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REVIEW

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From ambition to implementation: institutionalisation as a key challenge for a sustainable mobility transition in Germany

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Abstract

Background Transport and mobility contribute a significant share of greenhouse gas emissions, and fossil fuel consumption must be reduced for mobility to meet sustainable development goals. Strengthening public transport is a key element of the required mobility transition, including technological innovation. To address the related institutionalisation processes, we analyse the interplay between technological development and the intensifying mobility transition debate. We focus on the challenges for the roles of public transport professionals, who are essential for the implementation of sustainable mobility measures at the local level.

Case selection and methods We present two cases: First, we address urban ropeways as an incremental option to extend public transport networks. In a series of three expert workshops (23 participants in total), local public transport professionals discussed the potential of urban ropeways, and challenges concerning the related institutional framework. Second, we chose an exploratory approach to understand how public transport professionals engage in the debate on the potentially disruptive role of automated driving in the future of public transport. This included an analysis of strategy documents and experimentation, as well as observations at sectoral events and stakeholder forums. In both cases, we focus on the specific context in Germany, which ensures a coherent institutional framework and a consistent analysis.

Results We found a general openness among public transport professionals to consider the potential of mature urban ropeway technology. However, critical gaps remain in planning instruments and the densely regulated public transport planning regime. Concerning automated driving, a strong technological focus can be observed in the related transport policy debate. At the local level, despite numerous technical tests, there is hardly any discussion of more far-reaching requirements regarding integration of the technology into the mobility system in a way that ensures sustainability-oriented goals are met.

Conclusions Beyond both incremental and potentially disruptive technological drivers, the proactive and targeted design of corresponding institutionalisation processes proves to be a key challenge for achieving a sustainable mobility transition. Institutionalisation and the related roles of public transport professionals must be considered in relation to the mobility transition's substantive goals and the associated political discourse.

Keywords Mobility transition, Public transport, Transformation, Institutionalisation, Directionality

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Background

A mobility transition has long been recognised in the expert debate as an essential prerequisite for more sustainable mobility. Transport and mobility contribute a significant share to energy consumption and greenhouse gas emissions. Therefore, in order to achieve sustainable development goals and mitigate climate change, reducing fossil fuel consumption is a key element of sustainable mobility [1]. Undisputedly, a sustainable mobility transition includes strengthening public transport, both through the expansion of conventional services and through new forms of service and use [2, 3]. In practice, however, there is a persistent implementation gap, undermining the far-reaching ambitions articulated by many actors in the sector.

From the perspective of innovation research, understanding this discrepancy requires analysing institutionalisation processes in the existing regime of public transport actors, technologies, formal frameworks and practices [4]. In this article, we address the challenges related to the institutionalisation of new technologies or services, and how these may slow down or influence diffusion pathways. To do so, we consider specific innovations that promise to contribute to a sustainable mobility transition. Due to the complex interrelations between regulatory contexts, public transport structures, economic structures, etc., inherent to the mobility system, and in order to ensure a consistent analysis, we focus our study on the specific situation in Germany.

Beyond creating suitable framework conditions, the implementation of the multitude of small measures that will ultimately build the sustainable mobility transition is particularly in the hands of various actors at the local level, in cities and municipalities, where a significant share of citizens' mobility takes place [5]. Considering public transport, these actors are not limited to transport companies, transport associations, or specialist planning offices, but also include public administration at various levels, all of which have varying responsibilities in infrastructure planning and public transport provision [6–8]. In the following, we refer to this group of actors as public transport professionals. The relevance and the theoretical embedding of this perspective are explained in the next section.

Our focus is on an area of conflict experienced by public transport professionals in their everyday practices: various technological innovations for public transport are developing rapidly, sometimes also politically promoted; but the complex regulatory frameworks and well-established planning routines used by public transport professionals do not easily fit with these innovations (cf. e.g. [9, 10]). Linking this issue back to the mobility transition debate leads us to the following *research question*: What role do the limits of existing regulatory frameworks and organisational structures and routines play when public transport professionals are confronted with the intersection of technological developments and alternative public transport options on the one hand, and the expectations directed towards a mobility transition on the other?

The role of local public transport professionals

Cities and municipalities are currently confronted with two major issues in the field of mobility that are unfolding in parallel, interacting with each other: technological developments on the one hand, and the public debate on a sustainable mobility transition on the other.

Technological developments range from incremental developments in individual modes of transport (e.g. new drivetrain technologies, use of ropeways in public transport) to new types of mobility services (e.g. bike- and scooter-sharing, ride-pooling, multimodal apps), and to developments in the field of automated driving (with expectations ranging from a 'third place' to automated taxis). At the same time, there is increasing public debate on a mobility transition, which is characterised by a normative orientation towards sustainability [3]. However, the terms used require careful attention. Some aspects relate to technological improvements for more efficiency in existing transport modes (particularly considering drivetrain technology), but the concept of a sustainable mobility transition explicitly widens this claim and includes the rebalancing of transport modes and the reconsideration of framework conditions in the mobility system in general [2, 11, 12].

The interaction between technological development and the mobility transition debate creates a need for societal negotiation, and conflicts of interests between various actors are to be expected. A broad debate is taking place in research and politics as well as in municipal and public transport practice, which is dedicated in particular to technological possibilities and developments, as well as new business models, but also to regulatory requirements to enable new solutions. In contrast, little attention has been paid to how the various technical elements could be integrated into a sustainable mobility transition. This shortcoming has been identified as a major criticism of the current discourse. For example, Schwedes [13] observes an overall retreat to a technological focus in current transport policy. Stickler [14] substantiates this finding with regard to the debate on automated and connected driving. Regulations particularly in road transport (and committees for their further development) appear equally ill-equipped for a sustainable mobility transition [15–17].

The dissonance becomes even more apparent when considering that, at a strategic level, sustainable mobility has been incorporated into policy documents at diverse levels, including European and national governments as well as regions and municipalities. However, not least as a result of the horizontal and vertical segmentation of responsibilities for transport policy and its side-effects, there is a lack of concretisation, operationalisation and discussion of trade-offs, both within the field and in interactions with other policy fields. No single institution takes ownership for an integrative perspective (cf. [18]). As a problem in its own right, this segmentation might promote the narrowed technological perspective of key actors, further contributing to the observed dissonance between the technology-centred innovation discourse and overarching sustainability goals. Consequently, public transport professionals at the local level cannot rely on a coherent framework that comprehensively corresponds to those sustainability goals. There is a 'discursive gap', where a framework for a coordinated negotiation of interactions between the various developments and trade-offs is missing.

Institutions in the socio-technical regime

As a heuristic framework for analysing transformation processes, the mobility system can be understood as a socio-technical system. Geels [19] proposed the so-called multi-level perspective to describe technological innovation trajectories within such systems. This perspective considers, (a) socio-technical niches as protective spaces (cf. [20]) where learning takes place and innovations may gain momentum, (b) socio-technical regimes as sets of deeply anchored rules and routines through which technologies, companies, institutions, politics, users and interest groups in a specific field are coordinated and harmonised with each other, and (c) the socio-technical landscape, with general policies, societal values, economic trends, etc., influencing the niche and regime levels [19]. Within the multi-level perspective, in order to understand potential transition as well as barriers, the socio-technical regime level and its associated processes of change are essential. In essence, its deeply interwoven elements lead to a high degree of stability and rather incremental development, due to path dependencies [19, 21]. Nevertheless, transformation processes can take place in different ways, for example through the 1:1 exchange of individual technologies, or through more complex reconfigurations or disruptive change [22].

Institutions are a defining element of socio-technical regimes. They include fixed regulation and established routines of action, but can also be informal [4, 23]. Considering the mobility transition debate, they are particularly important: In principle, a purely technological change is conceivable (e.g. replacing drivetrain technology, or efficiency gains through automation), leaving the basic structure of the socio-technical regime unchanged (technological substitution pathway, cf. [22]). From the perspective of sustainable mobility, however, such a pathway falls short of solving major challenges in the mobility system (e.g. land consumption, noise, pollution, urban sprawl) due to the far-reaching path dependencies of today's dominant automobility [21]. A more fundamental transformation is therefore indispensable, especially since greenhouse gas emission reduction targets may not be achievable within the necessary timeframe when relying only on technological change.

For the same reason, the technological side of innovation, as driven by 'enactors' [24], can be considered of less interest for the analysis of dissonance between technological change and the mobility transition debate, as introduced above. Our analysis focusses on the societal and political processes dealing with the technology (e.g. regulatory framework conditions, new infrastructures), for which the 'selectors' [24], i.e. innovation actors who assess, fund and regulate new technologies, are more relevant. Regarding a mobility transition, the selectors include regulatory bodies, local councils and public transport authorities, and transport planners and operators, all of which are involved in making choices about the technological elements of future mobility systems. While enacting and selecting are co-evolutionarily intertwined [19], the mobility transition debate's normative orientation towards sustainability requires directional decisions to be consciously made, in particular by public sector selectors [25, 26].

Public transport professionals and professional practices

At the local level, public transport professionals generally act within complex frameworks of professional practices and routines [7, 27–31]. However, they are confronted with challenges that may be incongruent and come with trade-offs, leading to conflicts when relating concrete projects to the normative framework of sustainable mobility (which itself is partially open to interpretation). We therefore argue that local decision-making particularly shapes the actual transition process. This raises questions of how normative orientation is ensured and how, for example, different transport policy priorities, and possibly underlying divergent normative positions, are negotiated.

This focus follows the assumption that it is at a particular level of planning, where officials, etc., actually require this negotiation (cf. e.g. [32]). While incongruities may well be identified (but only partially resolved) at a strategic level, the implementation of projects and measures requires actual choices to be made. Public transport professionals at the local level therefore also need to be distinguished from the officials, etc., involved in formulating higher level policies (cf. [33]). It should also be noted that political processes also need to be considered and related to professional practices, especially in the case of socially controversial issues [34, 35].

Table 1 Analytical framework

Technological developments	→ *implicate* →	Incremental and/or disruptive transformation	← *requires* ←	Mobility transition debate
		Public transport professionals and their practices		

The relevance of this perspective towards professional practices is twofold. It provides insights into a more comprehensive understanding of the societal acceptance (in a broad sense) of technological change and a sustainable mobility transition [36, 37]. In order to become effective, socio-technical change needs acceptance not only in civil society, but also among professional actors who also shape transformation. This becomes visible in other elements of a mobility transition, for example regarding qualitative changes in the provision and promotion of cycling infrastructure [28, 38–40], or the emerging field of mobility-as-a-service [9, 41, 42]. Thus, the perspective towards professional practices also promises concrete starting points for the future design of mobility transition measures. It adds an explicit consideration of current practices and how to proactively engage with emerging trade-offs, which in turn may reveal where further changes to framework conditions could be required.

Analytical framework

Joining the considerations introduced above, our analytical focus is on the triple interface of technological developments, the mobility transition debate, and the role of public transport professionals. The relations between these elements have been discussed from a multitude of angles: For example, Holden et al. [3] relate technological developments to their relevance in a mobility transition, including both potential and limits. Other studies analyse how sustainable mobility goals are or could be translated into changing practitioner routines (e.g. [28, 31, 38, 39, 43]), but lack specific consideration of technological developments as a driver. In some studies, for example the mobility-as-a-service studies mentioned above [41, 42], this is a dedicated focus, but they lack comprehensive consideration of the relation between the technology and its potential for a mobility transition. At the triple interface, what makes public transport professionals specifically relevant is their dual role, combining a) their planning practices and responsibilities towards a mobility transition, and b) their selector role in technological innovation processes. This is also why we specifically consider public transport professionals and not only their practices, keeping in mind earlier criticisms of agency being obscured in the multi-level perspective and respective analyses of transition processes (cf. [44]). Similar approaches bringing together the three elements are rare, or set a different focus: For example, Pel et al. [26] include transport professionals in their analysis of the "Dutch 'Driverless Car' transition", but focus on the synchronisation between the public and the private sectors. Docherty et al. [9] also include the three elements in their analysis concerning smart mobility, but do not consider local public transport professionals and their practices in detail. The main value added by our study is thus our specific lens on the triple interface, as summarized in Table 1, which aims at an improved understanding of its role in institutionalisation as a key element of transition processes.

Furthermore, the analytical framework includes a differentiation between incremental and disruptive transformation. Concerning the technology side, this considers the bandwidth of technological promises from minor efficiency improvements to game-changing new technologies and services. At the same time, however, the magnitude of change required to meet the sustainability goals linked with a mobility transition [1, 3] also calls for both incremental improvements and disruptive change. Since incremental and disruptive change will most likely challenge local public transport professionals and their practices in different ways (cf. [22]), the explicit consideration in the analytical framework ensures this is also reflected in the case selection for the present study.

Methods

Case selection

In order to study the role of institutionalisation processes at the triple interface introduced above, we look at innovation processes for two technological options that have recently become the subject of local transport policy strategies. First, we look at *urban ropeways* as an incremental option added to conventional public transport, using steel cables to support and move passenger cabins between stations. Despite a general openness of public transport professionals, a number of systematic planning challenges can be identified. Being positioned as a promising public transport tool in both the political arena and the media, the innovation process provides useful insights into concrete challenges in the public transport regime. Second, we discuss *automated driving* with its potentially disruptive effects, including the way public transport is organised. Despite technological progress, this technology must still demonstrate its technical and economic feasibility under real-world conditions. Moreover, uncertainties concern changing actor roles or regulatory requirements. However, far-reaching expectations regarding the technology's contribution to the mobility transition and more efficient mobility are already being articulated in the political arena—even though it is not yet clear whether the transformative potential of automated driving will rather strengthen individual transport. Both cases share the link between a certain technological development and specific potential for a mobility transition, and both may challenge public transport professionals in specific but different ways. The inclusion of one incremental and one potentially disruptive case aims to cover a richer bandwidth of potential challenges for public transport professionals. As mentioned above, the complex institutional environment leads us to focus on the specific context in Germany, ensuring a consistent analysis. Necessarily, however, the different characteristics of the two cases imply different methodological approaches, which are detailed below.

Methods—urban ropeways

The urban ropeway case discussed in this article builds on material collected by Reichenbach and Puhe [45]. In order to analyse the interactions between public transport professionals and their planning challenges, hypothetical planning processes for urban ropeways were discussed in three expert workshops in different cities.[1] A qualitative research approach was chosen to explore public transport professionals' views and reasoning about urban ropeways. For each of the workshops, which were conducted in 2017, a group of seven to eight selected public transport professionals was invited (23 participants in total). This represented typical involvement in public transport planning in the respective cities, including representatives from administration, local public transport operators and associations, and non-governmental organisations with an interest in public transport planning. The workshops started with a brief introduction about urban ropeways by the project team. The participants were then asked to identify potential corridors for urban ropeways in their respective cities. The main part of the semi-structured discussions was guided by open questions concerning the respective urban ropeway project's hypothetical impacts on the mobility system and the city as a whole, as well as opportunities and potential challenges, especially concerning the hypothetical planning process.

The workshop discussions were digitally recorded and transcribed. Analytical categories were built iteratively, with a dedicated focus on distinguishing between local factors, general perceptions of the suitability of urban ropeway technology, and considerations regarding the socio-technical regime, particularly concerning planning routines (cf. [45]). For the present study, we focus on the latter.

Methods—automated driving

Despite decades of technological development oriented towards automated driving, the professional debate on its role in a mobility transition is still rather young and in vivid progress. Therefore, we chose an exploratory approach to analysing the relation with public transport professionals and their practices and routines.

A brief historical overview provides some background regarding the technological development pathways that have prepared the current state of the automated driving debate. Partly building on a literature review by Reichenbach [46], we then relate this to the current uncertainties regarding the effects of automated driving on the mobility system, and discuss the relevance of our observations for public transport professionals. One approach already chosen by public transport professionals to face the present technological challenges is to promote local field trials and real-world laboratories. Even though many of these focus on technical issues, and despite the heterogeneity of local or regional constellations, they often also provide insights into organisational configurations and institutional challenges (cf. [46]). Furthermore, we evaluated strategy documents, particularly those of the Association of German Transport Companies (VDV), with a focus on whether institutionalisation challenges and changing professional practices were considered. This was supplemented by observations at various academic events and stakeholder forums in the public transport sector. We paid specific attention to how general perceptions of potential opportunities and/or threats from automated driving were voiced, and if more specific reflections were articulated regarding how public transport professionals may be challenged in their roles and routines.

As a guiding principle for our exploratory analysis of the case, we followed a rationale of capturing new arguments and lines of thought until a reasonable degree of

[1] Three cities in the state of Baden-Württemberg were selected for the analysis, ensuring similar actor constellations and a consistent regulatory framework. A pre-selection of cities was made where urban ropeways seemed generally conceivable, for example due to major natural barriers and already ongoing discussions about extending public transport. The final selection included Stuttgart (gaps in commuter rail and light-rail networks), Constance (new backbone for public transport considered), and Heidelberg (complementing the tram network).

saturation was reached. We explicitly acknowledge the limitations of this approach; however, we are confident that it provides a useful lens that is able to capture the key elements of the ongoing debate without a major time-lag.

Results

Urban ropeways: uncertainties regarding internal public transport routines

In recent years, urban ropeways have been increasingly discussed as an option to expand public transport networks where conventional modes of public transport reach their limits. Combined with its technical characteristics of low land consumption and energy-efficient operation, the technology promises to contribute to more sustainable urban mobility [47–49]. Obviously, this contribution is limited, but still relevant, considering a specific range of applications where the technological advantages become effective, for example crossing topographical barriers or serving as point-to-point shuttle services to complement urban rail networks. At first glance, urban ropeways may still be considered a simple incremental innovation to conventional public transport with its typical fixed routes and stations. However, the public transport sector in Germany is characterised by a complex institutional structure built over decades that does not consistently include urban ropeways. As a result, implementing urban ropeways comes with significant challenges in the planning process [45, 47].

During the expert workshops, uncertainty emerged as a recurrent theme and a primary challenge. The uncertainties addressed by public transport professionals were twofold, including both a lack of experience, and fundamental doubts regarding the suitability of current routines and instruments.

Uncertainty due to a lack of experience is no surprise. While being an established technology in other fields, ropeways have not been common in public transport in Central Europe. Accordingly, there has been no need for public transport professionals to concern themselves with ropeway technology. Therefore, the novelty of the topic comes with a lack of concrete experience, illustrated by a multitude of questions concerning the detailed technical and operational possibilities, costs and construction methods, or safety requirements. Although such questions can be a major challenge at the local level, they can generally be answered by specialist planners and are not open questions regarding ropeway technology itself. This kind of uncertainty is therefore also not a primary issue concerning institutionalisation processes in the public transport regime. Experience will naturally build over time, if urban ropeways become a common public transport option. In order to make this happen, however, there are a number of structural uncertainties to be overcome, which are addressed in the following.

Fundamental procedural uncertainties

Today, German public transport planning is characterised by complex regulations and professional practices and routines. Using these, established means of public transport can be planned reliably. The underlying mechanisms, however, also result in struggles when considering technological innovations, despite the general fit of urban ropeways with the public transport logic of fixed routes with stations.

The responsibility of public agencies and the use of taxpayers' money have led to a system that extensively relies on empirical reference values, particularly when justifying transport investments, including a standardised tool for cost–benefit analyses. This is a major challenge for urban ropeways, because the necessary calculations cannot (yet) be carried out with the same depth and reliability that would be required for solid assessments and, in particular, comparisons with alternative means of transport. For example, parameters for transport modelling concerning the user acceptance of urban ropeways, affecting modal shift calculations, cannot be based on the same level of evidence, compared with established means of public transport. Similarly, the guidance on cost–benefit analysis provides detailed reference values for construction- and operating costs, depreciation periods, accident costs, environmental costs, or noise emissions for established means of transport, but not for urban ropeways. Some criteria are not considered at all, despite their potential relevance when comparing urban ropeways.

While building-up experience is a common step in innovation processes, the specific routines in public transport planning result in a critical 'chicken-and-egg' problem due to its fundamental reliance on empirically-validated reference values. Because of the fundamental relevance of these planning tools, particularly when applying for public subsidies and justifying investments, they cannot easily be skipped, and learning is inhibited.

Relating uncertainties to public transport professionals' general openness

While the uncertainties sketched above may read like general scepticism of a whole sector characterised by structural inertia, a contrasting general openness towards innovative solutions must be highlighted that could be observed among public transport professionals. The potential of urban ropeway technology has been recognised as a possibility to expand public transport networks and close existing gaps. This openness alone is an important step towards full institutionalisation, in that ropeways are no longer intuitively dismissed as simply a means of transport for tourism. It also includes an explicit willingness to consider in detail the possibilities as well as the planning challenges.

However, this does not solve the problem of unsuitable planning instruments. Despite local ideas on how ropeways could provide a building block for a sustainable mobility transition, the gaps in the formal framework conditions, unclear responsibilities, etc., remain further. Acting as a pioneer requires accepting trial-and-error procedures and interpreting existing regulation. It is noteworthy that public transport professionals did not fundamentally call the usefulness of the regulatory framework into question, since its reasoning (e.g. efficient use of public funding) remains relevant. However, the framework was perceived to be too restrictive, particularly when considering new technological options. This issue is a consistent source of criticism beyond urban ropeways [50].

Regardless of the criticisms voiced, public transport professionals at the local level can only work within the current formal framework, using the instruments that are available to them. Considering the potential identified in urban ropeways, a need for their support by political actors was also deemed necessary. This could be carried out through both further development of the regulatory framework and supporting experimentation at the level of local councils, etc.

Notably, this issue has been noticed at the national regulatory level, where urban ropeways are for the first time considered in the ongoing revision of the standardized tools mentioned above [45]. Furthermore, following a parliamentary initiative, urban ropeway projects are now eligible for federal investment subsidies.

Automated driving: moving beyond a technology perspective

The idea of automated driving in road traffic is not new. It can be traced back at least to the 1930s. Following isolated efforts in the 1970s, especially in Japan and the United States of America, a strong wave of activities for vehicle automation can be observed in the 1980s. At that time, research and development on 'artificial intelligence' enjoyed an upswing, and information and communication technology (ICT) increasingly became the trigger and object of industrial policy. Associated with this were specific application programmes, among others for driverless vehicles in the military sector, and also for private and public transport. One of the central, if not the most important, funding projects in this field in Germany in the 1980s was the Eureka research programme 'Prometheus' (1987–1994). This was understood as an integrated transport concept in which the social and ecological consequences of individual transport were to be reduced, and its advantages further utilised by exploiting the benefits of new technologies, in particular by combining transport technology with ICT [51]. The work carried out at that time, which also included fully autonomous vehicle guidance in real road traffic as well as a general analysis and problem definition of ICT application in road traffic, had a significant influence on further research and development activities in Germany and beyond (e.g. regarding telematics, intelligent transport systems, and automated driving).

In the new millennium, following a decade of low public visibility, a renewed 'renaissance' of automated driving began, initially motivated primarily by new technical possibilities. This time, the developments are particularly driven by two large industrial sectors: the automotive industry, and companies in the so-called platform economy. In the countries where the globally important players in these sectors are based, they are considered key industries and therefore enjoy direct and indirect political support. As early as 2015, the German government adopted its "Strategy for automated and connected driving" [52], which emphasised the importance of these developments for industrial and transport policy, stating that Germany should shape the digital innovation cycle in this area and become a lead market. To this end, numerous political fields of action were proposed and implemented, concerning innovation and legal issues. This approach was reinforced in the 2019 action plan "Research for Automated Driving" [53], which formulated three guiding principles: (1) automated driving must be safe, (2) automated driving must be efficient, sustainable, clean, barrier-free, affordable, and oriented towards the needs of citizens in the best possible way, and (3) Germany's technological leadership concerning the automotive industry should also be secured concerning automated driving.

The latter points illustrate a striking phenomenon in the current developments on automated driving: the existence of a widely shared (and only slightly varying) expectation statement which permeates policy documents and public statements by innovation actors worldwide. According to these, automated driving should, among other things, improve road safety (significantly reduce the number of traffic-related fatalities and serious injuries), make traffic more efficient and reduce environmental impacts, enable (individual) mobility for population groups that have so far been excluded for various reasons (age, physical or cognitive capacity), and allow new forms of time use during the change of location. These expectations not only come about with major goal conflicts; a selective combination (or even just different weights put on the different aspects) also allows representatives of fundamentally different interests and ‘mobility futures’ to each recognise ‘their’ future technology in automated driving. The variance of expected (new) mobility services is interwoven with a whole variety of different automation concepts. These can be further differentiated in two regards: First, concerning the technological approach (and thus traffic performance and the current (socio-)technical maturity), and second, concerning how the execution of the driving task is distributed between human and machine (entailing consequences with regard to e.g. responsibility, liability, and ethical issues).

Regardless, there seems to be a broad consensus that automated driving, should it be commercialised, will lead to far-reaching changes in the mobility system (and beyond). However, it is both unclear and controversial whether or how far automated driving will support or hinder a transition to more sustainable mobility (cf., among others, [9, 54–57]). Some experts argue that (public) mobility services based on automated driving will lead to a significant decrease in private car ownership and reinforce a regime of seamlessly connected intermodal on-demand mobility options without users owning the vehicles, thereby reducing some of the negative impacts of current mobility (automated driving ‘heaven’). Others argue that automated driving will lead to a significant decline of public transport and an intensification of car-based mobility with negative impacts on health, the environment and land use, as automated driving will provide highly efficient and extremely convenient individual transport (automated driving ‘hell’). However, these differentiations and nuances regarding the expected effects on the mobility system have hardly found a place in the political discourse so far, which continues to focus on technological potential and industrial policy [14].

Public transport professionals’ scope for action

Considering the scenarios sketched above, one of the most important questions concerning the future of the mobility system is whether automated driving will further consolidate current (auto)mobility patterns and thus perpetuate existing traffic problems, or whether (new) mobility services will be enabled and implemented that can contribute to alleviating or eliminating the undesired effects of current mobility. If automated driving is to have the latter effect, then public transport operators and authorities are particularly challenged in their selector roles, deliberately shaping the innovation process. They could have a considerable influence on the design and speed of implementation of new mobility services if they were to become aware of these options and actively use them. At the same time, however, coordination between them is challenging, particularly due to their embeddedness in local and regional policy contexts, in which problem perceptions, solution strategies and options for action can differ greatly, and reflective capacities may be limited.

In acknowledging the possibility of fundamentally changing supply and demand structures in the mobility system (with automated driving being more than a simple replacement of, or supplement to, any existing transport mode), such a perspective directly points to the related transport policy opportunities and challenges. However, anticipating automated mobility impacts comes with significant limitations, since relying on extrapolations of current and historical trends and interrelations cannot fully reflect the underlying social processes involved in the expected changes to the mobility system. These uncertainties in deriving transport policy effects are thus confronted with routines of (transport) policy monitoring, legal requirements and administrative practices. Under these circumstances, acting in favour of transformative innovations is not only riskier for public transport professionals than pursuing incremental innovation approaches, but the appropriate incentive and reward structures are also generally lacking.

Technically-oriented experimentation in public transport

Notwithstanding the limited knowledge about the potential future role(s) of automated driving, the technology is well-recognised as an important issue within public transport, likely affecting public transport professionals. Automated driving technology is being tested in countless projects by public transport operators (often together with industry or research actors), with a strong focus on the technical requirements of “driverless public transport” [58]. Mostly, these projects look at the vehicles’ technical requirements and the feasibility of operating in traffic, and less at the meaningfulness of the new service for passengers. Since the operational routes and areas can typically be well-defined (e.g. certain lines or neighbourhoods), SAE International’s level 5 (full driving automation, most complex technological requirements) is not generally necessary, and level 4 (high driving automation) is used for the trials (cf. [59]). Despite the driverless operation being limited to specified areas, already level 4 is of great interest for public transport applications.

A second field of experimentation does not yet relate specifically to automated driving, but also prepares its technological basis for future mobility services. This involves new, flexible forms of public transport (beyond conventional dial-a-bus services etc.), which are also being tested in numerous projects, and in some cases have already been installed as a permanent service. These projects also point to established operators’ increasing openness to new mobility services. For passengers, digital solutions bring more convenient and flexible booking options, mostly via smartphone apps (which accounts for the increase in attractiveness and thus the great additional potential seen, compared to conventional on-demand transport). For public transport professionals, however, this also requires new or greatly intensified cooperation, for example considering specialised ICT service providers for vehicle dispatching software. These forms of cooperation add to the already complex network of actors established around conventional public transport services (e.g. data provision regarding timetable information and route planning).

Two examples from the greater Stuttgart area illustrate this new kind of cooperation: In the Schorndorf real-world laboratory, the city and a medium-sized bus company worked together with several research partners and the local population to optimise routing and the virtual bus stop network [60]. The on-demand service 'SSB Flex', run by Stuttgarter Straßenbahnen AG (SSB), Stuttgart's public transport operator, used Moovel's platform for both dispatching and the user app. As a company, Moovel illustrates the dynamics of the sector: started as part of the Daimler Group, activities were merged with Daimler's competitor BMW from 2019. In 2020, Moovel's mobility platform business was taken over by Mobimeo (part of the Deutsche Bahn Group), while SSB switched to rival provider ViaVan for the operation of SSB Flex in 2021. While the two services (and similar ones) use conventional vehicles and drivers, they gain their economic attractiveness from the perspective of future automated operation. Automation is also expected to allow for service extensions (e.g. regarding population density or service hours) beyond current economic feasibility. Because of this link with potential future service concepts, public transport authorities are often directly involved in the latter projects.

Between a vision of the future and today's planning practice

At the industrial level, the VDV is strategically concerned with the possible disruptive effects of automated driving. For example, a comprehensive statement from 2020 covered regulatory issues, operational requirements and responsibilities, pilot operation, municipal control, data management and software, and keeper obligations [61]. Yet, despite the general awareness of the relevance of the topic, discussions on the occasion of sectoral events reveal the challenges in translating this insight into action. At a summit in 2021 ("VDV Digitalgipfel"), a comparison was made with digital ticketing (and the passenger benefits associated with it), with many years between first general discussions and actual implementation, building on a multitude of small steps and complex legal arrangements. Concerning automated driving, the industry can only hope that things will be different, but concerns are voiced that it may not be able to keep pace with technological development. Keeping this in mind, a multitude of questions will arise anew in the sector, despite its many well-established routines. For example, experiences from conventional modes of public transport concerning subjective safety may not be valid for automated shuttles. The typical small to medium-sized bus companies, especially in rural areas, with their local identities and political support, do not appear to be well-equipped for entering automated driving technology—which may, as another example, affect current public tendering practices.

At the municipal level, automated driving is also recognised as an important issue. However, municipal representatives regularly voice how intangible the topic is for them and how many uncertainties it carries. Moreover, day-to-day planning processes are (or have to be) prioritised, leaving little room for dealing with strategic questions. This is exemplified by a recent publication of the German Road and Transportation Research Association [62], which discusses opportunities and risks briefly—but seems to lag far behind the current scientific debate.

Our observation is supported by a recent survey among public transport professionals in the German federal state of Saxony-Anhalt, where respondents questioned the technological readiness of automated shuttles and suitability for their requirements, despite a general interest in the technology [63]. This is also in line with international findings of significant uncertainties regarding automated driving technology, eventually prohibiting a systematic consideration of potential challenges by public transport professionals [64, 65]. To put this into perspective, such findings must be contrasted with the rather limited cases where public transport professionals proactively engage beyond technological experimentation with automated driving, for example the new forms of collaboration and planning (incl. tendering) for an automated shuttle service in an urban development area in the Stockholm region [66].

Regulatory issues for new forms of public transport supply

Regulatory issues are also being discussed by the VDV and other associations in the sector, especially in the context of an amendment of the German Passenger Transport Act. Its organisational framework is concerned with how, by restricting, enabling or promoting certain forms of service, public transport can be designed in a way that benefits sustainable mobility [67], linked to the federal states' respective laws. In contrast, the law on autonomous driving, which was passed in May 2021, only deals with operational issues, and not with the organisational integration into public transport and sustainable mobility, although the law does focus on public transport applications.

A number of further questions arising from automated driving have not yet been discussed in a recognisable way: With a view to standardised cost–benefit analyses, it could for example be asked how public transport investments building on automated driving solutions (beyond technology testing with separate funding) should be planned within the current regulatory framework which heavily relies on empirical reference values (cf. the findings on urban ropeways presented above). Again, similarities with digital ticketing become apparent, since investments in booking platforms, etc., likewise do not fit seamlessly into today's established financing mechanisms—despite the more advanced technological development.

Discussion

In the discussion, we want to explore what can be learned from comparing our observations regarding urban ropeways and automated driving in public transport, with a more general view towards transformation processes in a sustainable mobility transition. Which need for action does the disruptive potential of automated driving create, and what is the role of institutionalisation processes?

Institutionalisation challenges

From both of the perspectives presented, the thematic diversity of the various facets that join the technology and its development becomes clear. For urban ropeways, the challenges are clearly definable: The innovation seems to be just an incremental supplement to conventional public transport repertoires; yet, a lack of experience and the need for adaptation of planning instruments contribute to an implementation gap. In contrast, automated driving in public transport illustrates the dissonance between technological innovation and mobility transition discourses, as discussed in the Introduction: Beyond a focus on technological development, consideration of the necessary institutionalisation processes (in order to shape the transformation in a sustainability-oriented manner) remains diffuse and lags behind. This is striking, since only institutionalisation determines how technologies (and experimentation with them) ultimately become, or can become, innovations that modify the existing regime in one way or another, and thus become effective. Notably, the close link between transition and institutionalisation has been discussed for a wide range of socio-technical transition processes: For example, the interplay of agency and institutionalisation processes has been analysed in the water sector [27, 68], a specific attempt to change regulations has been analysed in the Dutch taxi sector [69], and alternative institutional logics have been discussed regarding their role in endogenous regime change [70].

While the consideration of necessary institutionalisation steps may be left to an internal debate about suitable public transport solutions in the case of urban ropeways, it is much more critical in the case of automated driving. Its disruptive potential at the level of the mobility system clearly includes scenarios opposed to the requirements of sustainable mobility. Bringing automated driving in line with a sustainable mobility transition therefore requires synchronization efforts [26].

Contrasting both technologies with conventional public transport, Table 2 highlights the most important institutionalisation challenges. The comparison underscores the differences not only in magnitude, but also in the areas to be considered in the synchronization tasks.

Both urban ropeways and automated driving in public transport bring about specific institutionalisation challenges as an inherent element of their respective innovation processes. Considering urban ropeways, institutionalisation takes place essentially within the existing public transport regime. However, strategically using their potential to extend public transport more generally already requires targeted frameworks to facilitate this. On the other hand, more is at stake when considering automated driving (cf. 'heaven' or 'hell' debate). Yet, the main challenges do not lie in supporting (or not) the technology's disruptive potential per se, but in shaping the transformation process. Recalling the sustainability orientation of the mobility transition debate, this requires a well-founded normative compass, particularly on the selector side, in order to ensure that the disruption supports more sustainable mobility ("directionality", cf. [26]) and moves beyond alternative drivetrains and more efficient car traffic (cf. [12]).

The question remains whether the greater disruptive potential of automated driving (compared to the urban ropeway niche) and the need for action are perceived by public transport professionals, as well as policymakers and regulators, in such a way that they engage in the debate early on and proactively adapt the framework conditions of current professional practices. The current rise of climate policy may be a supportive trigger in this regard (cf. [28]); however, even if the need for action is more widely recognised, goal orientation remains a challenge because it requires a change of perspective from technology to mobility by a multitude of actors. Up to now, formal institutionalisation of a mobility transition orientation has not become visible in Germany, for example considering the friction between cycling promotion and car-orientation which is engraved into road traffic regulation. There is thus a

Table 2 Comparison of transformative potential and institutionalisation challenges

	Technological challenges	Transformative potential	Challenges for a mobility transition
		Challenges for public transport professionals	
Conventional public transport	Established technology; in some places reaching capacity limits	Incremental (service extension)	Insufficient for mobility transition under current (e.g. financial) framework
		Established planning instruments & extensive experience; limited implementation capacities	
Urban ropeways	Adjusting established technology to a new field of application	Widening public transport portfolio, applications where conventional options are not viable	Filling knowledge gaps & adjusting framework details – within public transport regime
		General mechanisms & criteria applicable; lacking experience	
Automated driving in public transport	Early phase of technological development, many unsolved issues	Disruptive potential, linked with major uncertainty regarding its orientation	Ensuring ‘heaven’ & prohibiting ‘hell’ – across socio-technical mobility system
		New instruments, competences & responsibilities required to ensure integrated system	
		↓	
		Strategic reconsideration of socio-technical institutions (in prospect of automated driving) may simultaneously facilitate incorporation of mode-consistent public transport innovations & conventional service extensions	

risk of missing the moment when important questions about the integration of automated driving into the mobility system need to be answered (and even asked in the first place). While there are early signs of a rising debate, its comprehensiveness and persistence are difficult to assess. In particular, it is not yet clear to what extent the approaches to regulating new types of public transport services will remain tied to an internal public transport perspective, or if interactions in the mobility system (also with regard to the parallel development of individual mobility tools) will be included consistently. If adhering to current structures, this may inhibit important elements of institutionalisation, such as adapting professional practices in evaluating transport policy measures across transport modes.

In order to conceptualize this challenge, we first refer to an approach developed with a view towards the enactor side of innovation processes: Smith and Raven [20] distinguished a “fit-and-conform” strategy (developing one’s own technology in such a way that it fits smoothly into the existing regime) and a “stretch-and-transform” strategy (actively influencing the regime framework in order to help one’s own niche achieve a breakthrough) in supporting niche innovations. Both strategies are also visible in the field of digitalisation and automation of mobility [71]. We suggest that a similar distinction can be made for selector strategies: A “directional decision-making” strategy would consistently consider interactions in the mobility system, including proactive support for the institutionalisation of new professional practices. This corresponds to a “stretch-and-transform” strategy by enactors. It also includes “directionality” [26] as a second point of reference in a twofold way: First, it is itself guided by a strong normative orientation towards

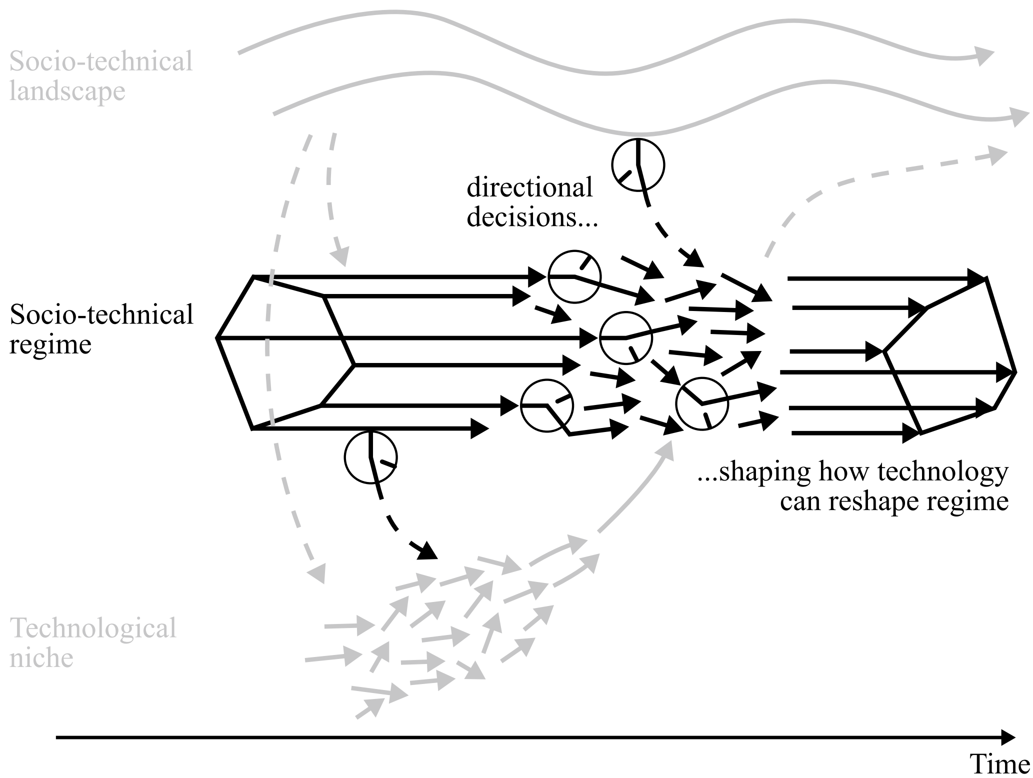

Fig. 1 Directional decision-making in the socio-technical regime (own adaptation, based on [19]). (© Springer Nature, originally published in [73], reproduced with permission from Springer Nature, not covered by CC-BY license)

sustainable mobility; second, it provides orientation and shapes how technology may further transform the regime (Fig. 1). In contrast, a "passive enabling of technologies" strategy would correspond to a "fit-and-conform" strategy on the enactor side, leaving the fundamental structures of the existing regime untouched.

Lyons and Davidson [72] suggested a similar distinction between policy modes following a "regime-compliant pathway" or a "regime-testing pathway", emphasising the better suitability of the latter for dealing with the uncertainties inherent in transformative processes. The importance of strategic agenda-setting is also one of the conclusions drawn from the Swedish case mentioned above [66]. In view of the challenges of a sustainable mobility transition, selectors' decision-making responsibility should be appropriately satisfied (cf. [25])—implying a "directional decision-making" strategy—in order to move ahead of an otherwise threatening technological disruption that lacks normative orientation. The proactive adaptation of professional practices as an independent policy component would thus become part of shaping disruption and form one element of an actual mobility policy (instead of current transport policy) (cf. [18]).

Limits of the perspective towards (local) public transport actors

The examination of institutionalisation processes, especially with regard to professional practices at the local level, provides valuable insights regarding the challenges for a sustainable mobility transition that are associated with them. However, it is undisputed that there are various other challenges or obstacles (as well as drivers) affecting a sustainable mobility transition. The analysis presented in this article does not allow for a definitive assessment of all relationships between those factors. Our perspective towards public transport professionals provides only a limited piece of the puzzle, precisely because transport policy is a socially controversial topic (cf. [34]). The same, however, holds true for any narrow analysis, for example focussing on only customer preferences, user needs, or regulation. Particularly for automated driving in public transport, an analysis focussing on the interdependencies of the various perspectives would thus be worthwhile.

One important area to be considered is how professional practices are embedded in a wider policy context, including legislative processes, (partially lacking) political will, increasing political polarisation (affecting transport policy), or challenges engraved into federalism and the related distribution of regulatory responsibilities (cf. [35]). For example, urban ropeway investments in Germany have become eligible for public funding following a parliamentary initiative, but have not been systematically reflected by the related cost–benefit analysis guidance until most recently. In turn, the debate on automated driving is deeply interwoven with the debate on the future of automobility more generally, which, in addition to transport policy, is deeply interrelated with industrial policy, particularly in Germany. From a theoretical perspective, this also means that there is no clear dichotomy between the two strategies discussed above: passivity from a mobility angle may for example be linked with clear directionality driven by a motivation to protect the automotive industry. In practice, this comes with obvious trade-offs and divergent interests, and for the authors a consistent national diffusion strategy is not yet visible. In any case, there is reason to suspect that a reliance on selective processes purely based on competitive processes would be extremely critical from a sustainable mobility transition standpoint.

In addition to sectoral policies, different policy levels also play a role. Discrepancies between a strategic orientation towards sustainable mobility and the actual regulatory framework conditions set at a supranational or national level may result in significant obstacles for local policy actors and public transport professionals who want to implement certain measures. It is therefore worth asking where a lack of instruments may be matched by a lack of ambition in the policy system, addressing power relations between actors (cf. [74]).

Conclusions

Our analysis shows the importance of public transport professionals in the mobility system. They are the ones who actually implement the building blocks of a sustainable mobility transition at a local level. However, the work of public transport professionals is clearly guided by frameworks at the socio-technical regime level, shaping professional practices and the development of policy instruments. Moreover, the institutionalisation processes (or sometimes their absence) at the regime level closely relate to developments in the wider political landscape. In this article, the insights on urban ropeways and automated driving serve as examples, but many other topics in transport and mobility bring similar challenges, including cycling policy, the promotion of car sharing, or negotiating between procurement laws and a passenger-oriented provision of public transport services.

Beyond the detailed challenges linked with individual technologies or planning tools, a sustainable mobility transition is thus primarily a matter of comprehensive synchronisation at a strategic level (cf. [26]). In this regard, Hausknost and Haas [25] call for new institutions "for transformative innovation [...] to improve the capacities of complex societies to make binding decisions in politically contested fields" (p. 1). Our contribution shows the concrete need to go beyond the visionary level of policy goals and to consider the routines and practices of transport professionals in this synchronization process.

Hence, further research is needed at the triple interface of technological developments, the mobility transition debate, and professional practices across the mobility system. Future research addressing transition governance approaches and technological innovation should more explicitly consider the role of professional practices in innovation processes, taking into account wider political processes and power relations, as well. Particular attention should be paid to further developing, testing, and refining tools and processes in support of consistent sustainability-oriented institutional learning and directional decision-making.

Abbreviations

ICT	Information and communication technology
VDV	Association of German Transport Companies [Verband Deutscher Verkehrsunternehmen]
SSB	Stuttgarter Straßenbahnen AG

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Author contributions

MR was the lead author of the manuscript. The analytical approach was developed jointly by MR and TF. Sects. "Methods—urban ropeways" and "Urban ropeways: uncertainties regarding internal public transport routines" on urban ropeways were written by MR. Sections "Methods—automated driving" and "Automated driving: moving beyond a technology perspective" on automated driving were written jointly by TF and MR. The discussion and the conclusions were written by MR with contributions by TF. Both authors read and approved the final manuscript.

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Availability of data and materials

The transcripts from the expert workshops (cf. Sect. "Methods—urban ropeways") are not publicly available due to privacy reasons (transcripts contain internal information of the participants' institutions). Not applicable for Sect. "Automated driving: moving beyond a technology perspective".

Declarations

Ethics approval and consent to participate
Not applicable. No medical research was conducted. Participants of the expert workshops (cf. Sect. "Methods—urban ropeways") participated in their roles as representatives of the respective institutions and no ethical approval was required.

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