increase in cycling, compared to 2008. Public transport is growing in terms of the number of trips, partly due to increasing numbers of commuters. But at the same time, public transport is perceived as the least popular means of transport in the MID-survey from 2017 (Nobis and Kuhnimhof, 2018). Around 80% of Germans agreed with the statement, "I like car driving". The highest level of agreement is found in the middle-age groups, but 73% of 20–29 year-olds also agreed. In the case of public transport, approval drops to 40%, and in the 40–49 age group to 28%. A survey conducted by Opinion Train (2020) shows similar results.

Since Diesel-gate[1] the share in newly sold diesel cars decreased and awareness of air pollution increased. In Eurobarometer (2020, 105), 56% of Germans would be willing to pay more for daily personal transport, if this was significantly better for the environment (48% in EU average). Notwithstanding recent public and political debates about climate change, emissions of pollutants and scarcity of space in growing urban areas, a current trend is the increasing interest in SUVs and off-roaders. Together with VANs they reach market shares of more than 25% amongst newly sold cars in Germany, with growing tendency (KBA, 2021). This reflects the general interest in all-purpose vehicles that can be used for any kind of trip. Furthermore, it illustrates that fuel consumption and environmental concerns are not always amongst the decisive factors when it comes to the selection of a new car. Emotional aspects still seem to play a significant role, and it can be assumed that cars still function as a status symbol for many people. Land Rover's recent German commercial spot promises "dumbfounded neighbours" when driving a car of the brand. Gössling (2018) highlights the symbolic connotations of cars with personal independency and freedom.

New cars are usually equipped with advanced driver assistance systems. So far, cars are operated in isolation. However, better connection between cars, as well as between cars and infrastructures, will bring various benefits, in particular in the field of security (e.g., cars could pass warning signals to other cars in case of accidents or slippery roads), and that users will be willing to invest in respective technologies when purchasing a new car.

For several years, different sources have indicated that the proportion of younger people in urban areas who have more pragmatic attitudes to car use is growing (Puhe and Schippl, 2014; Nobis and Kuhnimhof, 2018; Römer, 2017). This means that cars may still be used to get quickly from A to B, but this group seems to be less sensitive to the emotional aspect of car use (Calmbach et al., 2016). Among seniors, car use is growing quite significantly, especially in the older age groups (Nobis and Kuhnimhof, 2018). The causes include rising life expectancy and higher rates of driving license ownership, but presumably also belonging to a generation strongly accustomed to the private car ("Generation Auto", Nobis and Kuhnimhof, 2018).

As mentioned above, a broad range of new mobility options has emerged in the last decade, mainly in urban areas. Pilot projects with ride-sharing and ride-hailing show promising results. In large cities, more than one-in-ten households already owns a car-sharing membership (Nobis and Kuhnimhof, 2018). Nevertheless, up to now car-sharing cars are most commonly an occasional option with low mileage; it is still considered normal to drive alone in the private car. The average car occupancy rate of cars has hardly changed over the past decades. In 2017, as in 2002 and 2008, it was around 1.5 persons per car (Nobis and Kuhnimhof, 2018). Wells and Xenias (2015) recently emphasized the increasing importance of "cocooning" in the private atmosphere of a car for resistance to changes in personal private automobility.

Table 2
Institutional dimension 2: Common patterns of car use and modal choice.

Institutional dimension 2: Common patterns of car use and modal choice		
Characteristics of specific institutions	Indicators for institutional change - towards less car orientation	Indicators for institutional change - Towards stabilisation or intensification of car orientation
- car as a means to organise daily life	- virtualisation of many activities such as working, shopping	- 80% of km travelled by car; 2/3 of commuting trips done by car - cars still have to serve a broad range of different purposes
- perceived attractiveness of alternatives to car use	- higher willingness to use public transport and intermodal services amongst younger adults - car-sharing gains in importance - Ride-sharing and hailing services become established	- Public transport is still the least popular mode - older people more active and car-oriented - driving alone in a car with 4 or 5 seats is still considered as normal; established occupancy rate is 1,5p/car;
- symbolic connotations of car ownership and use	- more pragmatic attitudes of younger adults towards car use	- growing share in SUVs and nicely designed cars (Mini, Opel Adam etc.) - Land Rover's recent German commercial spot promises "dumbfounded neighbours" - car as symbol of independence
- relevance of environmental aspects for choice of car (and transport mode)	- environmental performance gains in relevance in context of Diesel-gate and climate change	- average power of car fleet increased from 96 Kw in 2010 to 111 Kw in 2017.

[1] The term Diesel-gate is used in Germany in relation to so-called defeat devices installed by some German carmakers in their diesel engines in order to comply with exhaust emission standards.

4.3. Institutional dimension 3: Societal meaning of car mobility

This dimension refers to the prevailing social meaning and societal perspective on car-based mobility and car infrastructure (see Table 3). This includes citizens' views of transport infrastructures in relation to other functions and qualities of the urban landscape, as well as to broader paradigms and targets of urban planning, which are supposed to reflect societal preferences or expectations on how to develop the built environment. It goes beyond users' modal choice and established mobility patterns, and relates more to the users' role as citizens, voters and contributors to public opinion-building. For example, building infrastructures for public transport or achieving a city of short distances are long-term objectives, which need political commitment and public support. Key issues in this dimension can be substantiated by the following questions: Are cars perceived as a means to guarantee freedom, or rather as burden that reduces the quality of life in urban contexts? To what extent are investments in car-related infrastructures welcomed, is car friendly planning publically expected or not, what is the understanding of quality of life in urban areas, etc.?

As in most other countries, the mobility sector in Germany is characterized by settlement structures and dense support infrastructures that are strongly aligned to the requirements of widespread car use (Gössling, 2018; Schwedes and Hoor, 2019). A whole infrastructure was built around the car, and society widely accepts and even expects that considerable public resources are invested into roads, parking facilities etc. (Holz-Rau and Scheiner, 2020). Public subsidies for commuters have been critically discussed for decades, but prevail and contribute to the acceptance of longer commuting distances.

According to a survey by Kfw Research (2017), there is obviously an awareness among the population that, in addition to the energy transition, a transport transition is also necessary: around 81% of those surveyed see an immediate need for action. There is an increasing societal awareness of the negative consequences of car traffic on human health and the environment (Horn et al., 2018). The "paradigm of sustainable transport" (Banister, 2008) formally dominates transport policies in many urban areas, usually (at least rhetorically) backed by large numbers of inhabitants. A modal shift away from cars usually is a central target of urban transport plans. In the Position Paper of the German Association of the Cities, more livable cities of the future are pictured with fewer cars and much space for pedestrians and cyclists (Horn et al., 2018).

A certain sensitivity towards climate change, cleaner air and livable cities can be observed in public debates. In (Eurobarometer, 2020), it was asked, "Thinking about daily mobility, what do you see as the biggest challenge for transport?". 43% of Germans answered "availability and connectivity"; 40% said "damage to the environment" (EU-average: 29%), with the same value for "congestion" (39% in EU average). Recently, a broad debate about bans for diesel cars and general access regulations for urban areas have emerged, mainly triggered by the Diesel-gate affair and by NOx emissions significantly over thresholds in several German cities. The intensity of the debate is new. But up to now, German cities usually did not dare to implement car bans for larger areas. Nevertheless, the city of Halle has recently decided to establish a car-free inner city. The decision remains controversial, however. What is widely accepted and also appreciated by consumers are pedestrian zones in inner cities. However, usually these are surrounded by parking decks. Affordable accessibility by car, also in inner city areas, is still highly valued by many actors, and many city councils do not dare to increase parking fees. In general, ideas of car-free cities have their proponents but also clear opponents (Schippl and Arnold, 2020). In a recently-conducted survey (Schwietering, 2020), it was found that 35.3 % of respondents tended to agree that German city centres should become car-free. 56 % were rather against. Interestingly, the survey does not show a clear urban–rural divide.

Up to now, concerns about the implications of "big data" for the transportation sector are occasionally voiced, but the general public discussion about the challenges of these developments is only loosely linked to mobility behavior. However, a study (ADAC and Zukunftsinstitut, 2020) on the future of mobility in Germany assumes that data protection will be of immense importance in 2040. In a representative survey (DsIN, 2020), only 10% agree with the statement, "I prefer to pay for a digital service with my data than with money". As expected, younger people are less careful with their data than older people (e-commerce magazine). However, the Shell youth study (Shell Jugendstudie, 2019) finds a certain data-sensitivity also among younger people. 60 % don't like the fact that as Internet users they are part of a business model and that corporations like Facebook or Google make a lot of money from their personal data. Just as many (61%) fear that they have no control over the data they leave behind on the web.

Table 3
Institutional dimension 3: Common societal meaning of car mobility.

Institutional dimension 3: Common societal meaning of car mobility		
Characteristics of specific institutions	Indicators for institutional change - towards less car orientation	Indicators for institutional change - Towards stabilisation or intensification of car orientation
- acceptance of investments in car infrastructure	- modal shift is usually a central element of urban transport plans - ideas about livable cities with fewer cars gain in importance	- planning paradigms still support cars - financial support for commuting by car prevails - the idea of car-free cities remains highly contested
- perception of access regulations	- access regulations are increasingly discussed - ideas about car-free cities gain higher visibility	- access restrictions are opposed by majority of citizens - some city councils do not dare to increase parking fees
- perceived acceptability of environmental policies	- there seems to be an increase in awareness of air pollution and climate change	- SUVs become established - car mobility still perceived as too important to be banned - e-cars perceived as solution for environmental problems
- relevance of big data issues and security concerns	- so far big data and transport not really linked, but first data-intensive services emerge (platforms)	- cars are increasingly linked to internet

4.4. Overview of the current regime structures of German automobility

Figure 1 maps the dominant institutional dimensions of car use according to their degree of institutionalization. The figure draws on a method elaborated by Fuenfschilling and Truffer (2014), and by Truffer et al. (2017), for mapping socio-technical regimes as the highly institutionalized core of an organizational field. Circle segments represent basic dimensions of a regime. Distance from the center corresponds to the degree of institutionalization of individual elements. The regime can therefore be identified as the innermost circle of the plot. More peripheral elements represent less institutionalized rules that can be more easily changed.

On this basis, we can now depict major changes that we may expect over the coming years due to shifts in the perceptions, values and priorities of transport users. This will in particular enable to identification of different development trajectories in the field of automated vehicles.

5. Development trajectories of automated vehicles shaped by shifts in core institutions

In the following short scenarios, we illustrate how the two opposing dynamics of cognitive-normative institutions can lead to very different

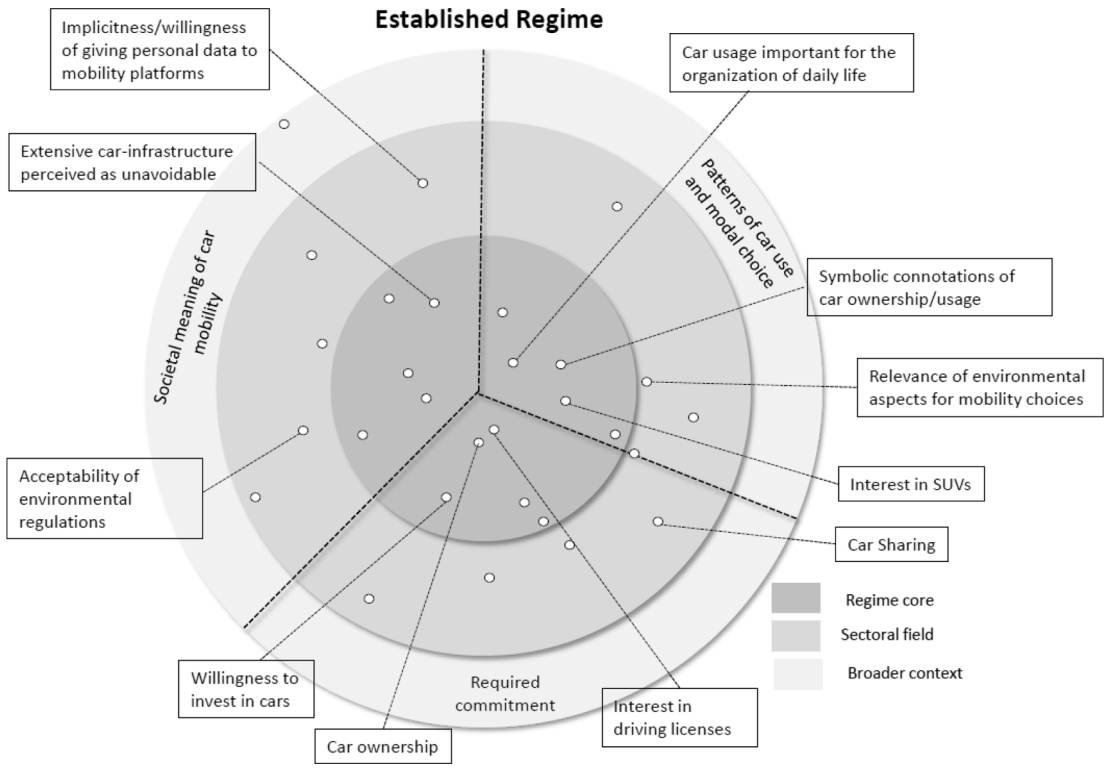

Fig. 1. The mobility regime with the prevailing institutional settings.

development pathways of AVs. The scenarios capture the impacts of these dynamics, the emerging path dependencies, the different roles that AVs are likely to play in the mobility sector, and the different requirements for technical design, marketing and governance of AVs. We want to show that self-reinforcing mechanisms can possibly lead to path dependencies and lock-ins that strengthen either disruptive or reinforcing tendencies. Selected institutions are mapped in a radar plot to depict the degree of institutionalization of the predominating 'configuration that works' (see Figs. 1-3). With respect to the time horizon, we assume that the sketched developments unfold over the next 10–20

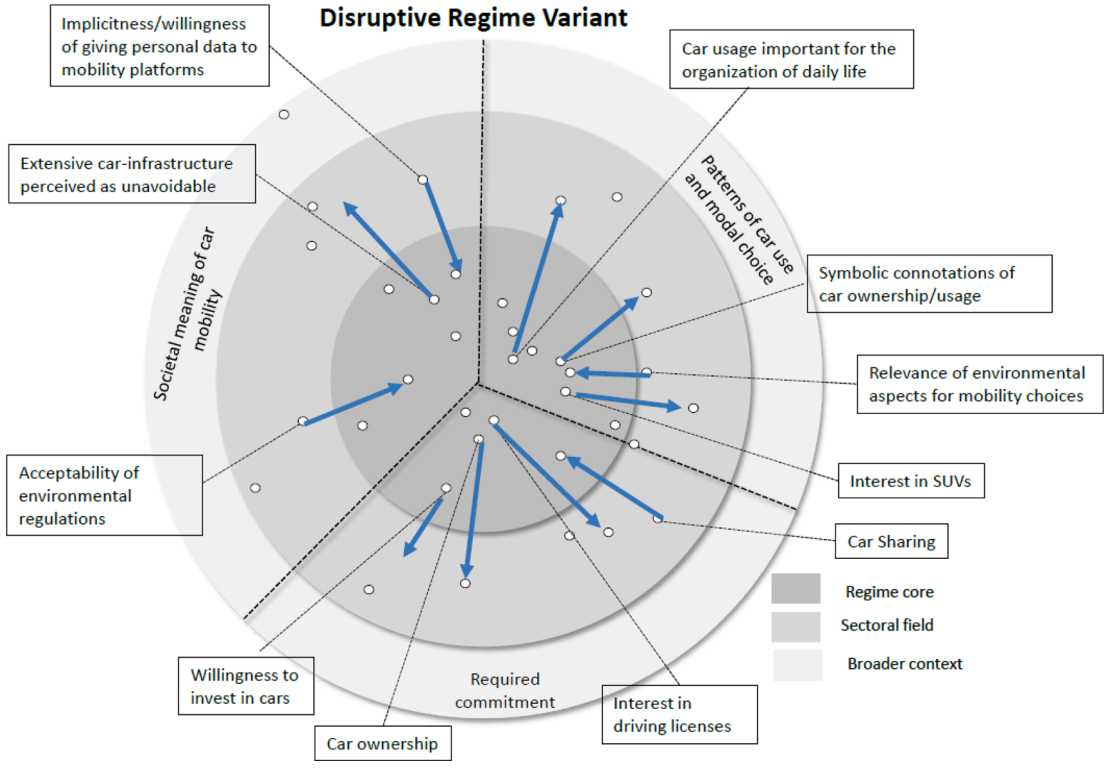

Fig. 2. Institutional settings in the disruptive trajectory.

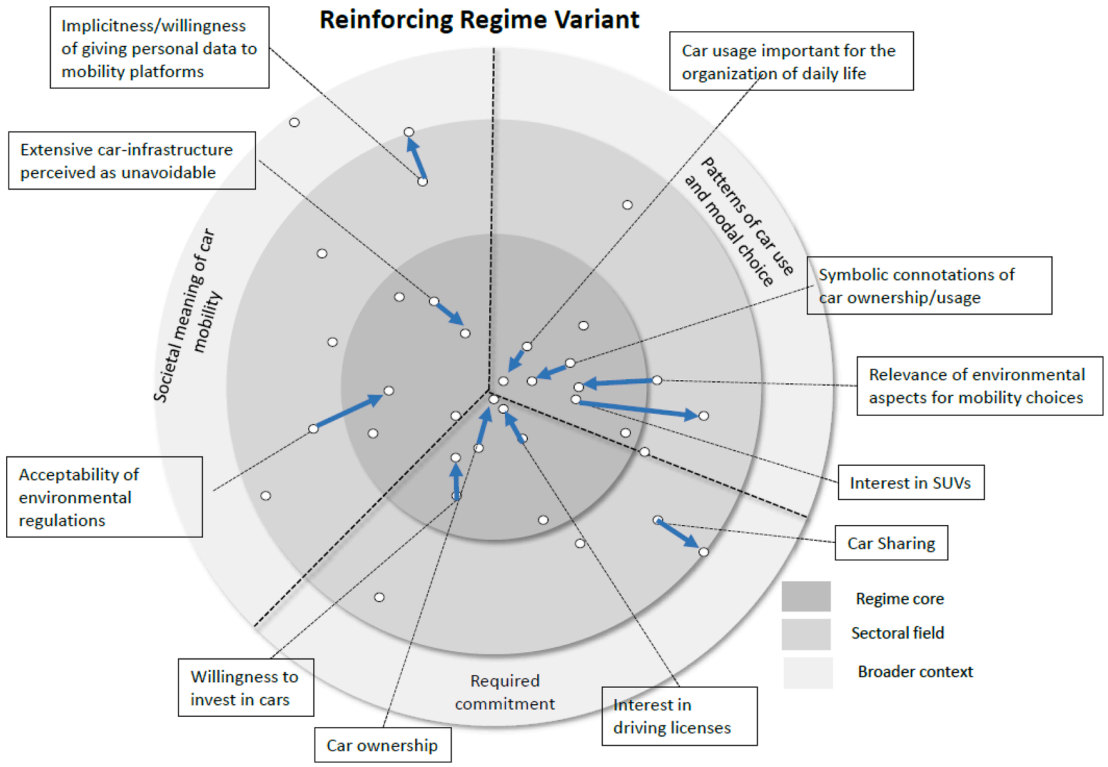

Fig. 3. Institutional settings in the reinforcing trajectory.

years. Scenarios outlined in Truffer et al. (2017) served as a starting point for the two storylines. We further extended these scenarios for the specific focus of this paper.

While elaborating the scenarios, we further assumed that the different institutional dynamics are triggered by broader societal trends. Here, we are also inspired by Truffer et al. (2017), who discuss the potential impacts of several megatrends on institutional configurations at the core of the mobility regime. Here, we elaborate on only two trends, which are widely discussed in the mobility sector. One trend is closely connected with disruptive dynamics, and the other with stabilizing or reinforcing dynamics. The first trend is related to what is termed the "sharing economy", which is assumed to strengthen the developments of shared and/or publicly accessible services in the mobility sector (Canzler and Knie, 2016). Here, society is moving closer to the "Age of Access" outlined by Rifkin (2001). A positive framing of the public sphere is constitutive for such a trend. It is closely linked to the megatrend connectivity, including ideas of openness, transparency, trust in each other and a general tendency of working together towards community-based solutions (Rifkin, 2015). The other trend is based on the concept of "cocooning" (faithpopcorn, 2015) and could contribute to stabilizing or even strengthening an institutional configuration that supports mobility patterns based on private car use (Wells and Xenias, 2015). Cocooning has gained relevance in the wake of the Covid-19 pandemic. Referring to dynamics in cognitive-normative institutions, (Wells and Xenias, 2015) argue that "cars as cultural objects have shifted from embodying the ideological philosophy of personal freedom to that of cocooning". The authors illustrate that such a cultural shift might lead to a "continuing commitment to mass car ownership and use" (Wells and Xenias, 2015).

5.1. Scenario I: Disruption

In this scenario, we assume that the disruptive institutional dynamics in the regime start to dominate (see Fig. 2). A central trigger is that daily life is increasingly permeated by sharing economy approaches; platforms are used for a wide range of different services. Digitization is increasingly seen as a solution to various problems, and less as a risk. Citizens are willing to provide personal data as long as they get a reliable and convenient service. A high level of social acceptance and trust in artificial intelligence and automation is inherently linked with these developments.

Developments in the mobility sector align with these broader societal dynamics. Mobility is increasingly understood as an On-Demand service, which is accessed via smart phones. More and more people tend to consider cars as just one amongst several alternative transport options in a seamless mobility network. With the commercialization of AVs, public transport and related services enter a virtuous cycle. Co-evolving with the changing institutional settings of the regime, automated cars contribute to a mobility system in which car ownership is continuously losing importance for the organization of daily life. Concomitantly, the attractiveness of public transport and related services is steadily increasing. A seamless web of mobility options is emerging, including traditional public transport as well as flexible shuttle services, robo-taxis and different car-sharing schemes. Also in smaller cities, these services are increasingly available and provide a robust and flexible alternative to private car ownership.

Triggered by impacts of climate change, environmental aspects gain importance for modal choice on the individual level, as well as for transport planning in general. Societal acceptance of investments in public transport is growing, and so is acceptance for the restriction of private cars, such as reduction in parking space or bans in some areas. There is a strong interest in making use of space that was occupied by private cars. Creating green and lively cities is high on the political agendas.

The number of privately-owned cars is declining sharply. Steering a car is considered a waste of time, and cars are not associated with social status. More and more people are no longer even applying for a driving license, which further contributes to self-reinforcing dynamics and path dependencies. Citizens get used to working and/or networking while travelling. In the automated services, there is no "direct" navigation by

the users, travel chains are booked via platforms and not the user, but the platform tells the vehicle which route to choose. There is a high demand and a huge acceptance of AVs because they are perceived as being extremely useful, convenient and safe. Research, demonstrations and field trials to further improve automated services are highly welcomed.

5.2. Scenario II: Reinforcement

In this scenario, cocooning is the overriding paradigm. Automated vehicles unfold in an institutional configuration where car ownership is still highly appreciated as the predominant use form of cars (see Fig. 3). External trends such as spreading diseases like Covid-19 as well as the fear of terrorist attacks nourish a tendency to cocoon in nicely arranged private spaces. The accompanying retreat from society extends to the mobility sector. Citizens avoid public spheres and public transport. The relevance of private cars for the organization of daily life is increasing heavily. Seeing themselves as independent and self-determinant individuals in a threatening world, people are interested in full control of where and how they move. For many citizens, cars are still a kind of status symbol and an important means of self-expression.

The central role of private cars in the transport regime is even further strengthened by the diffusion of different generations of AVs. AV technologies increasingly relieve the driver in stressful or annoying situations. In traffic jams, the vehicles drive themselves, and the car can usually find a parking space without the driver, at least at low speeds. Fully driverless cars are, nonetheless, not accepted in many driving environments, mainly because of safety and security concerns. Experiences with data misuse lead to a strong sensitivity to privacy issues; there is a sentiment against “big data” and a growing mistrust in mobility platforms. Another barrier for the acceptance of driverless cars is security concerns, because “hacking” and virtual hijacking of cars is seen as a real threat. The benefits of driverless cars are not perceived as too strong, they cannot outweigh security concerns. Level 4 turns into a good compromise between comfort, safety and security.

For public transport, a vicious cycle sets in. Alternatives to cars are becoming relatively less attractive. Public transport is increasingly reduced to services that are heavily-used and economically viable, such as underground systems and central tramway lines. The declining number of public transport users is accompanied by a declining acceptance of public investment in public transportation. Instead, more and more public funds are channelled into car-related infrastructures such as roads and parking facilities.

Climate concerns related to increasing private car mobility are calmed by electrification and improved efficiency, including reductions in the weight and size of the cars. CO2-lean production of cars and provision of electricity is successfully pushed. The strong dependency on and commitment to car mobility is leading to car-flooded cities and further urban sprawl. This induces a further erosion of public transport, which in turn further increases car-dependency in the form of a self-reinforcing cycle.

6. Conclusions

We have presented a systematic approach to explicitly address institutional dynamics in future-oriented technology assessment. In particular, we emphasized the key role of shifts in normative-cognitive institutions and argued for a focus on the emergence phase of new sociotechnical pathways. Automated driving proved to be a fitting case, emphasizing complex socio-technical dynamics, a high pace of change, risk, and chances of lock-ins and path dependencies, and high uncertainty in the directionality of future developments.

We conclude that, firstly, the approach is able to indicate different dynamics in the field of cognitive-normative institutions in the existing mobility regime. The regime concept, understood as a configuration of core rules and norms in a technological field, allows analysis of shifts in the direction of developments, as it represents the selection environment for new technological options. These developments can be mapped on a radar plot, which helps to formulate key assumptions of alternative scenarios in a transparent way.

Secondly, the brief scenarios demonstrate that changes in user-related normative-cognitive institutions could substantially impact the emerging trajectories of AV technologies. Some of the mapped indicators point at institutional dynamics that push the regime configuration towards the deep structural changes required for sustainable transitions. Others point in the opposite direction and could strengthen the prevailing regime configuration, with private cars as a dominating element of mobility systems. In other words: these dynamics may set the direction of technological development, which might be hard to reverse (lock-in). The two scenarios are not predictions; other future institutional configurations and pathways may be equally plausible. Nevertheless, we can demonstrate that variations in institutional dynamics can lead to the emergence of very different pathways, and that these pathways differ remarkably regarding their impacts on sustainability.

We can learn from the findings that developments in normative-cognitive institutions have to be taken into account more systematically in future-oriented analyses and in transport policymaking. Future directions of the mobility sector depend not only on visible technologies and regulations, but also on less tangible institutional changes. Further, it is certainly important to work with scenarios and models that refer to already implemented AV services in order to be able to assess the possible effects of these technologies and concepts. However, it is also useful to understand the conditions under which certain developments are initiated and become self-reinforcing. It is important to be able to anticipate institutional dynamics and their impacts in order to inform policy and avoid directionality failures (Weber and Rohracher, 2012).

The analysed data show, for Germany, that the prevailing regime configurations only allow for such changes to a certain extent. The indicators we used to map institutional dynamics show that there is no clear direction; both stability and change are plausible. Looking at the analysed data, we see a window of opportunity for a sustainable pathway; it is surely imaginable that AVs will strengthen non-car based mobility options such as public transport and related services. Some of the reasons can be found in the data analysed in section 4 and in scenario 1. Examples are the increasing familiarisation, particular of younger people, to access various services via apps, or the access regulation for cars which is discussed in many German cities. However, the results also demonstrate that the pathway to sustainability will not necessarily be “automatically” achieved, even with the commercialization of highly developed AVs in the level 4 or even level 5 range. On the contrary, stabilizing dynamics are also inherent in the regime. Without political action, non-sustainable pathways could emerge, which would reinforce the negative effects of the current mobility system. The more such a pathway becomes institutionalized, the more difficult it will be to change it later on.

Therefore, we argue that there are good reasons to start early-on with planning for the first regime scenario. Policies that push towards a sort of sustainable lock-in, supporting a reliable and “high-quality” set of multimodal options, can help to prevent the second pathway by increasing the attractiveness of alternatives to private car use today. If AV-technology then becomes commercialized on a broader scale, the likeliness that this will strengthen and accelerate the first pathway will surely increase. The recently passed amendment to the German road traffic law clearly supports the application of automated driving in public transport. However, additional measures to reduce the attractiveness of private cars will surely also be needed in order to steer the deployment of AVs towards more sustainable pathways.

The presented framework helps to identify important interrelations that could stabilize or destabilize institutions in the regime core, or bring peripherally-located institutions closer to the regime core. It can increase awareness among decision-makers about crucial dynamics (e.g. privacy, cocooning) and it helps to identify entry points for policy

options to influence the directionality of developments. In the approach outlined here, we had a clear focus on institutional dynamics in the existing mobility system. We focused on selected institutions and captured their dynamics through indicators. The list of selected institutions is by no means exhaustive. Future work should incorporate attitudes and perceptions of users and citizens towards the autonomous services themselves (Goldbach et al., 2022; Nastjuk et al., 2020) and the resulting social adoption and diffusion dynamics (i.e. should look at 'social acceptance' rather than consumer acceptance as well as at attitudinal changes and revised strategies among professional actors). On the basis of such studies, it should also be discussed how concepts such as trust in automation or trust in institutions can be integrated into the approach outlined here.

Variations in institutional dynamics could also be considered in modelling approaches, to get a detailed picture of the impacts of a certain institutional change on the mobility system in a specific city or a region. From a geographical perspective, different dynamics could become dominant in different geographical settings (Schippl and Truffer, 2020). Multimodal regimes may be more easily introduced in larger agglomerations, whereas rural areas are shaped by developments somewhat similar to the second regime variant. Finally, the proposed methodological approach should be applied to other countries or regions, taking into account their specific socio-technical settings. It would be interesting to see if similar or different institutional dynamics can be observed and to discuss what this could mean for the development trajectories of AVs.

CRediT authorship contribution statement

Jens Schippl: Conceptualization, Methodology, Writing – original draft, Visualization. **Bernhard Truffer:** Conceptualization, Methodology, Writing – review & editing, Visualization. **Torsten Fleischer:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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