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RESEARCH ARTICLE

An approach for prioritizing types of TA-knowledge for long-term governance of mobility

Jens Schippl[*,1]

Abstract • Several new technologies are expected to unfold their transformative potential in the mobility sector in the coming decades. Examples include electric vehicles (EVs), automated vehicles (AVs), or blockchain technology. Long-term governance must take these innovations into account, supported by knowledge from technology assessment (TA). A transparent and comprehensible choice of TA methods is of utmost importance, especially when it comes to long-term strategic decisions that may influence the direction of socio-technical transitions. This article proposes a typology of innovations in the mobility sector that helps justify and legitimize the prioritization of TA knowledge and methods.

Ein Ansatz zur Priorisierung von TA-Wissenstypen für Long-Term-Governance im Mobilitätsektor

Zusammenfassung • *In den kommenden Jahrzehnten werden voraussichtlich einige neue Technologien ihr transformatives Potenzial im Mobilitätssektor entfalten. Beispiele hierfür sind Elektrofahrzeuge, automatisierte Fahrzeuge oder die Blockchain-Technologie. Eine 'Long-Term-Governance' muss diese Innovationen einbeziehen, unterstützt durch Erkenntnisse aus der Technikfolgenabschätzung (TA). Insbesondere bei langfristigen strategischen Entscheidungen, die sich auf die Entwicklungsrichtung soziotechnischer Transformationen auswirken können, ist eine transparente und nachvollziehbare Auswahl von TA-Methoden von größter Bedeutung. In diesem Artikel wird eine Typologie von Innovationen im Mobilitätssektor vorgeschlagen, die dabei hilft, eine entsprechende Priorisierung von TA-Wissen und -Methoden zu begründen und zu legitimieren.*

* *Corresponding author: jens.schippl@kit.edu*

[1] *Institute for Technology Assessment and Systems Analysis, Karlsruhe Institute of Technology, Karlsruhe, DE*

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Introduction

The transition of large-scale infrastructures, such as energy and mobility, is widely acknowledged as unavoidable to achieve sustainable developments. Such transitions are long-term policy challenges, since they "last at least one human generation, exhibit deep uncertainty exacerbated by the depth of time, and engender public goods aspects both at the stage of problem generation as well as at the response stage" (Sprinz 2009, p. 2). Long-term governance (LTG) is about long-term strategic orientation towards desirable directions. A sustainable transformation of the mobility sector, with its infrastructures and routines that can only be changed very slowly, is a typical case of LTG. In Germany, however, the mobility sector has not been successful in reducing energy consumption, emissions and waste of space (Horn et al. 2018). Technological change is an important factor in improving this situation, although not the only one. Many new technologies with significant transformative potential are already available or are very likely to become effective in the mobility sector. Examples are electric vehicles (EV), automated vehicles (AV), personal aircrafts and blockchain technology (Schippl 2024).

All of these technologies could have a major impact and therefore need to be considered in the long-term governance of a sustainable transition in the mobility sector. This can be associated with challenges and uncertainties, not only because of the long time periods involved, but also because of the high level of complexity inherent in socio-technical systems such as mobility (Czada 2016). It cannot be taken for granted that innovations will contribute to a desirable direction of development in the long run. In some cases, simply upscaling new approaches may not be sufficient to avoid undesirable path dependencies. Weber and Rohracher (2012) refer to 'directionality failures' when the development of new technologies is not aligned with socially desirable visions, such as sustainability, and ultimately contributes to suboptimal and inefficient conditions. The urban planning objective of the car-friendly city of the 1950s and 1960s is often cited as an example of how new technologies can lead to suboptimal, long-lasting path dependencies that cannot be corrected without considerable effort (Holden et al. 2019). In addition to this uncertainty about the future development of innovations and their consequences, a second dimension of uncertainty may become relevant. If there are controversial views about what is and what is not a desirable development path, there may also be normative uncertainty (Czada 2016). Such normative heterogeneity often manifests itself in the mobility sector when it comes to the meaning of the car. For some, the car is an indispensable means of organizing daily life that should be available to citizens (almost) at any time and in any place (Urry 2004). For others, the negative impacts of private automobility, such as emissions or land use, represent an unacceptable reduction in the quality of life. According to these perspectives, mobility based on private cars should be restricted and replaced by more sustainable alternatives (Drexler et al. 2022).

Interdisciplinary research traditions, such as Technology Assessment (TA) and related approaches, have developed a broad range of concepts and method to address these challenges and uncertainties, and to provide knowledge to support LTG (Grunwald 2018). These include both mainly quantitative, model-based approaches and explicitly qualitative approaches such as focus groups or discourse analysis. Transparency and comprehensibility are core principles of TA processes. Accordingly, it is of utmost importance that the choice of methods used is also transparently justified and legitimized, which is particularly important when supporting decisions of long-term strategic relevance.

This paper shows why different types of new technologies require specific TA knowledge and methodologies in order to exploit the potential of emerging technologies in terms of sustainable long-term development and to avoid undesirable developments. To this end, a typology of (emerging) technologies in the mobility sector is proposed, which considers the two dimensions mentioned above: the potential applications of new technologies from a more consequentialist perspective, and their normative contextual conditions. The typology is shown to support transparent and systematic prioritization in the selection of appropriate TA methods, using automated and electric vehicles as well as blockchain technology as prototypical examples of what are introduced as 'modes of directionality'. It becomes clear that qualitative, interpretive research approaches deserve more attention, especially in cases of normative uncertainty.

Conceptual background

Directionality and different categories of knowledge

The typology is based on concepts from transition research and TA. A core tenet of transition research is the conceptualization of infrastructures as socio-technical systems, which are shaped by the co-evolutionary interplay of technical and non-technical factors. The regime is usually understood as the semi-stable institutional core of a socio-technical system and is strongly influenced by so-called normative and cognitive institutions (Fuenfschilling and Truffer 2014), which are often not directly visible and empirically accessible (Geels 2011). These are, for example, taken-for-granted assumptions, routines, attitudes, expectations or broader social values (Rip and Kemp 1998). Together with 'visible' elements, such as technologies, actors, and regulations, this institutional regime configuration co-determines the future development direction of a socio-technical system. A socio-technical regime does not necessarily have to resemble a homogeneous institutional configuration, but can be characterized by different, sometimes competing ideas about what is possible and what is a desirable direction of change. For example, in the mobility system we can observe that there are very different views on whether the private car should retain or lose its dominant position in future mobility.

The concept of directionality is used to indicate that transformative change in a system or sector has a specific direction, while other developmental directions are in principle also possible (Stirling 2009; Weber and Rohracher 2012). In the literature on innovation and socio-technical transitions, the concept is usually linked to the idea of promoting not just any innovation trajectory, but those that contribute to a desirable direction of transformative change and help mitigate societal challenges (Parks 2022). It is repeatedly emphasized that in some cases, especially in the case of wicked problems, such shared visions of desirable futures cannot be achieved without challenges and conflicts (Schlaile et al. 2017; Wanzenböck et al. 2020). As already mentioned, different ideas can exist in a regime about which direction of change is desirable. While the term directionality on the one hand refers to the direction of an entire sector, on the other hand, directionality can imply different development conditions for different technologies. In this sense, Yap and Truffer (2019, p. 1032) understand directionality from the perspective of innovations as being "tightly associated with the specific form of the selection environment to which the technology is exposed". Drawing on this understanding, in this paper, I want to highlight that different innovations can be categorized in different ways with respect to directionality (Schippl 2024). Different modes of directionality are distinguished on the basis of two dimensions: The first dimension refers to the characteristics of the technology itself, particularly its possible range of applications. The second dimension refers to the specific selection environment of the technology, primarily to its normative contextual conditions, such as the homogeneity or heterogeneity of societal expecta-

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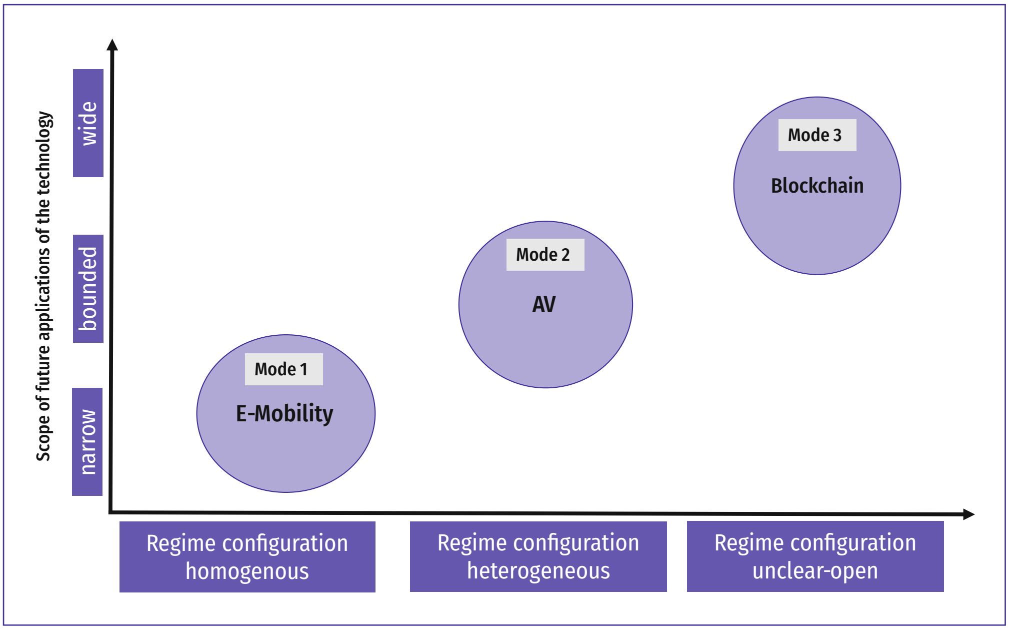

Fig. 1 Different modes of directionality. *Source: author's own compilation based on Schippl 2024*

tions, preferences or attitudes towards the potential applications of the new technology.

In the context of TA, the typology refers to the classification of five different epistemological insights or types of knowledge introduced by Armin Grunwald (2020). The governance of innovation and transition processes requires knowledge of different epistemic character (Grunwald 2018). Obviously, there is a need for what is referred to here as '*empirical system knowledge*' in order to achieve a good understanding of the conditions and causal chains in the current system. However, not all of the relevant factors and interrelationships are directly 'visible' and empirically accessible (Schippl 2024). For example, research into the configurations and dynamics of cognitive-normative institutions requires more interpretative, hermeneutic approaches (*hermeneutic knowledge*). Obviously, there is also a need to understand plausible future development paths of an innovation and potential consequences that lie in the future and therefore are again not empirically accessible (*future knowledge*). In addition, knowledge of the prevailing target systems (e.g. phase-out of internal combustion engines by 2035) and the underlying reasoning patterns is required. This category of *normative knowledge* aims primarily at 'direct' orientation in the sense of identifying desirable or undesirable directions of development with more or less specific target settings. The fifth category that can be distinguished is *instrumental knowledge*, which is primarily concerned with the concrete and practical implementation of measures, such as technical standards or legal rules. As will be shown, different types of innovation place different demands on the knowledge categories from which specific strategies or tactics for (long-term) governance can be derived.

Different modes of directionality

Figure 1 depicts different modes of directionality based on the abovementioned two dimensions. The y-axis shows the scope of possible future applications of the technology in terms of the primary function of the socio-technical system, the provision of mobility. For some technologies this range is rather narrow, while others have a wide range since they can be used for different purposes. The x-axis indicates whether the technology meets with a normatively more heterogenous or a more homogenous regime configuration in the selection environment. As will be shown below, the normative homogeneity of the mobility regime is significantly higher for EV than for AV. On the basis of these two dimensions, the following three ideal modes of directionality can be identified (Grunwald 2014; Schippl 2024).

Mode 1 The range of future applications of the technology is narrow in relation to the primary function of the socio-technical system. It is clear what the technology is used for. At the same time, there is a broad consensus in politics and society that the technology is desirable in its current or a further developed form, and this is associated with clear goals. What is needed is more systems knowledge, future knowledge and instrumental knowledge to further improve the technology and accelerate its implementation.

Mode 2 Here the technology can develop in very different directions with respect to the primary function of the socio-technical system. However, the scope of possible future applications can be considered as bounded, since there is already enough system knowledge and future knowledge to roughly understand how the technology could develop and what the consequences would be.

	Mode-1-directionality	Mode-2-directionality	Mode-3-directionality
Main challenges for LTG	Fast market penetration to ensure decarbonization of car mobility Ensure low-carbon production of electricity and cars (batteries)	Develop a longer-term vision or strategy for mobility Understand the current societal preconditions for the development of a vision	Understand emerging socio-technical configurations with their impacts Understand related expectations or concerns of societal actors
Governance strategies	Push for implementation (tactics)	Push for a guiding vision (strategies)	Improve knowledge base for developing strategies
Timing	Accelerate path-dependencies	Prevent unsustainable path-dependencies	Consider pace of change and risks for non-sustainable path-dependencies
Knowledge mainly needed	Emp. systems knowledge Future knowledge Instrumental knowledge	Normative knowledge Hermeneutic knowledge	Future knowledge Hermeneutic knowledge
Methods (examples)	Surveys to understand market potentials Modelling for planning of charging infrastructure Research on low-carbon production of components	Qualitative research to better understanding backgrounds to normative variations Participative development of guiding visions and objectives Rough quantifications as a basis for valuations	Structurally open methods, e.g. Foresight-workshops, Delphi-studies to understand future options Qualitative research to understand ideas and concerns, including their backgrounds

Table 1 Directionality and priorities for long-term governance towards sustainable mobility. *Source: author's own compilation*

At the same time, the technology encounters an institutional regime configuration that offers no clear guidance on the direction in which the technology should develop. The corresponding selection environment is normatively heterogeneous and characterized by competing expectations and interests. In particular, normative and hermeneutic knowledge is needed to better understand how and under what conditions effective guiding visions or target systems can be realized.

Mode 3 In this case, the possible scope of the future application is wide and can hardly be limited. There is a lack of future knowledge. The future development options of an innovation and its consequences are poorly understood, so that there is no clear basis for normative orientation. Further, it is important to better understand existing or emerging ideas, fears and expectations regarding possible application contexts of the innovation and their backgrounds (Grunwald 2014). This requires interpretative, hermeneutic approaches.

Examples from the field of mobility

Although the three modes of directionality are ideal types that do not necessarily exist in their pure form in reality, different innovations in the mobility sector can be assigned to these three modes (figure 1). The categorization helps to clarify why different technologies require certain research priorities and governance strategies in the short and long term (see table 1). The examples relate to the respective situation in Germany.

Electric vehicles as an example for mode-1-directionality

In the case of mode-1-directionality, the respective regime configuration is rather homogeneous and the application of the new technology is quite obvious. This is the case, at least so far, for battery electric propulsion in private cars, which will serve as an example here. The scope of future applications is rather narrow, at least when it comes to car-based mobility: An internal combustion engine (ICE) is replaced by electric propulsion, the car remains a car. The question is how to ensure a rapid uptake of electric cars, while car-based mobility as such is not affected by the new technology.

Looking at the relevant institutional configurations in the selection environment (x-axis in figure 1), it can be seen that there are very clear objectives for electric mobility. In the political arena in Germany (and in the EU; e.g. the ban for ICE in 2035 - even if the date may be postponed), e-mobility is predominantly seen as a desirable development and is supported by corresponding regulations. The German government has set a political target of 15 million electric cars in the car fleet by 2030. Yet, there are challenges and reasons for concerns which will be of relevance from a long-term perspective. The following issues are among the most relevant:

- Negative effects arising from battery production and the extraction of raw materials;
- performance (range, charging times) still not comparable with ICE;
- high cost and equity issues: EVs are relatively expensive and only affordable for higher-income groups;
- slow rollout of a charging infrastructure;
- increase in electricity demand.

However, technical progress and regulations can solve these issues. For this, future knowledge, system knowledge and instrumental knowledge are primarily crucial. Future knowledge can be generated, for example, through model-based exploratory scenarios to anticipate future renewable electricity demand and charging point locations. System knowledge includes research on new batterie materials or on understanding of the variability of charging patterns, for example based on user surveys, in order to calculate the impact of these variations on the energy system. Instrumental knowledge includes developing regulations or incentives for the installation of charging stations, or the adjust-

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ment of charging behavior to the availability of electricity from renewable sources.

Automated vehicles as an example for mode-2-directionality

AV may exemplify mode-2. Automated driving has great transformative potential for the future of mobility and society (Cohen and Cavoli 2019). AVs can be used in conventional cars to relieve drivers and enable new services like driverless robo-taxis or shuttles. Various long-term path-dependencies are possible (Schippl et al. 2022). It is currently uncertain whether AVs will create a sustainable, climate-friendly mobility system by providing flexible, accessible and affordable public transport options, thereby significantly reducing the use and ownership of private cars, or whether they will make private cars more attractive, ultimately leading to increased emissions, land consumption and urban sprawl (Lyons 2022). Nevertheless, AVs must adapt to existing infrastructures and mobility needs (Fraedrich et al. 2015), which have co-evolved over decades and cannot easily be changed. The scope for future development is therefore bounded. Despite AV's potential to change the mobility system in different ways, plausible future developments are fairly well understood (Schippl 2024). From a long-term governance perspective, the main challenge is the prevailing normative heterogeneity in the mobility sector, in particular when it comes to the role and relevance of the private car. To counter unsustainable path dependencies, clear visions and objectives for the mobility system as a whole are needed, but at present these are at best fragmented and controversial. Many observers point to this lack of strategic clarity and direction (Horn et al. 2018; OECD 2018). Drexler et al. (2022) conclude that there is no common understanding among actors in the German mobility sector of the problems and solutions for promoting a mobility transition. As a result, there are no clear overarching goals to guide the development of AV. AV interact with a selection environment that is open to both sustainable and unsustainable path dependencies (Schippl 2024).

The German government recently published a strategy for autonomous driving on the roads (BMDV 2024), focusing on promoting AV in public transport as key driver for AV development. This supports sustainable path-dependency. However, a robust long-term perspective requires linking the strategy to a broader vision of future mobility in Germany, which would provide a target system or at least a coherent orientation framework for long-term governance. Austria provides an example of how such a lack of normative knowledge can be addressed: A few years ago, a mobility master plan was adopted with a clear vision and concrete targets for the model split in 2040 (BMK 2021). Furthermore, in the case of mode-2-directionality, hermeneutic knowledge is needed, especially to better understand the underlying reasons for normative heterogeneity. Again, there are studies that could provide starting points for future research. Groth et al. (2023), for example, examined how everyday mobility is portrayed in popular crime series and found that the current controversy about the future role of the car is also reflected in the media, with car-centered storylines dominating. Mögele and Rau (2020) show that a culturally sensitive approach can reveal differences in mobility culture that have an impact on the development of sustainable mobility.

Hermeneutic knowledge is needed to understand normative heterogeneity

Blockchain as an example for mode-3-directionality

A current example of mode-3 directionality in mobility is blockchain technology. The technology is evolving, with many applications being discussed and tested in various sectors. Some align with current mobility trends like mobility-on-demand, autonomous driving, and electrification (Karger et al. 2021). Blockchain could lead to significant changes in the mobility system (Gösele and Sandner 2019) such as simplifying carpooling and private vehicle rentals, increasing efficiency, reducing cost, and mitigating market power concentration. However, blockchain aims to replace controlling intermediaries such as commercial institutions with decentralized peer-to-peer networks. In the mobility sector, it has to be considered whether a self-regulating system could develop that evades public planning and control or is possibly controlled by a market-dominating tech company. Blockchain's immutable recording of transactions can pose privacy problems and data protection issues. Potential developments and their effects are not yet well understood.

In the political arena in Germany e-mobility is predominantly seen as a desirable development and is supported by corresponding regulations.

To better understand the range of possible developments, future knowledge is needed. It is advisable to use structurally open methods (Schippl and Fleischer 2012) such as brainstorming, open space, world café, etc., which enable a deliberate generation of new ideas. Furthermore, it is important to better understand the ideas, fears and expectations regarding the possible application contexts of the innovation and their background (Grunwald 2014). This requires interpretive, hermeneutic approaches. Such expectations have a direct or at least indirect impact on the design of the technology – otherwise it would be a case of technological determinism. It is by means of such methodological approaches that the basis for normative evaluations can be created; the innovation (or specific fields of application) may then become mode-2 or mode-1 directionality.

Discussion and outlook

The present approach and its underlying line of reasoning aim at a better understanding of the specific TA-challenges for LTG in relation to new technologies. In the broader context of TA and social science, it should support both researchers and funding organizations in selecting and legitimizing research priorities and methodologies. In many cases, the focus of research projects related to new technologies is dominated by consequentialist, modelling-based perspective on future developments and their consequences. This is necessary but not sufficient. Even if the consequences and impacts of a technology are well understood, the problem with mode-2-directionality is that there are very different views on the extent to which these effects are desirable or not.

Particularly in cases of mode-2- and mode-3-directionality, qualitative approaches are needed to help develop hermeneutic and normative knowledge. Nevertheless, it should be emphasized that the call for greater attention to normative and hermeneutic knowledge does not mean that other types of knowledge are negligible or irrelevant. For example, instrumental knowledge on how to organize and regulate AV-based mobility services has recently been a central issue for further deployment of AV in Germany. However, from the perspective of LTG towards a sustainable transition, a robust normative framework is needed. Only by establishing more or less clear targets can LTG become effective and go beyond short-term problem-solving approaches. Such normative orientation may be more difficult to achieve than technical progress, especially in the area of mobility.

Further research should look at other innovations in the field of mobility and discuss how they fit into the three modes, or whether additional modes or variants of the three modes can be observed. Candidates could be personal air vehicles, hyperloop systems or underground logistics systems such as CargoCap. Particularly with regard to LTG, another important question for further research would be whether and for what reasons technologies switch from one mode to another over longer periods of time. The proposed approach could also be applied to other sectors. An obvious candidate is the energy system, where the transition has been quite successful so far, at least if the steadily growing share of renewable energy in electricity generation is considered. In the energy system, there is a fairly clear and still widely recognized system of targets to promote the integration of renewables. However, it would be worth examining the extent to which technologies such as wind, photovoltaic or geothermal energy can be assigned to specific modes of directionality.

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JENS SCHIPPL

is senior researcher and works in the research group 'Mobility futures' at the Institute for Technology Assessment and Systems Analysis (ITAS), Karlsruhe Institute of Technology (KIT) since 2006. His research is focused on socio-technical processes of change, foresight and technology assessment in the mobility sector with particular interest in the development of automated driving and its interrelations with path-dependencies in the mobility system.