Directionality of transitions in space: Diverging trajectories of electric mobility and autonomous driving in urban and rural settlement structures

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Abstract: How does the spatial context shape early innovation trajectories and how will this influence the directionality of transitions? We elaborate these questions for the case of transitions in personal mobility, focusing on emerging trajectories of electric vehicles and autonomous driving. We analyze how the dynamics depend on whether innovation and transition strategies are primarily geared towards urban or rural contexts. In order to identify potentially diverging trajectories, we specify socio-technical regime structures at two levels: the level of service regimes (i.e. rules that relate to specific means of transport, like the car) and the level of the sectoral regime (i.e. rules that regulate the interplay between the different service regimes). We will show that depending on whether the early innovation strategies are oriented at rural or urban contexts, quite different directionalities can result both regarding the technological trajectory of the new service option, but also regarding the overall sector configuration.

Key words: geography of transitions, sustainable mobility, service regimes, sectoral regimes, electric mobility, automated driving

1. Introduction

The mobility sector is key for solving the global sustainability problem (Holden et al., 2019; Sims et al., 2014). To accommodate for these grand challenges, far-reaching transformations are needed and they will most likely be influenced by the rapid progress in electrification and digitalisation of individual vehicles and overall traffic management. Many experts believe that after long years of rather incremental change, these new technologies boost fundamental transformations leading ultimately to more sustainable mobility sector (Canzler and Knie, 2016; Docherty et al., 2018; Schippl and Arnold, 2020; Transport & Environment, 2019). However, the mobility sector will not only be shaped by the more or less rapid diffusion of individual technological solutions. Rather, we have to analyse how societal and technical dynamics co-evolve in order to assess how new technologies and services will shape future mobility options and their performance in terms of sustainability (Noy and Givoni, 2018; Sheller, 2012; Truffer et al., 2017). In other words, we have to disentangle the different forces, which will ultimately shape the directionality of these emerging transformation processes. In view of these major expected transformations, it is increasingly important to anticipate the outcome of current sociotechnical dynamics. Policy makers seeking to support sustainable development as well as industrial strategists seeking positions in these emerging mobility sectors should base their decisions on a solid understanding of potential future directions of such developments.

Over the last decades, a rich body of literature emerged in fields such as technology assessment, foresight, and transitions research, which provides tools and concepts for tackling this task (Decker et al., 2004; Geels et al., 2012; Grunwald, 2018, 2009; Markard et al., 2012). In the transitions literature, the question of directionality has been treated rather implicitly by many authors assuming that through the scaling and maturing of “clean technologies” more sustainable socio-technical systems would almost automatically be realized (Weber and Rohracher, 2012). The question of how to anticipate the overall impact of new technologies on sustainability requires an explicit evaluation of alternatives, which is typically outside of the scope of most transition studies. The technology assessment literature, on the other hand, has built up a broad set of foresight and assessment approaches (Grunwald, 2018) but is less explicit about how alternative development trajectories may emerge in the first place (Truffer et al., 2017). In the present contribution, we therefore explore how a better understanding of directionality in socio-technical dynamics may provide a solid basis for technological assessment that aims at advising sustainability oriented policies.

Given that mobility sectors essentially provide means to overcome spatial distances, density and form of settlement structures may have a strong influence on which technologies and services are better or less well suited for this task. In other words, we will in the following analyse in how far spatial structures influence the shape and direction of technological development and of transition processes (Binz et al., 2020; Coenen et al., 2012; Hansen and Coenen, 2015). We know from the history of technology, that specific context conditions may shape path dependencies and create lock-in of technological trajectories, like in the classical example of diverging directionalities in typewriter keyboard layouts (David, 1985). In order to tackle these questions, we have to elaborate how selection environments differ between different contexts and how they support particular trajectories rather than other ones. Issues of directionality have only rather recently gained prominence in transitions studies (Weber and Rohracher, 2012). As a consequence, a variety of specific studies started to address mechanisms for shaping directionality. Yap and Truffer (2019), for instance, analysed how emerging economies can shape technological trajectories by “internalizing windows of opportunity”. Or, van Welie et al.(2019) enquired how a wide variety of transition trajectories have to be considered in a context of informal settlements of the global south. Yang et al. (n.d.) (submitted) analysed how strategies of niche and regime actors in different Chinese regions resulted in competing dominant designs in solar PV technology. All these studies focused on the role of geographical variation in transition processes at the level of different jurisdictions (i.e. cities, regions, or countries) (Coenen et al., 2012; Hansen and Coenen, 2015). But, to our knowledge, no studies have elaborated on the differences of physical settlement structures so far.

We will build on this earlier research and elaborate how spatially variegated settlement structures influence the specific shape of the mobility regimes and through this influence the directionality of specific technological trajectories and thus ultimately lead to diverging (in the sense of more or less sustainable) transition pathways. More specifically, we ask which kinds of innovation and transition dynamics may be expected depending on whether policy and industry strategies had primarily addressed urban or rural context conditions. Empirically, we will elaborate on these questions for the case of mobility transitions as currently discussed in Germany and how they relate to alternative development trajectories of battery electric vehicles (BEV) and automated vehicles (AV) when embedded in rural or urban contexts. Both technologies are considered to contribute to a fundamental restructuring of the automotive sector with potentially beneficial impacts on the sustainability of the mobility sector. Electric vehicles are already commercialised – however future directions of development have not fully panned out, yet. Autonomous vehicles, which enable the driver to pass partial or full control to the vehicle, are not commercialised yet. However, in many countries, pilot projects are running and there is widespread agreement that these vehicles will substantially impact the way we organize mobility services in the future (Fraedrich et al., 2017; May et al., 2020). Robo-taxis and similar forms of collective mobility, for instance, are expected to replace conventional private cars, or at least to push it into a subordinate niche (May et al., 2020; UITP, 2017). BEVs are often presented as a clean element of future 'smart cities' dominated by collective mobility offerings (Finger and Audouin, 2019; Vienna City Administration, 2014). Other authors highlight that BEVs are also well suited for rural areas (Plötz et al. 2013; Kester et al. 2020). Whether and to what extent the different technological trajectories will emerge and stabilize in these different settlement contexts is however rarely elaborated. Strategies to achieve sustainable mobility cannot only focus on urban areas. In Germany, for example, only about one-third of the population lives in cities with more than 100'000 inhabitants (Nobis and Kuhnimhof, 2018). We will show that, in contrast to the mostly urban inspired visions of collective mobility, rural settlements may be pushed onto less sustainable trajectories by these urban inspired visions. AVs, for instance, may lead to increased car-dependency and further weaken of public transport services. Once such self-reinforcing processes gain momentum, it might be difficult to reverse them. It is therefore essential to consider the context-specific dynamics of early innovations, in order to avoid non-desirable path-dependencies to emerge.

In order to analyse the role of spatial contexts on the directionality of innovation trajectories and transitions, we need to elaborate how different places provide distinct selection environments to support or hinder alternative directionalities (Yap and Truffer, 2019). In transition studies, the selection environment is strongly conditioned by the prevailing rules and norms that apply to specific services in a sector, i.e. the prevailing socio-technical regime. The regime concept has been widely applied for analysing mobility transitions (Geels et al., 2012; Whitmarsh, 2012). In particular, in the fields of electric mobility and automated driving, studies have provided valuable insights on sociotechnical dynamics and potential development pathways (Augenstein, 2015; Dijk et al., 2013; Skjølsvold and Ryghaug, 2020; Truffer et al., 2017). However, these applications of the regime concept usually treat space as a rather homogenous dimension and are therefore not well equipped to address spatially divergent development trajectories. Spatial divergence represents, however, a rather mundane reality in the mobility sector. Typically, design, organization and performance of different transport modes vary considerably between urban and rural areas. For instance, public transport is usually much more widely available in large cities than in small villages. In many OECD countries, in the last years, these differences even grew stronger with the introduction of a broad range of new mobility options, primarily in urban contexts. Striking examples are sharing and renting schemes for cars, bikes and scooters (Shaheen and Cohen, 2018). Moreover, the integration between modes substantially improved in particular in larger cities through online mobility platforms, integrating ticketing concepts and the like (Hirschhorn et al., 2019). Rural areas have experienced far less changes and in most cases, the private car remained by far the dominant form of transport.

We take from these empirical observations that we have to conceptualize the spatial variation of mobility regimes as operating at two levels: the level of the single modes or services, and the sectoral regime level that regulates the interrelations between the different modes. This is in line with a recent proposal by van Welie et al. (2018), who defined service regimes as "specific institutionalized combination of technologies, user routines and organizational forms for providing the service" (van Welie et al., 2018, p. 260). "Sectoral regimes refer to broader economic and societal realms (or organizational fields) that cover a societal function like transport, food, safe urban water, electricity, and so forth" (van Welie et al., 2018, p. 261). We draw on this understanding and add that different constellations in urban and rural sector regimes may give rise to different technological development trajectories.

The paper proceeds as follows: In section 2, we elaborate on the directionality of sociotechnical regimes before we introduce the concepts of service and sector regimes, in general. In section 3, we elaborate the service and sector regime structures in urban and rural mobility sectors in Germany. In section 4, we then show how these different selection environments may give rise to divergent directionalities for the development of electric vehicles and self-driving cars, and how this would impact the sustainability of future urban and rural mobility sectors. The concluding section 5 will elaborate on the wider implications of our findings both for the governance of mobility transitions in Germany and in other countries and for the role of space in shaping directionalities.

2. Towards conceptualizing the spatial variety of regime structures

The socio-technical regime represents one of the core concepts in sustainability transition research. Regimes consist of the highly institutionalized set of formal and informal rules, habits, beliefs and norms in a certain organizational field (Fuenfschilling and Truffer, 2014; Geels, 2002). In an established regime, these dimensions are well aligned into a stable "configurations that works" (Rip and Kemp, 1998). Misalignments in such configurations, for example when a technology does not meet prevalent societal expectations, can function as triggers for change. Transitions can be understood as major shifts in regime structures, either through external shocks and jolts, as a result of internal tensions (Fuenfschilling and Truffer, 2014), and/or because of emerging challengers, which start to reshape the alignments of the different rule sets (Geels, 2002; Smith and Raven, 2012).

The sociotechnical regime concept sheds light on interdependencies among actors, technologies and institutions. It explains how stability emerges in highly complex socio-technical configurations and how this stability can be reproduced under widely varying context conditions. Socio-technical regimes may be considered as rather uniform across different contexts. However, local, regional and national context conditions will lead to manifold adaptations of these regime structures, which may lead to regional variations of potential transition pathways (Fuenfschilling and Binz, 2018). So far however, the spatial variation of regimes has not yet been sufficiently conceptualized (Coenen et al., 2012; Hansen and Coenen, 2015; Murphy, 2015; Schippl and von Wirth, 2018). This is especially problematic in cases of critical infrastructures, such as transport, where an overly homogenous understanding of regimes may lead to a too narrow understanding of how sustainability transitions could actually develop (van Welie et al., 2018).

We therefore propose to conceptualize spatial variations of regime structures in order to identify differences in directionality of transitions. We follow Weber and Rohracher (2012) in their claim for more explicit focus on “directionality failures” in the transition literature. This essentially denotes the problem that a new technology that will be promoted for sustainability reasons, may actually result in only substituting a prevailing problematic solution with a new one. In our context, we consider directionality failures as result from specific technological trajectories meeting and being shaped by specific selection environments that are defined by the prevailing regime structures. Directionality challenges may therefore result at two levels: at the level of individual technologies, prevailing regime structures may favor one technology over another and therefore lead to divergent growth prospects (e.g. mono- or polycrystalline solar photovoltaics). At a second level, the impact of specific innovations may reshape the overall sector configuration (Yap and Truffer, 2019, 1031) (e.g. as in whether or not the growth of photovoltaics will contribute to a more centralized or more decentralized electricity sector, see Yang et al. submitted). The latter kind of dynamics have been identified by Smith and Raven(2012) as mostly following a *fit-and-conform* resp. a *stretch-and-transform* pattern. A few recent contributions have delved deeper into the particular processes, by which actors aim at shaping directionality at these different levels. Yap and Truffer (2019), for instance, proposed a framework to analyze how different actors may try to shape development pathways in favor or their preferred alternatives. Van Welie et al. (2019) analyzed how different governance modes in technological innovation systems may impact the directionality of urban sanitation transitions in informal settlements. However so far, regime structures that differ between settlement structures have not yet been tackled in the literature.

In the extant transitions literature, directionalities at different levels of systems have rarely been addressed. The prevailing view for the mobility sector for instance, was that the automobile defined the core of the socio-technical regime. Other mobility options were treated as mere niches or sub-regimes (Geels and Kemp, 2012; Parkhurst et al., 2012). However, such an approach has serious limitations, for comparing directionalities between different spatial settings. The functioning of urban mobility regimes relies fundamentally on the existence of a variety of complementary options. An urban mobility sector based on private cars alone would quickly lead to massive impacts on human health, the environment and increasing congestion. For these reasons, the vision of a fully car-friendly city was abandoned long ago by most countries (Banister, 2002). Therefore, the conceptualization of non-car based mobility options such as public transport or cycling as mere niches is not convincing. Public transport has been around before automobiles in modern history. It is organized by well-established rules and regulations, organizations, dominant technologies, business models, and user behaviors. The same is true for cycling, which reaches modal shares between 20% and 30% in many German cities (Nobis and Kuhnimhof, 2018). The term of subaltern regimes (Geels and Kemp, 2012) takes these realities into account. However, it still supports a ranking order of cars constituting the “actual” (kind of monolithic core of) regime in urban mobility, while the other means are secondary or supportive at best.

Mobility regimes are always composed of different services options such as cars, cycling, walking or public transport. The quality of the single service can differ substantially between urban and rural areas. This is obvious in the case of public transport, which is usually very well developed in urban centers, while rural regions are usually poorly served. However, not only the single modes but also the distribution of (e.g. the modal split) and interrelations between different modes is important for delivering reliable mobility services to citizens. For example, the recent innovation of integrative mobility services rely on the connecting of single modes of transport. Therefore, to achieve a more detailed and open perspective on the directionality of mobility regimes, we argue that both, the performance of the single modes as well as the performance of the sector as a whole has to be taken into account.

This implies that the prevailing rather "flat" understanding of regime structures has to be extended into a multi-layered understanding, where rules, which regulate the operation of individual services are distinguished from those rules that enable a smooth interoperation of the different services. This is exactly what van Welie et al. (2018) recently proposed in order to better grasp path dependencies and potential transition pathways in rather complex situations like informal settlements in cities of the Global South. They proposed to distinguish two levels of regime structures: i) service regimes, which encompass several alternative ways to provide a particular service to people (in the mobility sector, it would be cars, public transport, walking etc.) and the ii) level of the sectoral regime, which regulates the interplay of services in a sector (in the mobility sector it would correspond to overarching traffic regulations, shared infrastructures, or aspirational rankings of services among users). A sectoral regime, in general, consists of more than one service regimes..

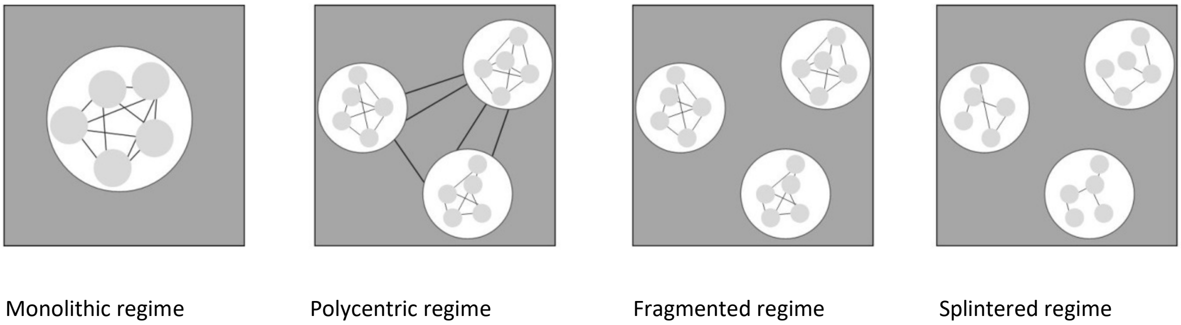

Figure 1: Four types of sectoral regime constellations - sectoral regime (grey square), service regimes (white circles), dimensions of service regimes (grey circles), alignments (lines). Adopted from van Welie et al., 2018

Each service and sector regime is characterized by its specific institutional settings, including norms, regulations, taken for granted assumptions, user routines and preferences, ways of doing things, and/or practices. Depending on the number and the strength of alignments within and among the different service regimes van Welie et al. (2018) identified four ideal type constellations of service and sectoral regimes (figure 1): i) the monolithic sector regime with only one dominant service regime; ii) the polycentric regime, where several service regimes co-exist and are well aligned among each others; iii) the fragmented regime type, where strong service regimes are not well aligned and finally, iv) the splintered regime where alignments are poor both within and across the different service regimes. This generic set of constellations can be used to illustrate specific situations for different empirical cases. That's what we will turn to in the following.

3. Rural and urban service and sector regimes in the German mobility sector

We will build on these conceptual ideas to characterize the different service and sector regime constellations in urban and rural areas in the German mobility sector. This will enable us to assess whether and how new services, such as electric vehicles or autonomous cars, might contribute to a more or less sustainable reconfigurations of the sector in the future.

3.1 Case selection and methodology

In many areas, Germany is a representative case for most OECD countries as it provides well established infrastructures and services both for private car and public transport. A specificity of the German case is that German automobile companies are of great importance to the national economy. There is a strong governmental interest to keep the industry in a globally leading position. The creation of a networked, digitalised and electrified mobility sector is a central tenet of the governments' High-Tech strategy , which should position Germany as a globally leading supplier and market for electromobility (BMBF, 2019). Automobile manufacturers recently started to invest heavily in electric vehicles and automated driving. Furthermore, nearly all car companies experiment with new mobility services (e.g., Daimler and BMW with ShareNow, VW with MOIA). There is an ongoing debate about sustainable mobility in general and on the potential impacts of electric mobility and automated driving in particular in national public discourses (Canzler et al., 2019; Lemmer, 2019; Plötz et al., 2014, 2013; Schippl and Arnold, 2020). In terms of governance structures, Germany is a rather decentralised country and municipalities have considerable influence on local transport policies. Modal Shift away from private car use and towards more environment friendly modes of transport have become central strategies in the urban mobility plans of larger German cities (Horn et al., 2018).

Differences in the socio-technical configuration among urban and rural contexts are obvious in Germany. Figure 2 depicts the spatial layout of mobility sectors in the center of the City of Karlsruhe and of a rural village. The urban mobility sector consists of elements such as roads, bus lanes and stops, trams with tracks and stops, interchanges between different lines, cycle lanes and pedestrian areas. It is a rather heterogeneous mix of infrastructures, which are more or less aligned with each other. In rural areas, the situation is much simpler. Transport infrastructure consists mainly of roads and parking lots, some sidewalks and a bus stop can be seen as well. To accommodate for this varying combination of mobility offers, we apply the regime concept of van Welie et al. (2018). Firstly, we identify different service regimes and describe their manifestations in prototypical urban and rural settlement structures. Secondly, we describe differences in alignment between theses service regime at the sectoral level in urban and rural areas. Recent data on mobility patterns is an important source for doing so (see Nobis and Kuhnimhof, 2018).

Based on this two-layered regime concept, we then elaborate on how BEVs and AVs may affect existing alignments both at the service and the sector level. The trajectories sketched out in section 4 are no predictions, but rather plausible scenarios. What we produce is largely what Grunwald terms "prospective knowledge", which is intended to illustrate the space of possible future developments for enabling consequentialist reflections, such as, for example, indicator-based sustainability assessments (Grunwald, 2018). This is a well-established methodology in foresight and technology assessment (Cagnin et al., 2008; Grunwald, 2018) and also in transition research (Elzen et al., 2004; Truffer et al., 2017). We have a particular focus on self-reinforcing, co-evolutionary processes, which may induce path-dependencies already in early stages of the diffusion of innovations on the service and/or on the sectoral level. We show that new technologies that only affect the service level in one settlement structure, may reinforce co-evolving developments at the sectoral level in other settlement structures.

Mixture of serive regimes in an urban area. Example: City Center of Karlsruhe, Germany

Car as dominating service regime in a rural area. Example: Center of the Village of Göllsdorf close to Rottweil; Germany

Figure 2: Examples of urban and rural transport regimes (source: the authors)

3.2 Specification of the most salient service regimes

To identify and delineate the most important service regimes in the German mobility sector, we take as our starting point four generic transport modes, which are firmly established in mobility related research, planning and policy. These four are cars, public transport, cycling and walking. However, in order to accommodate for the dynamics around alternative forms of car use we add car-sharing/car-rental as well as taxi/ride-sharing as additional service regimes. Their share in the modal split is usually still rather small. Nevertheless, these two services increase the range of mobility options in urban areas and are often mentioned in policy reports on sustainable mobility futures (Canzler and Knie, 2016; Schippl and Arnold, 2020) . In the German metropoles, at least one car-sharing member lives in 14% of households. If one considers only those households that do not have a car of their own, this share rises to 19% (Nobis and Kuhnimhof 2018). Moreover, in many visions on the future of mobility, both alternatives to private car mobility are supposed to play an important role, in particular when it comes to a transition towards more sustainable urban mobility sectors (Canzler and Knie, 2016; Shaheen and Cohen, 2018). We treat these two forms of car use as different service regimes, since in the one case the user coincides with the driver, whereas in the second case, the service is provided by a separate driver and the user passively consumes the service as a passenger.

These generic transport modes may now be interpreted as different service regimes by elaborating on their alignments with a number of socio-technical dimensions:

- "Technologies and infrastructures" denotes the material elements of the respective service regime, the hardware, the physical infrastructure, urban design, etc.;
- "Organizational mode" refers to the way the service is managed and how user interfaces are designed; it includes the preconditions/constraints of providing the service and the interests of providers in viable business models;
- "User requirements" refer to the skills, knowledge or competencies that are required to use a certain service. "User expectations" refer to the interest of the users to have access to functioning, reliable, affordable, safe, clean and convenient mobility;
- "Planning practices and public financing" refers to the formal planning guidelines and regulations as well as to informal, taken-for-granted assumption that guided, for example, the car-euphoric planning period in the 1950'ties and 1960'ties;
- "Societal meaning" relates to general societal connotations with a service regime, for example "sustainability", "health", or "freedom", "climate change", and others.

In the work of van Welie et al.(2018) the identification of core dimensions on the service level was based on social practice theory (Shove et al., 2012) focusing on materials, competences and meaning (covered by our dimensions technologies and infrastructures, user requirements, societal meaning). We added organisational mode and planning practices since these are essential for an organised provision of mobility service, similar to the proposal by Puhe and Schippl (2014), who called it "basic structure" of the mobility sector.

Strength and stability of a service regime depend on the degree of alignment between these core dimensions (Fuenfschilling and Truffer, 2014). Alignment is present when technical artefacts, interests of users and providers as well as planning paradigms and broader societal expectations and goals are pointing in the same direction. For instance, in order to be well aligned, the service regime of the privately owned car needs specific infrastructures (parking lots, roads, traffic lights), users need to acquire driving licenses and be prepared to spend a large share of their household's budget on car mobility. Planners have to ensure that the system is functioning by reserving sufficient public space for the infrastructures. To give another example, a well-aligned service regime of public transport also needs infrastructures such as bus stops or tracks, and it needs viable business models that rely on public funding, in most cases. Therefore, societal commitment to invest public money is needed, as well. Public transport has to meet user expectations about the density of accessible destinations and frequencies. User skills are needed to get access to the services. A good alignment between user requirements, safe infrastructures and corresponding planning practices is of utmost importance for the service regime of cycling to function smoothly. For car-sharing, users need to trust that the organizational mode of the operators provide a sufficient density in vehicles. On the other hand side, the sharing fleet has to be used frequently enough in order to make the business model viable.

Misalignments are, for instance, if there is a lack of dedicated lanes for bicycles, which prevent negative interactions with other traffic participants, or if cycling is just seen as a disturbance to car traffic flows by a majority of society. In the case of older diesel cars, weak alignment with regulations and concerns about health impacts can lead to a weaker position of the service regime of private cars. Or, public transport in rural areas is not well aligned with user interests if sparse time schedules prevent flexible use of these services.

3.3 Alignments and misalignments at the level of the sector regimes

The sectoral regime consists of those structures that are necessary to coordinate the different service regimes in a certain place and at a certain point in time. The strength of the sectoral regime depends on the alignments or misalignments among the different service regimes, which lead to either varying forms of frictions among these services or alternatively to complementarities, which improve overall access and availability of mobility solutions (van Welie et al. 2018).

Alignment and misalignment between the service regimes is a question of how the interfaces between them are designed. We propose three different types of interfaces or interrelations: i) Technical/infrastructural interfaces: In particular in urban areas all transport modes compete for space, as illustrated in the pictures for the City of Karlsruhe (figure 2). But interfaces also refer to infrastructures that are designed to provide a smooth and convenient connection between two service regimes such as bike-and-ride facilities that allow for a high alignment between the service regimes of public transport and cycling. ii) Organizational interfaces: This can relate to integrated ticketing that allow using one ticket for trips with different operators or smart cards that provide access to public transport, car-sharing, public bikes or taxis. Another example would be an operator, which organizes different transport services in an integrative way (e.g. "German Railways" is also offering car- and bike-sharing). iii) Institutional interfaces: This can relate to integrative planning paradigms such as, for example, flexible and seamless mobility as an official goal in transport planning. It refers as well to the more hidden competition for resources in different planning departments, deciding on allocating financial resources and planning capacities to the different service regimes. It finally refers to user expectations or social meaning related to sustainable mobility. To what extent should the mobility sector be effective, efficient, affordable, clean, safe etc.?

These three dimensions describe general aspects of interfaces between service regimes. In reality, most interfaces show elements of all three dimensions, but may be dominated by one of them. For example, the option to board a bike on a train can be framed as a technical interface, but it is also an organizational interface since the train ride or the bike needs to be paid for. It may also be institutional, if administrations push towards its realization since it is considered beneficial for sustainable mobiliy.

Innovations may address all three interfaces and by this transform the regime structures at the sectoral level: An example for technical/infrastructural interfaces are bicycle racks at train stationsor bike trailers on long-distance busses. Good examples for organizational innovations are multimodal platforms or apps that provide information and allow for booking and payment for different service regimes. For instance, the platform Moovel allows for booking and payment of public transport, car-sharing, myTaxi and trains in some German Cities (see https://www.moovel.com/de/en). There is also a close connection to the regime of car ownership since Moovel started as a spin-off of Daimler Financial Services. In the institutional dimension, significant dynamics can be observed: In most European countries, the leading paradigm for urban transport in the 1960s and, to some extent in the 1970s, was to create a city optimised for motorised individual transport with broad roads and parking areas. Public transport was considered old fashioned and quite often tramway lines were removed. In the last decades, the situation has clearly changed, at least at the level of transport development plans or sustainable urban mobility plans (SUMP). Formally, sustainable mobility is now high on the agenda of urban transport planning in many European cities (Schippl et al., 2016). It is usually linked with concepts supporting public transport, cycling and walking, in order to incentivize a modal shift away from the private car. The "sustainable mobility paradigm" (Banister, 2008) has started to materialize in many urban areas, at least to a certain extent.

3.4 Differentiating regime structures in urban and rural contexts

Service and sector regime structures will configure differently depending on local conditions, in particular those that are associated with settlement structures. In particular population density is a major factor with implications on the availability of infrastructures, time schedules and demand structures. Rural and urban areas represent two extremes on a gradient with regard to population density. We therefore want to elaborate how the service and sector configurations pan out under these two ideal type settlement conditions.

	Private Car (PC)	Public Transport (PT)	Taxi and Ride-Sharing (RS)	Sharing-schemes and car rental	Bicycle	Walking
Alignment in urban areas	Partly aligned because of congestion, lack of parking, pollution, waste of space	PT can move large amounts of people; does not always fit with individual needs;	Taxis is always available; alignments with user needs limited by costs	Aligned if service is well developed and if access is easy – but this is not always the case	Alignment depends on infrastructures, weather and physical condition of users	Often aligned; allows for easy access cities; side-walks sometimes to narrow; waiting times at crossings;
Alignment in rural areas	Aligned and highly institutionalized; environmental impacts remains problematic	Poor alignment since service does not meet user needs (frequency) and/or is costly for the operator	Partly aligned since taxi not always available; high costs	Poor alignment, usually not available or only in a basic variant	In villages with few traffic cycling is comfortable; Outside villages only safe on cycle lanes	Partly aligned, usually enough space for side-walks, but many activities not in walking distance;

Assessed degree in internal alignment of service regimes:

Poor alignment; conflicting institutional arrangements — Partly aligned; clear deficits / conflicts — Aligned, but clear drawbacks remain — Well aligned

Table 1: Internal alignment of service regimes in prototypical rural and urban areas

In terms of internal alignment of the service regimes, the main differences between urban and rural areas are highlighted in table 1. For nearly all service regimes, significant differences can be identified between the two ideal types. For the car service regime, in urban areas internal alignment is relatively low because of manifold conflicts about use of space, high emissions and users' expectations regarding smooth traffic flow and convenient parking. In rural areas, space is usually not as scarce and the internal alignment of the car regime is therefore stronger. The service regimes of public transport, taxis and sharing reach higher internal alignment in cities, since urban density allows for relatively high frequency and availability of the services (Horn et al., 2018). Car-sharing schemes are usually not financially viable in low density areas (BCS, 2018). For cycling and walking, the differences are not always as clear as they are for the other modes. The respective design of the infrastructure is an important factor in these cases.

For mapping sectoral regime structures, we build on the four ideal type configurations identified by van Welie et al. (2018; see figure 1) and specify them for the rural and urban contexts. Figure 3 depicts the degree of alignment in and between service regimes in the two ideal settlement conditions. A polycentric sectoral regime is typical for many urban areas. Private car usually is the service regime with the highest shares in terms of modal spit, but also other service regimes are important (see Nobis and Kuhnimhof, 2018). Especially cars and bicycles are often in strong competition for space, there is no real alignment between these two service regimes. There is usually at least a weak alignment between walking and most other service regimes, sidewalks and pedestrian areas are separated and most other service modes can be accessed by foot. In many urban areas, cooperation between public transport and car sharing is becoming established (BCS 2018), the alignment between these service regimes is at least moderate in these cases.

In rural areas, we observe more of a monocentric regime pattern dominated by the car (Nobis and Kuhnimhof, 2018). The majority of trips in rural areas and smaller towns are definitely covered by car. When measured in terms of kilometers driven (instead of the number of trips) the dominance of the car is even more pronounced. The dominating position of cars surely is one reason for the low degree of alignment between other modes. The number in multimodal trips usually is much lower than in urban areas (see Nobis and Kuhnimhof, 2018).

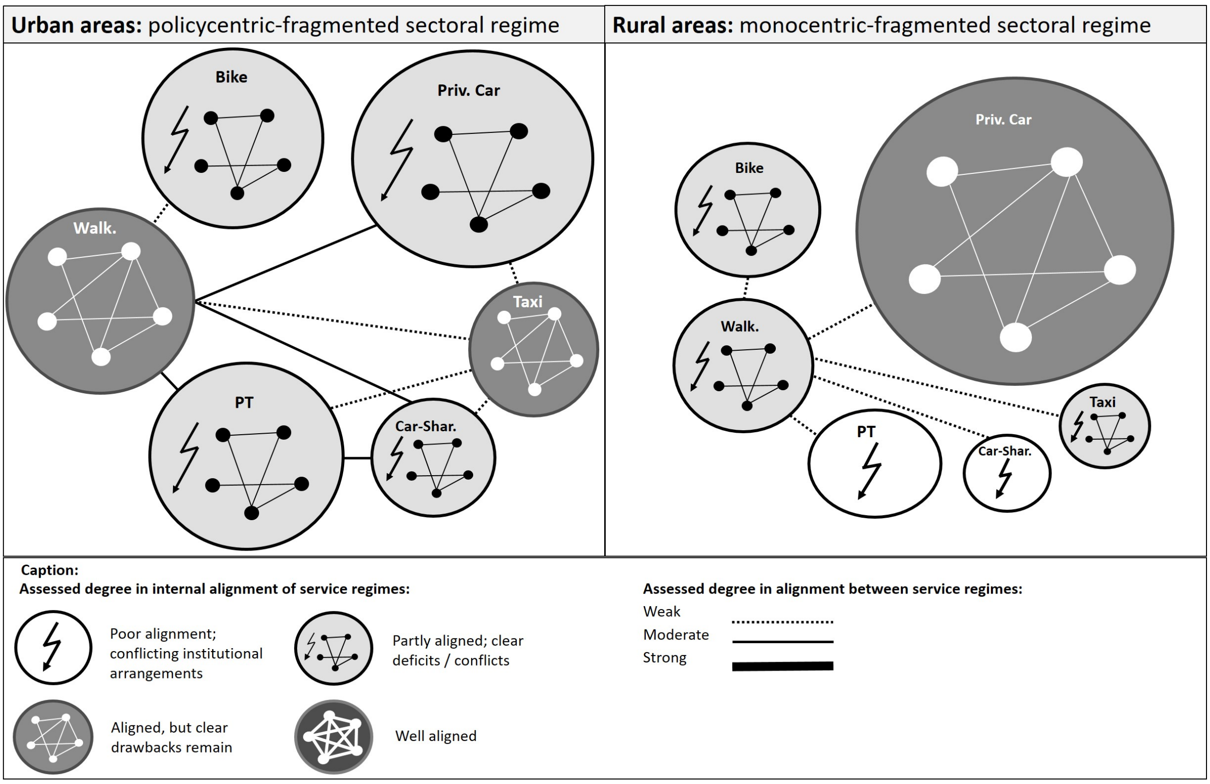

Figure 3: Examples for prototypical sectoral regime configurations in rural and in urban areas.

4. Diverging technology and regime directionality in German rural and urban regions

The differentiation between sector and service regimes serves the better understanding of how spatial contexts may impact the directionality of innovations and transitions in the mobility sector. We will elaborate on two examples of innovations that are associated with strong transformative potentials in the mobility sector: electric mobility and automated driving. For both cases, we sketch prototypical transition pathways for Germany and illustrate how this informs future-oriented strategic analysis and/or the governance of sustainability transitions. Because of different stages of maturity of the two technological fields, the empirical data bases differs. Electric vehicles are already on the market. In that case, we can draw on literature that deals with the basic fit of BEVs with different settlement structures (e.g. Kester et al., 2020; Plötz et al., 2013). We can further draw on empirical data on early adopters of BEVs in Germany (Frenzel et al., 2015; Nobis and Kuhnimhof, 2018). In contrast, fully automated vehicles only exist as prototypes. But in the meantime a broad range of studies deal with potential future development trajectories and/or potential impacts of different forms of AVs (e.g. shared vehicles, individual usage) on mobility patterns, settlements structures and the environment (Bernhart et al., 2018; EBP, 2017; Fraedrich et al., 2017; Lemmer, 2019; Trommer et al., 2016). Furthermore, some studies try to predict the adaptation of different forms of AVs on the basis of stated preferences (Saeed et al., 2020; Stoiber et al., 2019). However, as indicated above, the trajectories we will develop should not be interpreted as predictions. They have the character of scenarios that can be considered a plausible in the light of the evidence and experts expectations in the field.

4.1 Electric mobility

As in many other countries, the diffusion of battery electric vehicles (BEV) is an important topic in sustainable transport debates in Germany[1]. Since 2016, the German government used to subsidize the purchase of BEVs with 4’000 Euro and 3’000 for plug-in hybrid electric vehicles (half of the money came from governments, half comes for the industry). As part of a Covid-19 package to support the industry subsides were raised in 2020. BEVs up to a net list price of 40’000 € now receive a total of 9’000 € in subsidies until the end of 2021.

In the discussion about possible early adopters of BEVs, it was repeatedly assumed that they live in urban centers (Ioannides and Wall-Reinius, 2015; Kester et al., 2020) . The most important arguments for an urban focus are that people have to cover shorter distances in cities, that a charging infrastructure can be operated economically, that the necessary technology-oriented customers are available and that there is specific pressure on urban mobility to reduce the emissions of harmful substances. Kester et al. 2020 show that this line of reasoning has been dominating the discourse on BEVs in many European countries. The idea is that e-cars fit well with these urban conditions, and may even improve the internal alignment in service regime of cars because they provide locally clean mobility.

In the meantime, many studies for Central and Northern European countries, for Norway in particular, have shown that the general conditions in rural areas are no necessarily less favorable for BEVs (Kester et al., 2020; Newman et al., 2014) . For Germany, Plötz et al. (2013) pointed out as early as 2013 that the longer distances mean that BEVs make economic sense especially outside large cities, because the lower operating costs pay off particularly well and the higher acquisition costs,

[1] By the term BEVs we mean exclusively battery-powered vehicles and no hybrids.

compared to ICE cars, can be written off more quickly. And indeed, data about the first private owners of BEVs in Germany illustrates that only about 22% of them lived in larger conurbations (Frenzel et al., 2015). The majority of the early adopters lived in small cities or even in the countryside. Data for Germany (Table 2) from 1.1. 2017 confirms that less densely built areas are still hosting a considerable share of registered electric vehicles. Only vehicles owned by individuals are shown in this table and not those registered by companies or governmental organizations. About 70% of these cars (11’813) were registered by individuals living in cities with less than 50’000 inhabitants. This is supported by an analysis carried out by Hajek (2018).[2]

Categorisation of city size	Population per spatial category	Share in population per category	Cars registered to private persons	Cars per 1000 inhabitants	**Pure electric vehicles** (registered to private persons)	Share -in all e-cars registered to private persons	Pure electric vehicles per 1.000 inhabitants per category
Very large city (more than 500.000 inhabitants)	14.150.941	17,22%	4.988.078	352	**2.016**	12,03%	0,14
Large city (100.000-500.000 inh.)	11.704.214	14,24%	4.942.939	422	**1.634**	9,75%	0,14
Large medium-sized city (50.000-100.000 inh.)	7.544.292	9,18%	3.697.143	490	**1.200**	7,16%	0,16
Small medium-sized city (20.000-50.000 Inh.)	15.935.422	19,39%	8.460.654	531	**3.320**	19,81%	0,21
Small city (10.000-20.000 inh.)	12.941.475	15,75%	7.280.184	563	**3.201**	19,10%	0,25
Very small city (5.000 – 10.000 inh.)	11.275.064	13,72%	6.533.809	579	**2.928**	17,47%	0,26
Rural communities (below 5.000 inh.)	8.624.276	10,49%	5.173.338	600	**2.364**	14,11%	0,27
Not classifiable			285.826		**96**	0,57%	
Total	82.175.684	100,00%	41.361.971	503	**16.759**	100,00%	0,20

Table 2: Pure electric vehicles registered to private person in different spatial categories at 1.1.2017 (data from Kraftfahrtbundesamt [German Federal Motor Transport Authority], analysed by the authors)

As in other European countries (Kester et al., 2020; Morton et al., 2018) it was found that electric vehicles were relatively often purchased by families who owned two cars or more (Frenzel et al., 2015), which means that many users do not necessarily expect an all-purpose car since they still own an ICE-car. In 2017, only 25% of the registered BEVs were the only car in the respective household, compared to a share of 51% in the total car fleet (Nobis and Kuhnimhof, 2018, 81). In rural areas, the share in households with more than one car is considerably higher than in urban areas (Nobis and Kuhnimhof, 2018). In general, there are far more single households in urban than in rural areas. Another advantage of low density areas is the higher availability of private parking space, often on the property of individual car owner (Ahrens et al., 2015). In 2017, 92% of the registered BEVs in Germany had access to a private parking space (Nobis and Kuhnimhof, 2018). This facilitates the installation of personal charging points. In larger cities, where many people do not have the possibility to install a private charging station, a reliable and affordable charging infrastructure needs

[2] The database used by Hajek (2018), shows all electric vehicles per county and not only privately owned ones. This means that cars registered to legal entities are included in the data as well.

to be provided. Otherwise, there is a severe misalignment between the dimensions of user expectations, technological performance and organizational mode.

Besides private cars, also the service regime of car-sharing/car-rental deserves attention when it comes to the diffusion of BEVs. The different forms of car-sharing are still gaining market shares, particularly in larger cities in Germany. The fast growing free-floating car-sharing schemes do only operate in the larger German cities with far more than 100.000 inhabitants, and in the meantime they count more registered users than the traditional station-based schemes. (BCS, 2018). Of particular interest for our analysis is that about 10% of the 20’000 German car-sharing vehicles are BEVs (BCS, 2018). The internal alignment of the car-sharing service regime is strengthened since they should support the societal legitimacy of sharing-schemes by enabling zero-emission-mobility. Further, in case of stricter access regulation because of air pollution, BEVs may enable the use of car-sharing cars in inner city areas. Apart from these alignments within the car sharing service regime, we see an increasing number of attempts to better integrate public transport and sharing of cars and bikes – which means that strengthening the sharing regime can also lead to new alignments at the sectoral level. Usually, the alignment of the different service regimes into a seamless web of mobility options became a central element in visions on sustainable urban mobility futures (Canzler and Knie, 2016; CEC, 2017; UITP, 2017; Hirschhorn et al. 2019).

Besides impacts from emerging service regimes, the directionality of the overall mobility sector may also be influenced by a number of ongoing trends, which affect alignments primarily in urban areas (Truffer et al., 2017). Several studies point at a decreasing interest in car-ownership amongst younger adults in urban agglomerations (Kuhnimhof et al., 2012; Puhe and Schippl, 2014). Compared to the same aged group about ten or twenty years ago, a growing group of younger adults seems to be more open for car-sharing, for public transport and for multimodality in general (Delbosc and Currie, 2013; Nobis and Kuhnimhof, 2018; Puhe and Schippl, 2014). If this trend continues, it will further contribute to better alignment within, but especially between service regimes. Multi- and intermodal approaches may increase market shares in larger urban areas, which would mean that a modal shift away from private cars takes place. Moreover, this trend may weaken the internal alignment in the private car regime if private cars are more and more considered as an emission-intensive and space-consuming version of mobility that can be replaced by alternatives that provide good services and are better suited to the urban environment.

Looking through the lenses of the two-layered regime concept, BEVs can engender different dynamics on the service and on the sectoral levels in rural or urban areas. In a prototypical urban trajectory, changes on the sectoral level, affecting the alignment between service regimes could become the most important developments in terms of sustainability. A further co-evolution of BEVs with the abovementioned trends is imaginable. In the mid-to long term, this trajectory can lead to a multimodal, “seamless” sectoral regime, (CEC, 2017; Schippl et al., 2016; VCÖ, 2015), which is based to a high degree on alignment between the service regimes of public transport, sharing, taxis and walking. Cycling is strengthened and better aligned internally because a shrinking car regime needs less space and creates less conflicts with cyclist and pedestrians. Electrification of cars is desirable and may contribute to the attractiveness and acceptability of electric car-sharing and, thus, to the internal alignment of sharing regimes. This self-reinforcing dynamics may lead to a new and more sustainable configuration for urban areas.

In the rural trajectory, there is no reason to assume that alignments between the service regimes will be affected significantly by the diffusion of BEVs. The car dominated sectoral regime might even be strengthened, since internal alignment might be slightly improved due to the improved environmental performance. But, no significant change in mobility patterns should be expected as users would just switch to buying a different kinds of car. Alignments between car regimes and public transport may be improved somewhat by park-and-ride facilities and similar measures. But in most rural areas, the main environmental improvements by BEVs will lie in the electrification of the drive train. The disruptiveness of the new technology for the existing regime structures differs among urban and rural settings. This rural trajectory would rather unfold as a substitution of an old technology with a new one and mainly affect the internal alignment in the car regime. The urban pathway would imply a significant change in alignment on the sectoral level. Figure 4 shows the composition of and alignment between service regimes in the two pathways.

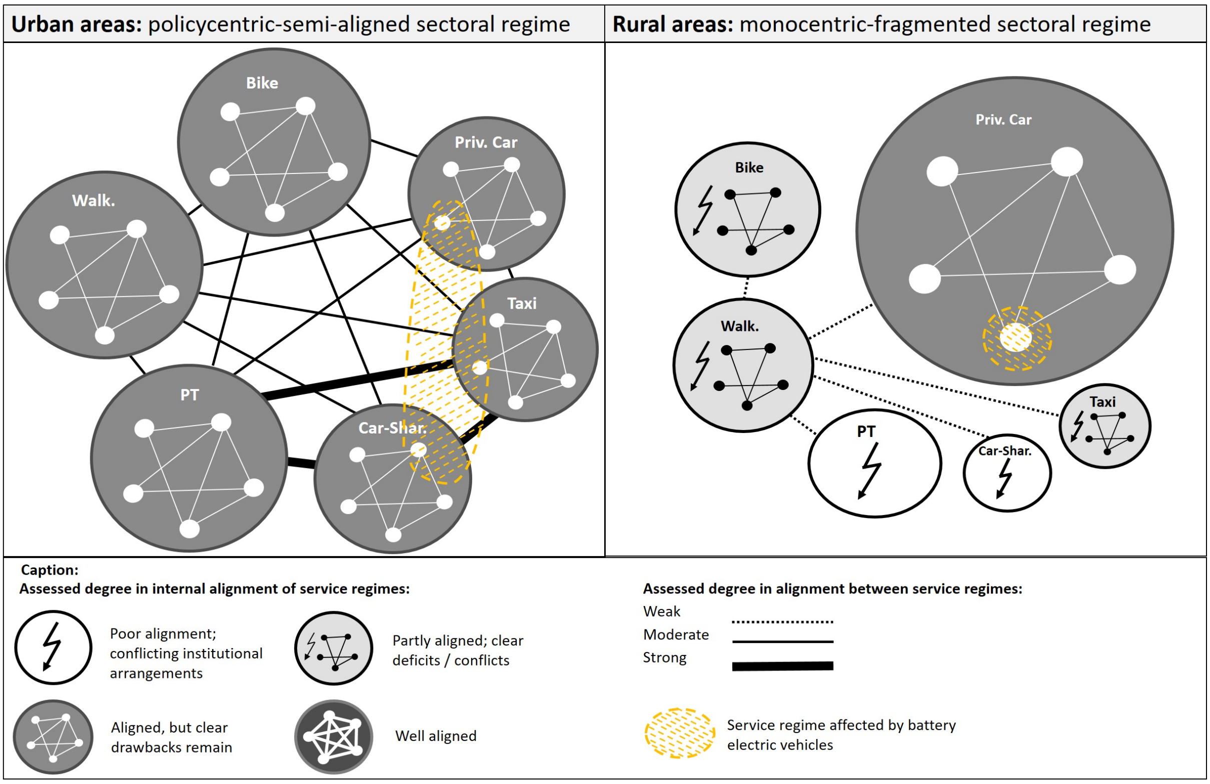

Figure 4: BEVs in an urban (left) and a rural (right) development trajectory towards sustainable mobility futures

In order to consider directionality towards more sustainable mobility sectors, a blanket approach to technology policy seems not very appropriate. In urban areas, BEVs might potentially contribute to deep-structural changes at the sectoral regime level. Subsidies could be particularly used to support electric car sharing and, thus, support a development that can affect the reorganization of the sectoral regime. A somewhat contrary development would set in, if BEVs strengthened the internal alignment of the private car regime. This may improve its social legitimacy and its attractiveness and thus, rather hamper than support reorganization at the sectoral level. Such kinds of self-reinforcing mechanisms may even strengthen the service regime of cars also in urban areas. It can be concluded that in order to tap the full transformative potential of the BEVs in urban areas, it is important to focus on their impact at the sectoral level. In rural areas, where rearrangements at the sectoral level are less likely, policy strategies may focus on the internal alignment in the service regime of cars. For example, subsidies could address a better integration of electric vehicles in the local production of renewable energies to fully exploit the potential contribution of BEVs to sustainable development.

Furthermore, car industry and mobility providers should consider alternative market strategies associated with the different trajectories. In rural areas, they may increasingly consider charging of electric vehicles with renewable electricity from the owner's rooftop (as it is promoted, for example, by the company Tesla[3]). Building alliances with energy providers or renewable energy installers might be a promising strategy. In urban areas, shared e-cars can contribute to a better alignment at the sectoral level and co-evolve with a growing market for mobility services. In such a trajectory, car companies have to redirect their focus form private cars to other service regimes as well as to the alignment between these. Some car companies already started projects in this direction. Prominent examples are ShareNow (a joint venture of BMW and Daimler) and the large-scale field trial with flexible shuttle services in Hamburg operated by MOIA (a subsidiary company of Volkswagen[4]).

Further and perhaps most interestingly, the different regime contexts will show definite impacts on the shaping of the new technologies, products and services. For sharing-fleets, robustness and easiness in handling could be important characteristics (see Truffer et al., 2017) . Fast charging might also be important to ensure that the cars are not blocked too long due to charging and to enable a high utilization rate. In rural areas, this might be of less importance at least if e-cars can mainly be charged at home during nighttime.

4.2. Automated driving

Different urban and rural configurations of service and sector regimes may also give rise to diverging trajectories in autonomous driving. Automated driving is among the rapidly rising topics in debates on the future of mobility (Deloitte, 2019; Lemmer, 2019). Different degrees of automation are distinguished that range from already established driver-assistance systems to fully autonomous, self-driving cars (see SAE International, 2018). It is still contested amongst experts, which degree of automation will be commercialized at which point in time and in which regions (acatech, 2015; Fleischer and Schippl, 2018). In the following, we limit our analysis to self-driving cars (Level 5 in terminology of SAE 2018) for reasons of complexity and because it is sufficient for the purpose of illustrating the potential longer-term impact of this innovation on the mobility sectors. It is widely acknowledged that this technology comes with a huge transformative potential for the mobility sector and maybe also for land-use patterns (Fagnant and Kockelman, 2015; Skinner and Bidwell, 2016; Trommer et al., 2016).

How AVs will affect the mobility system, however, remains controversial. Which socio-technical dynamics will be relevant in the future can depend on various technical, social, political and also spatial factors. (Cohen et al., 2018; Givoni et al., 2018; Haugland and Skjølsvold, 2020; Hopkins and Schwanen, 2018).

[3] See https://www.tesla.com/support/energy/solar-panels/learn/combining-systems (access 21.10.2019)
[4] See www.moia.io (access 21.10.19)

One of the key questions is whether the service regime of private cars will be strengthened by self-driving cars or if, in contrast, self-driving vehicles will better align with collective forms of transport, such as car-sharing, ride sharing and also traditional public transport (Thomopoulos and Givoni, 2015; Transport & Environment, 2019). The latter would be accompanied by considerable changes on the sectoral level. For both development pathways, individual or collective transport, self – reinforcing dynamics are plausible which could lead to positive of negative lock-ins in terms of sustainability. We will use the extended regime concept to sketch how these dynamics may differ between rural and urban areas.

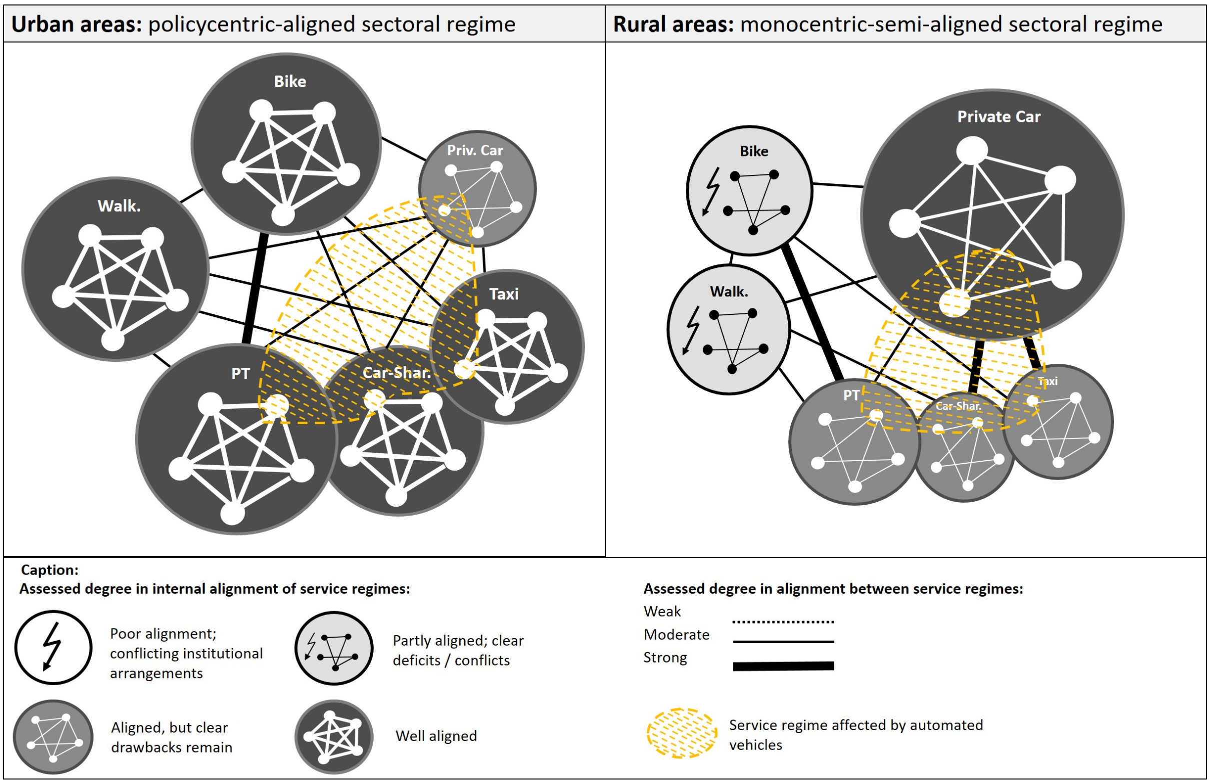

Figure 5: AVs in an urban (left) and a rural (right) development trajectory towards sustainable mobility futures

A potentially virtuous cycle is usually assumed in visions of multimodal urban mobility futures with low shares in private car use (see Fraedrich et al., 2017, 2015). For example, EBP (2017) argue that driverless robo-taxis may improve public transport. Driverless vehicles could operate more flexibly in time and space than conventional public transport and lead to better internal alignment of this service regime. This holds particularly regarding the alignment of the dimensions of user expectations towards flexible services and organizational mode. Further, such developments may strongly contribute to an improved alignment between service regimes in urban areas by offering affordable and flexible last-mile options and by supporting seamless mobility alternatives. If such options are perceived as attractive alternatives for private car use, it is conceivable that political measures to further reduce car use will find broader acceptance and become easier to implement. This could lead to a further decrease of car use and other modes will, as a consequence, get increasingly aligned and attractive. More space for cycling and walking would strengthen the internal alignment of these service regimes. Figure 5 (left) depicts a potential endpoint of such a development.

For rural areas, autonomous cars may strengthen new forms of collective transport (Bernhart et al., 2018). As for urban areas, autonomous cars might contribute to public transport as well and make it better adapted to user needs.. Again a kind of virtuous cycle may set in, with collective transport extending its services and increasing its market shares (see figure 5, right). The more attractive the public transport services the more users will be attracted, and the more promising it may be to further extend it. Organizational alignment with the taxi or the sharing regime is possible and may support such developments. However, compared to cities, it is much more difficult to establish economically viable business models due to the lower population density. It is hard to imagine that the dominance of the car regime will be broken in rural areas since it is too well aligned with user expectations.

On the other hand, the directionality of mobility regimes in rural areas could also lead to a viscous cycle. Self-reinforcing dynamics could strengthen the alignment of the car regime and lead to misalignments with public transport and other alternatives to the car. The relative attractiveness of the public transport services could be weakened, which could in turn reduce its economic viability (Fraedrich et al., 2017; Givoni et al., 2018). Service levels might be further reduced and the alignment with user expectations regarding frequency of services might be further weakened. Consequences are fewer customers, less viability, again less alignment and so on. The fragmentation of the sectoral regime might increase due to this self-reinforcing process. Such an erosion of public transport is less likely in urban areas, since public transport services are needed to move large numbers of people and these services are usually internally better aligned in larger agglomerations. However, a negative development is not impossible, also in urban areas. Automated cars can increase the internal alignment of the car regime, for example the tolerance of congestion may increase since car drivers (or better “users”) have the possibility to engage in other activities such as working, reading or sleeping (Thomopoulos and Givoni, 2015). Moreover, individualized transport based on self-driving cars may reduce the attractiveness of urban areas as a place to live, since they will be dominated even more by cars. Living in rural regimes could gain in attractiveness, since here the internal alignment of the car regime may benefit the most from transforming drivers into passengers. Urban sprawl and more traffic might be the consequences.

Also in this case, applying our approach reveals the differences in directionality between urban and rural areas. In urban as well as in rural areas, extremely different development pathways are plausible. Processes of alignment or dis-alignment on the sectoral level are decisive for the future sustainability of the mobility regime. Among the possible directionalities of urban mobility sectors, a virtuous cycle appears less likely than in the rural case. In rural areas, the car service regime is in a much stronger position compared to urban areas. This already strong internal alignment can be further strengthened if automation leads to even more convenient car use. If these cars were powered by clean electric energy, also a high level in alignment with broader societal meanings could be achieved. The extended regime concept helps to shed light on underlying dynamic cause-effect relations in urban and rural areas. There surely is a “window of opportunity” to make urban mobility, and to a certain extent also rural mobility, more sustainable when self-driving cars will be commercialized. But policy measures to ensure improvements in alignment on the sectoral level are definitely needed in order to support virtuous rather than vicious cycle dynamics (see Deloitte, 2019; Givoni et al., 2018; UITP, 2017). Otherwise, “directionality failures”, in the sense of Weber and Rohracher(2012), may lead to less rather than more sustainable mobility futures.

It is possible therefore, that we will have converging dynamics in rural and in urban areas, when services based on automated vehicles start to complement public transport and automated public transport connects rural areas better with urban areas. It is also imaginable, however, that we will see divergent dynamics if concepts such as robo-taxis only get traction in areas with a high population density. Industrial strategists have to be aware of the fact that very different development trajectories with their specific market potentials are still possible. The approach may help to better understand and anticipate the underlying dynamics that will be crucial for determining the direction of developments in urban and in rural areas.

5. Conclusions

We proposed a reformulation of the socio-technical regime concept in order to accommodate for spatial variety in context conditions. Our approach helps to better understand how transitions in the mobility sector depend on how new technologies interact with regime structures both at the service and at the sector level. Urban and rural contexts may support different directionalities when electric mobility or automated driving is introduced by national policies. And this may impact the overall sustainability record of the future mobility sector.

We selected two technologies representing different degrees of maturity, showing both established, as well as future technologies may be discussed with the framework. Furthermore, and related to both cases, the approach is able to address a very timely issue: Alignments between different modes is an explicit target of urban sustainability strategies and also of concepts such as "Mobility as-a-Service" or integrative platforms. The extended two-layer regime concept, with the differentiation between service regimes and sectoral regimes, allows for an adequate and transparent consideration of these dynamics.

For the case of BEVs, we showed that they may contribute to two different development pathways in urban and rural areas. The approach exposes different dynamics in alignment: mainly internal alignment in the service regime of cars in rural areas versus a higher importance of alignment between the service regimes, at the sectoral level, in urban areas. An innovation that stabilizes the internal alignment in a regime, such as e-cars in rural areas, is reinforcing the established directionality of the sectoral regime in this region. Concomitantly, in urban areas, BEVs might weaken the established car regime and contribute to the take up of new business models like car-sharing. These in turn, can make an important contribution to restructurings at the sectoral level. For one and the same technological innovation, the factors and dynamics in the regime, and the resulting directionality, may vary considerably in different spatial settings. These differences in directionality between urban and rural area might even get stronger in the future, if the developments unfold as sketched in the scenarios elaborated in this paper. Diverging dynamics between the two spatial categories can be assumed that may lead "to fundamentally different future sector structures" (Yap and Truffer, 2019: 1031) in urban and rural areas.

Technology assessment and foresight has to be based on a solid understanding of future development pathways (Grunwald, 2018; Könnölä et al., 2011). The two-layered regime concept allows for more detailed look on sociotechnical processes of alignment or de-alignment and, thus, a more fine-grained understanding of varying directionality in urban and rural settlement structures. It helps to consider spatial factors in future-oriented analyses related to sociotechnical change. Early detection of risks and opportunities of new technologies is essential for managing the directionality of emerging technological dynamics. Governance strategies have to acknowledge that the diffusion of electric propulsion and automation does not necessarily lead to similar patterns of change in different spatial settings. In our case studies we illustrated how such insights can be used to develop more targeted policies or industrial strategies.

From the perspective of planners and policy maker it is important to be aware of the differences in directionality that a spatial innovation strategy may imply. The approach helps to raise awareness for barriers and opportunities of innovations that have the potential to contribute to transformative dynamics in the mobility sector. Particularly for AVs, literature and reports emphasize that the transformative potential is immense (Lemmer, 2019; Trommer et al., 2016). This is confirmed by our prospective analysis. The extended regime concept helps to identify alternative pathways. But it also illustrates that directionality failures, in the sense of Weber and Rohracher (2012), are definitely a possibility and should be considered accordingly.

Moreover, the differentiation between service and sectoral regimes should be easy to grasp for planners and other practitioners. The level of service regimes brings the regime concept closer to the established structures in administration and economy and to the routinized ways of thinking and planning. By considering sectoral level institutional structures, the overarching and integrative aspects may be addressed more systematically, which is particularly important when implementing the widely held vision of more integrated mobility futures

In transport planning, the approach can be used in different ways: Either as an analytical tool for understanding how new technologies may affect different components of the mobility sector and their composition in different regions; or for developing and communicating goals in the form of ideal and/or attainable degrees of alignment in or between service regimes. Scenarios of desirable developments could be created that differentiate between service and sector regimes. Such scenarios could be an entry point for debates with stakeholders, which are usually focusing on specific service regimes, to discuss joint strategies or roadmaps towards sustainable mobility futures in an era of electrification and automation (Hickman et al., 2011; Soria-Lara and Banister, 2017). Planers and policy makers may build spatially sensitive policy strategies as elaborated in this paper. Developers of technologies and industrial strategist may apply the approach to better target test market strategies or the eventual formulation of dominant designs.

Future research activities may explore to what extent the approach can be further developed and/or adapted to other world regions. We assume that the core idea, the differentiation of the regime concept into service and sector levels, is basically applicable to mobility sectors in all geographical regions (provided that more than one service regime is available) as well as to water, food, health and other sectors. However, the concept has to be adapted to the specific conditions in other geographical contexts, just as we have adapted it to the two prototypical regions in Germany. In Asian cities, for example, it might be necessary to redefine the service regimes according to local circumstances. Ghosh and Schot (2019), recently identified twelve regimes for public transport in Kolkata. Also the description of the core dimensions of the service regime may have to be adapted accordingly. However, we assume that the differentiation between regime structures at the service and the sectoral level will be relevant irrespective of the geographical settings and may even be applied to other sectors.

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