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Decentering technology in technology assessment: prospects for socio-technical transitions in electric mobility in Germany

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ABSTRACT

Sustainability transitions of sectors like energy, transport or water have become explicit goals of national policy programs in several parts of the world. The governance of associated innovation and transformation processes requires an integrated assessment on how new and seemingly superior technologies will interact with manifold societal, economic, industrial and political contexts. Failing to do so is likely to quickly undermine political support for these ambitious and long term projects. Part of the program of technology assessment is to anticipate the impacts of new technologies on society and the environment. However, in order to address the challenge of sustainability transitions, institutional dynamics have not been considered explicitly enough in existing approaches. We elaborate a methodological proposal on how to analyze the interaction between technological and institutional developments in specific technology fields. We identify potential future variations of core institutional structures of a socio-technical regime, construct matching regime constellations, and elaborate on interactions with technological design alternatives. The framework will be applied to recent developments in the field of electric mobility in the context of the German *Energiewende*. The results provide some fresh perspectives for academics and policy makers on how to better consider interactive dynamics in socio-technical systems.

1. Introduction: assessing transitions in the making

The need for fundamental transformations of economic sectors towards more sustainable future states (so called sustainability transitions) has been voiced repeatedly over the last decade worldwide (Stern, 2007). The German *Energiewende* (energy transition) is currently one of the most ambitious national policy programs to respond to these challenges. These initiatives focus strongly on the development of more sustainable technologies. Actual transitions however require much more: new value chains will have to be established, institutional arrangements will have to be aligned to the new sector structures, business models of utilities and use patterns of consumers will have to be developed etc. What is at stake is not only the scaling up of new technologies but the reconfiguration of entire socio-technical systems. For policy makers, the associated dynamics represent no small challenge: it means that they have to be prepared for surprises, disruptive changes, and that outcomes of political interventions will be riddled with unintended consequences (Hoppmann et al., 2014). Transitions furthermore represent very difficult cases for public policy as they need a long-term engagement, including the anticipation of different possible courses of technology development in its interaction with institutional and political change (Voss et al., 2009). A scientific approach that aims at giving orientation to such complex cases for public policy in technology driven domains is technology assessment (TA).

Actually TA is a field of distinct, but nonetheless closely intertwined, movements in science as well as in science and technology policy. Historically, the roots of TA can be traced back to institutional changes in Western countries after WWII when comprehensive national policies on scientific research as well as on support of science and diffusion of certain technologies were introduced for the first time. The foundations of modern science and technology policy were laid during that period, leading to a much deeper involvement of governmental actors in science and technology development. This changing role of governments also led to new responsibilities. In the light of growing public concern about the implications of the development and use of new technologies during the mid-Sixties, policymakers in parliaments started investigations into the unintended and previously unanticipated implications of new technologies. They also (re-)introduced the previously neglected analysis and consideration of non-technical dimensions in the science and technology decision-making process and

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installed institutions specifically aiming at advising policymakers about scientific developments and related policies as well as its broader societal implications, thus establishing a form of TA today being considered as the "classic" TA.

Practical experiences with the application of this concept as well as substantial scientific and political critique of its limitations have led to a diversification of the TA landscape, not least by developing and applying new forms of TA beyond the 'classic' parliamentary TA model. During the Eighties, actors outside policymaking started working towards a broader foundation of TA as a program "to reduce the human costs of trial and error learning in society's handling of new technologies, and to do so by anticipating potential impacts and feeding these insights back into decision making, and into actors' strategies." (Schot and Rip, 1997). In a way, TA became an umbrella term for a broader social-intellectual movement, rooted in academia as well as in politics, aiming at anticipating impacts of technological change on society and on developing instruments to govern these interactions. Since it is required to investigate the combination of ecological, social and economic conditions, to present "digestable" assessment for decision making (Bechmann et al., 1997), it has to pursue a transdisciplinary approach, which at the same time has to be interdisciplinary and integrative, needs to produce additional knowledge that is not available from disciplinary research, and has to consider that this knowledge must be processed, organized and presented in a way to be useful for its various purposes such as orientation, action or decision making (for further information see (Grunwald, 2010).

The case of sustainability transitions of large-scale infrastructure systems, however, still represents a hard case for TA approaches. The intricate dynamics of socio-technical systems can give rise to very complex development patterns including rebound effects, the accumulation of stranded investments, technological cul-de-sacs, and so on. A core challenge for TA is therefore to more explicitly accommodate for interactions between institutional dynamics and technological development. Other future-oriented approaches, such as Foresight or Future-Oriented Technology Analysis (FTA) have started to tackle this problem but often apply similar methods (see (Technology Futures Analysis Methods Working Group, 2004). The label FTA has actually been introduced by the European Commission as a common umbrella term for technology foresight, technology forecasting and technology assessment. Cagnin and Keenan (2008, 1) state that differences within these communities are often greater than differences between them. Rader and Porter (2008, 20) are giving examples for so-called "Foresight-activities", which are difficult to distinguish from activities labelled TA elsewhere. In the present paper, we will elaborate how institutional analysis can be introduced to the tradition of TA since we see a clear added value here. The results may then be translated to other policy oriented analyses for transformative technological change.

In order to propose a suitable approach in TA to deal with the complexities of major societal transformations, we draw on recent insights from the sustainability transitions literature (Markard et al., 2012). Transitions research has explicitly conceptualized how material and institutional characteristics of socio-technical systems mutually shape each other (Rip and Kemp, 1998). Over time spans of decades, these alignment processes typically lead to entrenched socio-technical configurations – so called socio-technical regimes – which, once established, may constitute high entry barriers for alternative technologies. The concept of a socio-technical regime enables to develop a systematic and transparent approach for dealing with institutional dynamics in TA. It allows to "decenter" technology in the analysis, of sorts. With this, we however don't want to swap institutional for technological determinism. Rather, we want to introduce an analysis of institutional dynamics in its own right and not only as an afterthought of preconceived technological variations.

The methodological framework starts from potential dynamics in the institutional core of a regime and interrogates how these structures could interact with emerging technological trajectories. Given the complexities that the joint dynamics of institutions and technologies entail, we propose a simplified, stepwise procedure: First we identify potentially disruptive institutional changes in a given socio-technical regime. These will be grouped into coherent future regime configurations, which then serve as a backcloth to assess technological development trends in the given sector, both in the field of incumbent technologies and for various design alternatives of a new technology. Finally, this procedure will enable to tackle a number of relevant questions for policy makers: which kinds of institutional changes (or scenarios) are implicitly presupposed by proponents of specific technological variants, which sort of institutional changes are most critical with regard to spurring sudden major shifts in transition dynamics and finally, what sort of societal developments should be carefully observed by policy makers or industry strategists aiming to support transitions?

The method will be applied to the case of electric mobility (elmob) in the context of the German Energiewende. Very ambitious policy goals were recently formulated by the German government. German transition policies have proven to be extremely effective over the past two decades, especially in the field of renewable energy (Lauber and Jacobsson, 2013). A wide variety of expectations about the potential benefits of Battery Electric Vehicles (BEV) have been formulated by German policy makers: e.g. environmental benefits, international competitiveness, new forms of mobility/car-use. However, success of this political program still seems far from certain. Market uptake can be described as lukewarm at best and it seems far from trivial to identify a dominant design for electric vehicles on which all actors would agree. On the other hand, we see a number of very noteworthy trends in the institutional context of automobility, which at least question the unfettered continuation of the automobile regime as we know it: a trend towards decreasing car ownership among young urban people, increasing public discourses about the consequences of global climate change, demographic shifts in activities and spending patterns all seem to point towards a weakening of the automobile as the dominant form of transport, at least in many larger urban agglomerations in Europe. We therefore want to investigate in how far new institutional developments could interact with various technological trajectories of electric mobility and in what regard this could influence a possible sustainability transition in personal mobility.

The paper is structured as follows: first, we elaborate key requirements of TA in the context of sustainability transitions, as well as, how the transitions literature could inform this task by specifying core institutional dimensions in socio-technical regimes. This leads to a methodological procedure to assess institutional dynamics, which interact with trajectories of alternative technological designs. This procedure will be applied in Section 3 to potential transformation processes in the automobility regime in Germany. Section 4 discusses the implications of this analysis for current technology trajectories in electric mobility. Section 5 concludes by sketching out an agenda for policy oriented technology studies in the context of the upcoming *Energiewende*.

2. Analyzing regime dynamics in technology assessment

Technology assessment encompasses a set of transdisciplinary research practices that contribute specific knowledge to the decision-making processes in science and technology policy and enhance relevant decision-making capabilities in society. This includes, but is not limited to, attempting to anticipate intended as well as unintended implications of technological change, informing policy makers and society at large about these developments and, if appropriate, to propose alternative courses of action to avoid or to mitigate potentially negative outcomes (Bechmann et al., 1997; Fleischer and Grunwald, 2008; Grunwald, 2010). It has proven to be a valuable addition to scientific advice and policy support in numerous cases over the last decades. Assessing intended transitions in key economic sectors (like the German Energiewende) and advising policymakers on them, however, still represents a major challenge for the established tools and methods of TA. The long term transformations of socio-technical systems will likely be influenced by many different social and technological developments and it is, as a consequence, impossible to reliably predict end states and their likely impacts on societal or natural contexts – this process is, at least currently, not subject to anticipatory governance.

In the following, we elaborate how TA could embrace institutional dynamics in their interaction with technology development. We propose to "decenter" technology from the analysis in order to better grasp socio-technical system dynamics. To develop a procedural proposal, we will first specify the need for a more explicit focus on institutional dynamics within TA applications and then formulate a methodological framework for assessing socio-technical system dynamics, while maintaining the core requirements of a qualified TA approach: evidence-based, systematic, transparent, comprehensive, applicable in prospective context, policy relevant (see(Decker et al., 2004)), i.e. it should be suitable for "embedding TA knowledge and orientations into the perspective of decision makers" (Grunwald, 2009, 1111).

2.1. Addressing socio-technical system dynamics in TA

For TA to be of societal relevance, its analyses are expected to show societal impact, even if this impact is difficult to measure since it is usually just one source of influence on multifaceted and iterative political decision making processes. One of its most important quality criteria is transparency in terms of methods and arguments. TA claims to be neutral and unbiased. However, already the design of any study usually is not completely free of normative settings (Grunwald, 2009). One of the key challenges for TA is to anticipate future developments of a technology to determine potential side-effects. TA had, however, early-on in its history acknowledged the impossibility of deterministic predictions of future technological states (Schippl and Fleischer, 2012). The literature is full of examples of failed predictions, which mostly tried to derive future conditions by extrapolating from historical trends. Especially the longer-term societal, political economic and technological context is impossible to predict (Grunwald, 2011). As a substitute for predictions, TA scholars propose to use participatory scenario construction processes, which synthesize the combined occurrence of key driving factors that impact the course of new technologies. These scenarios do not represent predictions about future situations but are rather a means to elicit expectations of key actors in a technological field (see also (Truffer et al., 2008)). Participants may be different kinds of experts or lay people depending on the aim of the study (Schippl, 2016). The procedure, however, has repeatedly been accused of lacking theoretical grounding about the underlying mechanisms and processes (or as expressed by (Eriksson and Weber, 2008, 487), being largely "impressionistic"). Scholars have therefore started to relate to a variety of conceptual frameworks for the identification of coupled socio-technical dynamics.

Technology and Innovation Studies, in turn have worked very thoroughly to understand the interplay between institutional and technology development: for instance, institutional context factors may be hindering new and potentially superior technologies from maturing, or historical head starts of specific configurations may prevent rivaling alternatives from gaining market shares (David, 1985). Also it has been shown convincingly in historical studies, how the successful introduction of radically new technologies has needed major system building efforts aligning infrastructure buildup, regulatory renovation, the learning of new user preferences and cultural changes (Hughes, 1987). Others have shown how interpretative flexibility on the side of early users influenced the actual course of technologies (Bijker and Law, 1994). Building on these early insights, transition scholars concluded that institutional and technological transformation processes had to mutually shape each other over time in order to create institutionalized "configurations that work" (Rip and Kemp, 1998), so called socio-technical regimes (Geels, 2002). From this we conclude that the revamping of TA in the context of transitions needs to conceptualize institutional change as an integral counter-part of technology development. Institutional change should therefore be treated as more than a mere "context" condition.

Several authors have labored at this interface over the past few years. The broader transition literature provides multiple approaches that address co-evolutionary dynamics in socio-technical system (Van Den Bergh et al., 2011). TA and technology and innovation studies had an early contact point through the approach of Constructive Technology Assessment (Schot and Rip, 1997). The basic argument was here that due to the impossibility of predicting future states of socio-technical systems, TA should engage in experimentation with new technologies and thus become an integral part of technology management processes. Real-time technology assessment builds on the general idea of CTA, but is aiming at becoming embedded in the knowledge creation process itself by, i.e., making use of more reflexive methods (such as public opinion polling, focus groups, or scenario development) to elicit values and explore alternative potential outcomes, by investigating how knowledge, perceptions, and values are evolving over time, and by integrating socio-technical mapping and dialogue with retrospective (historical) as well as prospective (scenario) analysis in order to attempt to situate the innovation of concern in a historical context (Guston and Sarewitz, 2002). Another early approach are back-casting methods, which aim at solving the co-evolution problem by sketching out preferable end-states of a socio-technical dynamics and then ask in a second step, which sort of actual trajectories might lead to these specific future states (McDowall and Eames, 2006; Quist and Vergragt, 2006). Similar to CTA, innovation-oriented TA is interested in a better understanding of innovation processes and their influencing factors. Here the spectrum of influencing factors is broadened by adding social and cultural elements and users are getting an explicit emphasis (Grunwald, 2009, 1119).

More specific methodological proposals relating to transition contexts were formulated by a number of scholars. Carlsen et al. (2014), for instance, present co-evolutionary scenarios for creative prototyping. Based on an iterative participatory workshop methodology the authors aim at presenting a more transparent approach to co-evolutionary dynamics. However, they still put technical variants at the beginning of their analysis and discuss only in a second step to what extent different societal debates might affect the respective technological trajectories. Also in the field of electric mobility several valuable studies on co-evolutionary developments emphasize technological progress as a key driver or at least as a central point of reference in prospective analysis (Augenstein, 2015; BMVI, 2014; Dijk et al., 2013; Epprecht et al., 2014; Geels et al., 2012; Schippl, 2012). Recent theorizing in transition studies elaborated how future regime structures could emerge out of the interplay of regime, landscape and niche dynamics (Elzen et al., 2004; Truffer et al., 2008). In particular, Elzen et al. (2004) proposed co-evolutionary narratives for future socio-technical change in the transport regime. Here the focus is on impacts of different policy measures and strategies. van Bree et al. (2010) draw on the MLP to map future scenarios for the introduction of hydrogen and battery electric vehicles in the transport sector by taking the relationship between car manufacturers and consumers as a point of departure. Wiek et al. (2006) identified different functions that scenarios could assume in transition processes. Another approach focused more explicitly on the production structures of technological innovations framed as technological innovation systems. These studies proposed methods for varying organizational and institutional contexts that may shape specific technological trajectories (Markard et al., 2009; Wirth et al., 2013). Finally, the tradition of transition management proposed integrated governance approaches to modulate socio-technical transformation processes including future visioning, experimenting with niche technologies and organizing public discourse in so-called transition arenas

(Kemp and Loorbach, 2006; Kern and Smith, 2008).

TA-related work published under labels such as FTA or Foresight also provides valuable aspects for our task. Early on it was acknowledged in the FTA community that there is a need to better integrate a broader social dimension in future technology analysis, including social trends and changing institutional arrangements (Cagnin and Keenan, 2008; Georghiou, 2007). For example (Zimmermann et al., 2011) argue that transformations require combinations of technological, cultural, societal, institutional and organizational aspects. Recent FTA-conferences have called for innovative methodological combinations to tackle the interactions of social, technological, economic, environmental, and political and value/cultural contexts (Giesecke et al., 2014; Horner et al., 2014; Kanikdale and Venugopal, 2014). A rather sophisticated approach was presented by Weimer-Jehle et al. (2016), who introduces a systemic integration of societal "context factors" into sociotechnical scenarios based on a method called cross-impact balance analysis. But also this approach does not clearly explore how institutional dynamics can lead to new "configurations that work" in sociotechnical regimes.

Valuable as all these proposals may be, for the specific challenge of TA based support of transition policies, we maintain that an more explicit and systematic conceptualization of institutional dynamics and their potential impacts on sociotechnical change is required. Existing approaches often take technological variation as a starting point to identify sociotechnical dynamics. Institutional conditions are then added as a kind of afterthought to fit the needs of a specific new technology and not explicitly and systematically examined as starting points for the development of technical variations. Quite often, institutional interactions and dynamics are not explored in greater detail and only dealt with in a more general and sometimes rather unspecific way. This runs the risk of an overly technology fixated perspective that underestimates "autonomous" dynamics in the institutional conditions. As a consequence, plausible alternative future design variants and/or development trajectories of technologies might be overseen. Even more, surprises, accelerations and side effects may be underestimated and might therefore overwhelm policy makers (Hoppmann et al., 2014). The general risk of technology fixation is present in many TA approaches and transition studies (Shove and Walker, 2007). We will therefore in the following build on this earlier work but develop a more systematic approach to identify critical institutional dynamic processes, which can potentially impact technological development trajectories.

2.2. Outline of a co-evolutionary assessment framework

The analysis of institutional change in interaction with technology development increases the complexity of the TA task quite dramatically. It is for instance not sufficient to focus on technology developers as focal actor group. Successful innovation often depends on the interplay of a wide range of actors: research institutes, associations, government offices, NGOs and even citizens and users. All these actors are embedded in various institutional structures[1], which guide (to a stronger or lesser degree) their perceptions, preferences and behaviors. The shaping of socio-technical configurations is a two-way process in which neither technology nor institutions ultimately have priority. Once established, socio-technical regimes exhibit strong path dependencies as they narrow down the possible development paths by locking out potential radical alternatives. These co-evolutionary interactions cannot be anticipated in any detailed way. We therefore have to adopt a simplified approach which proceeds in four steps.

In a first step, we propose to identify the core elements of a socio-technical regime, namely its core actors, networks and institutional structures. Among the institutional structures, we furthermore differentiate between regulative, normative and cognitive dimensions. For any specific field, an exhaustive listing of these elements would quickly grow out of proportion. The regime-concept may however help to prioritize, by denoting the more strongly institutionalized elements, which as a consequence are hard to change through intentional action, but if they start to change they may lead to fundamental shifts in future development trajectories of the associated socio-technical systems (Fuenfschilling and Truffer, 2014). By focusing on those institutional dimensions, which have a disruptive potential, a more balanced perspective can be formulated as a complement to a primarily technology-focused analysis. Our approach builds on and extends the variation analysis approach presented by (Markard et al., 2009) in their prospective analysis of technological innovation systems. Their approach, however, focused mainly on the interaction between technological and organizational variations (focusing on specific configurations of actors and networks as business models and value chains). In the present paper, we extend this framework to include variations in core institutional dimensions.

Fuenfschilling and Truffer (2014) have recently introduced an interpretation of the socio-technical regime concept as representing the highly institutionalized core of an organizational field. Following this view, an organizational field can be represented in the form of a radar plot (see Fig. 1). Circle segments represent basic dimensions of a regime (like the ones represented in Table 1). Distance from the center corresponds to the degree of institutionalization of individual elements. The regime can therefore be identified as the innermost circle of the plot. More peripheral elements appear at the fringes.

As a second step, we have to identify the mutual relationship between the core elements that make up the regime core. The different institutional elements are not only individually institutionalized but also align into "configurations that work" (Rip and Kemp, 1998). Fuenfschilling and Truffer (2014) have argued that not all regime structures are fully aligned. Instead, the regime core may be populated by several internally coherent but mutually conflicting configurations that follow different institutional logics. As a consequence, regimes may only be semi-coherent and conflicts among different elements may generate manifold internal dynamics. A classic example in the institutional logics literature relates to modern hospitals. Today, it is quite normal that strong institutions of the medical care profession (such as standards of hygiene, concepts of caretaking of patients, etc.) co-exist and enter partially into conflict with rules of economic efficiency and managerial styles of hospital organization. These two institutional logics may create manifold tensions and lead to a wide array of internal dynamics in the regime core (Ruef and Scott, 1998). A way to identify interdependencies between different institutional elements is to interrogate whether and how much the position of one element would change if another element was suddenly shifting its position in the radar plot. An example in the hospital sector would be a shift in the professional culture of medical doctors embracing approaches of alternative medicine. This would probably impact the professional position and expertise of nurses, the type of medical devices used and expectations of patients quite fundamentally. The managerial concepts and accounting procedures would however not be impacted equally strongly. This approach therefore enables to relate shifts in the institutional environment to regime configurations.

A fully-fledged analysis of regime dynamics would have to analyze the interaction of all elements resulting from the application of Table 1. This is, however, impossible to achieve. Future regimes will typically develop over decades and the detailed mechanisms remain essentially unpredictable. However, by identifying feasible combinations and by distinguishing core elements from more peripheral elements, possible future regime constellations can be identified, at least qualitatively (see also (Markard et al., 2009). We therefore propose to construct new potential regime configurations by building coherent scenarios based on trends that impact the core institutional elements identified in step one.

In a third step, we may then proceed to elaborate how institutional

[1] We adopt here a sociological definition of institutions, relating to rules that guide the behavior of actors. Organizations are not part of this definition.

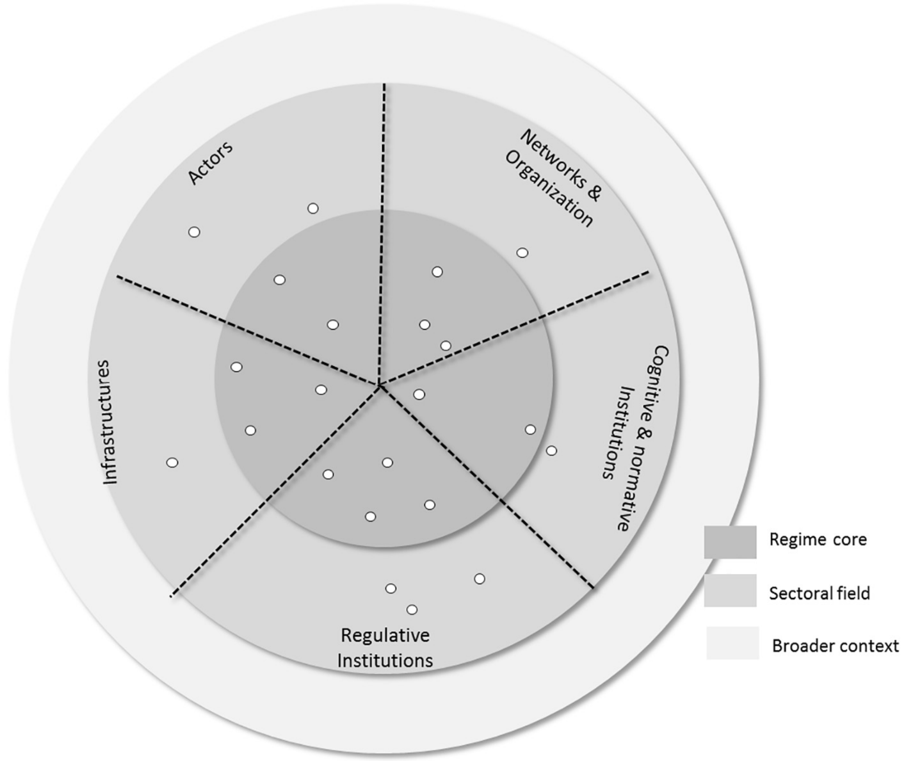

Fig. 1. Mapping of a regime core in an organizational field. Distance from the center corresponds with decreasing degrees of institutionalization, (following (Fuenfschilling and Truffer, 2014).

Table 1
Core regime dimensions and potential inroads for major shifts in the regime core (non-exhaustive).

Analytical dimensions	Specific factors	Indicators for trends potentially leading to radical change
Actors	Dominant actors in the field	Entry of new industry players
	Outsiders	New disruptive business models
	Interest groups/NGO's	Mobilization of public opinion
	Opponents	Mobilization of powerful outsiders
	Research institutions	Research budgets and academic excellence
	Typical users	Highly visible lead users
Organizational configurations, networks & institutional arrangements	Value chains (including their geography)	New business opportunities for local/national industry
	Intermediaries	New industry associations/lobbying structures
	Formal and informal Networks	Reorientation of networks
	Market characteristics	Shifting customer value and cost characteristics
	Educational systems and labor markets	New professions/capabilities
Cognitive and normative institutions	Widely shared expectations about technologies	Hype-disappointment dynamics, disenchantment with technologies
	Widely shared problem framings	Technology as a solution for what problem
	Establishment of standards	Technical standards, quality labels, dominant designs
	Fit with broader cultural values or fashions	Symbolic connotation of technology/complementarity with fashionable items
	Required commitment for using a technology	Enabling competence and/resource to use technology are perceived as high
	Dominant routines/patterns of usage	Alternative usage patterns become visible
	Symbolic connotations of product use	Symbolic associations with major societal problems (e.g. Climate change)
Regulative institutions	Dominant sector regulations	Shifts in formal sectoral regulations (safety, market structure, etc.)
	Promotional policies	Major focus on certain new technologies (e.g. Feed in tariff)
	Specific governments structures	Specific structure of ministries
	Complementarities with other policy realms	Synergies with industrial, regional, environmental policy
Technological context and infrastructures	Enabling technologies	e.g. new options through ICT, ubiquity of smart phone devices
	Resolution of technological bottle necks	Smart grid infrastructures

dynamics in the regime core interact with technological design characteristics. Specific technological variants will show more or less strong potentials for alignment with the developments described by the regime configurations in the scenarios. As a consequence, we may anticipate how alternative trajectories might develop under the specific institutional contexts and how the former may reinforce the latter over time. This interaction is sort of "technology neutral" as it enables to interrogate design alternatives both for incumbent and alternative technological designs. As a consequence, we claim that the present approach provides a sort of "decentering technology" perspective for TA on future socio-technical configurations.

This will, in a fourth and final step, enable the discussion of alternative policy and strategy options. On the one hand, policy makers and industry strategists may take the future regime structures as reference points for thinking out of the box and identifying robust approaches to their innovation strategies. In particular, this approach may help decision makers to set up observation programs for identifying potentially disruptive changes early on. On the other hand, analysts may use these regime structures to reconstruct the often implicit assumptions about future institutional context conditions that proponents of specific technological strategies entertain and reveal whether and under which conditions these assumptions may be justified. Obviously, the strategies of these different actors will not be neutral for the further development of the technological trajectory but will influence both technology dynamics and changes in institutional conditions.

3. Identifying potential regime dynamics

In the following, we apply this analytical procedure to the automobility sector since it is a highly illustrative example of a socio-technical system (Geels et al., 2012; Urry, 2004). Over the last hundred years, the development of the car co-evolved with a broad range of regulative, normative and cognitive institutions that finally enabled and determined its diffusion patterns and its widespread use in society (Puhe and Schippl, 2014). We furthermore focus on Germany because of its strong political dedication to be a leader in several sustainability related sectoral reforms (Quitzow et al., 2014) and because technology assessment and technology foresight approaches in its various forms and institutionalizations play an important role in informing and guiding stakeholders and policymakers in a typical neo-corporatist arrangement.

3.1. Characterizing the German automobile regime

As in other western countries, after WW II, car mobility developed to become the dominant form of transport in Germany. Guided by the institutional dimensions introduced in Table 1, the established form of the automobility regime in Germany can be characterized as follows: Motorized transport has a particular political position because of the strong relative role of the automotive industry in the country's economy. Some of the globally most successful OEMs and OBMs are based in Germany, including a dense network of suppliers. It is estimated that about 5-7 Million jobs in Germany depend directly or indirectly on the automotive sector. The car industry is well organized in formal and informal networks. But also strong critical voices exist, which address the negative impacts of cars on environment, human health and quality of life. The dominant design of cars has barely changed over the past hundred years: a vehicle with 4 wheels, seats for 4–5 persons, some room for baggage and a fossil-fuel based internal combustion engine (ICE) as propulsion technology. In its medium to larger size version, this configuration has been called by some authors as the "race-and-travel limousine" model (Rennreiselimousine, see Knie and Hård (2001).

At the level of institutional structures there is a well elaborate governance system that designs and maintains the infrastructural and legal framework of the transport system. Cognitive-normative institutions are present as paradigms and visions of transport policy and dominant planning approaches. A good example is the interplay between societal values and related planning paradigms, planning law and the development of transport infrastructure (Schippl and Puhe, 2012). Also, citizens and users' car-related attitudes and behavioral patterns are linked with various regulative, normative and cognitive institutions. The car-industry and also the political system tries to anticipate and partly influence their attitudes and preferences. It is widely acknowledged that transport is derived demand – at least to a large extent (Banister, 2008). This means, car-mobility is used to fulfil demands that are usually driven by motivations from outside the transport sector: working, shopping, recreation etc. Users are highly sensitive to broader cultural values, fashions or trends beyond the transport sector.

3.2. Specifying user related institutional structures in the regime core

In the following, we will elaborate an illustrative example on how this methodological framework can be applied by focusing on those institutional structures in the regime that have developed around the use of the car. We do this mainly for pragmatic reasons to limit the complexity of the illustrative case. User related institutions are doubtlessly key for stabilizing a specific socio-technical regime. However, the general approach could equally well have been illustrated for other institutional structures, like dominant regulations, changes in planning approaches, political discourses, new business models of industry and so on.

We assemble user related institutional structures in three broad dimensions[2]: 1) Dominant use patterns: This dimension relates to the dominant form cars are operated on a daily basis, the main transport purposes, the average distance traveled, the specific routines that depend on cars and so on; 2) Commitment required by users: This dimension relates to willingness of users to invest time and money to acquire a driver's license, to buy, own, operate and maintain a private vehicle or to access cars by other means. And 3) social and infrastructural embedding: This dimension relates to how use related activities are embedded in broader societal contexts such as road infrastructures, repair shops, gas stations, but also regulatory, normative and cognitive contexts for operating and maintaining cars. In the following, we will elaborate these three institutional dimensions for the car regime in Germany:

Predominant use form: The dominant mode of disposition in the German mobility regime is full private ownership, or at least permanent access to a personalized vehicle. Between 1992 and 2007 the car stock in Germany grew from 44,3 Million to 55,5 Million (BMVBS, 2009). The current regime implies that the dominant use form corresponds for most automobiles to an all-purpose vehicle and their size is conditioned by imagined or real peak-load requirements. Table 2 illustrates the share of the different segments in newly sold cars in Germany in 2015. Compared to 2014, some shift between segments can be observed. Most striking is the ongoing tendency towards comparatively expensive SUVs and off-road vehicles. Both together reached a market share about 15% of the roughly 3 million cars sold in Germany and experts expect this share to double until 2020 (Doll, 2014). It has to be noted that only 1/3 of the new passenger cars in Germany are sold to private persons. About 2/3 fall under different forms of business or company cars, which are formally used for commercial purpose but often are handed out to employees for private use as an incentive. The car model typically relates to the professional status of the employee. After some 4 or 5 years, many of the company cars are recirculated to the huge second hand market and become privately owned cars.

Car use dominates travel patterns of the Germans. For example in 2008 about 83% of all the trips made and about 80% of all the person kilometers were covered by motorized individual transport. Interestingly, 98% of the daily trips are shorter than 100km. Regarding travel purpose, commuting and business trips are losing importance. 2/3 of all trips are related to shopping, transactions, and

[2] These three dimensions are inspired by but not identical to the three core dimensions of in practice theory of Shove E., Pantzar, M., Watson, M., 2012. The dynamics of social practice. Everyday life and how it changes. Sage, London., which are material, competences and meaning.

Table 2
Passenger Car registrations by segment in 2015 in Germany (source: Kraftfahrt-Bundesamt (KBA) - Federal Motor Transport Authority).

Passenger car registrations in 2015			
Segment	Cars sold 2015	% Year 2015	Diff. to 2014
Mini	245374	7,7	+ 7,7
Subcompact car	468588	14,6	+ 2,4
Compact	848108	26,5	+ 5,8
Mid-size	423746	13,2	+ 11,4
Full-size	113978	3,6	− 6,6
Luxury	30755	1,0	+ 3,0
SUV	340097	10,6	+ 15,2
Off-Roader	259325	8,1	+ 11,0
Sports car	41455	1,3	+ 12,4
Vans	264474	8,2	− 9,3
Light commercial vehicles	129769	4,0	+ 5,2
Campers	28348	0,9	+ 10,1
Others	12025	0,4	+ 6,7
Total	3206042	100	+ 5,6

leisure, with still growing tendency regarding shopping and leisure (Infas and DLR, 2010). Therefore, we see a further strengthening of the all-purpose vehicle model with some remarkable changes.

Commitment required by users: In the current regime the willingness of users to invest time and money for their privately owned cars is relatively high. The automobile is typically one of the most expensive investment items for most households (just after housing). Furthermore, cars block a high share of a regular household's budget. But additionally, users are also confronting high opportunity costs, as operating a car requires a high investment in the form of time for learning and dealing with maintenance tasks. Obtaining a driver's licence has become costly, as well. A high share of the costs linked to car-ownership is generated by operation (e.g. fuels) and maintenance (e.g. repair). These total costs of ownership are usually underestimated by the users (Peters et al., 2012). The situation is somewhat moderated for the case of privately used company cars, where large parts of the cost for operation and maintenance are covered by the company and not by the user.

The third dimension relates to the *social and infrastructural embedding* of the use form. The current regime is characterized by settlement and dense support infrastructures that are strongly aligned to the requirements of widespread car use. A whole infrastructure was built around the car and society widely accepts and even expects that considerable public resources are invested into roads, parking facilities etc. For many citizens personal cars enable participation in societal life. On a symbolic level, cars still function as status symbols for many people. On the other hand, there is an increasing societal awareness for the negative consequences of car traffic on human health and the environment. The "paradigm of sustainable transport" (Banister, 2008) formally dominates transport policies in many urban areas, backed by large parts of inhabitants.

Fig. 2 depicts the core user-related institutional elements in the current car regime.

3.3. Megatrends and their potential impacts on institutional conditions

The three user-related institutional dimensions of the car regime are deeply embedded in broader societal contexts. In order to identify potential transformations of the regime core in the future, we will in the following elaborate a number of widely recognized trends that might impact the positioning of institutional elements in the regime core. Based on a large literature review of recent transport related Foresight studies (e.g. (faithpopcorn, 2015; Z_Punkt, 2015; Zukunftsinstitut, 2015), we have identified nine trends. For each trend, we assembled empirical evidence indicating that the respective trend is continuing over a longer time (Naisbitt, 1988). The trends are listed in Table 3 according to their specificity for the automobile regime (i.e. Ageing demographics is a very general trend that impacts all sorts of economic sectors, whereas peak car is a specific shift in the cultural meaning of cars). Furthermore, the table specifies how these trends might impact the positioning of core elements of the automobile regime in the three user-related dimensions.

3.3.1. Climate sensitivity

Several developments, amongst them the results of the 2015-climate-summit in Paris, indicate that political willingness to reduce GHG emissions is getting more momentum. Climate change impacts become increasingly tangible in the media but also in everyday personal experience. A plausible consequence would be increasing societal acceptance of regulations to reduce GHG. In such a context, "eco-efficiency" could become an established norm and a status symbol. In a stronger version of this trend, we assume a "cultural criticism" of gasoline cars as anticipated by Dijk et al. (2013). Potential impacts on the three institutional dimensions encompass a tendency to use and/or purchase more eco-efficient modes of transport and - related to the dimension "social and infrastructural embedding"- a higher acceptance of political regulations to reduce GHG-emissions of the mobility sector.

3.3.2. Ageing

The demographic development in EU countries is characterized by a trend often labeled as "aging society". In Germany, and also in other countries, birth rates decrease. It is expected that older people will be more active than the generation before. The number of women older than 65 that hold a driving license is growing and the cohort 60 + is using the car more often than earlier generations (KIT, 2010). There will be huge differences in physical abilities, however. In general, we assume an extension of this trend in the next decades but also a differentiation of activity patterns, mobility related preferences (individualization) and, thus, more variations in the predominant use form. This accounts equally to living conditions, and settlement structures. In general, we assume a higher service orientation, affecting in particular the dimension "commitment required by users". More recently, even older citizens start to find inner city areas more attractive due to the higher quality of infrastructures and medical services, which can be linked with the third institutional dimension.

3.3.3. Individualization

Individualization is affiliated with various aspects. In 2014, in 75% of the 40 million households in Germany lived only one or two people. About 20 years ago, it was 65%. It is expected that the share of households with three or more people is further slightly decreasing over the next decades. On this basis, we assume that for nearly 80% of the households all members could be transported in a small car with two seats only and the need for larger "family cars" is decreasing ("predominant use form"). Further, there might be an increasing flexibility related to mobility patterns and more variations in the willingness to invest in car-mobility. With the diversity in household composition variations in settlement structures could increase. So, all three dimensions could be affected by these developments.

3.3.4. "New work"

Several observers assume that in the future, working is less bound to fixed timeslots. In addition, there will be more people without children, which is further increasing flexibility in daily life. It is also discussed that the boundaries between work and private time will increasingly be blurred. As a consequence, we assume higher flexibility in commuting patterns and an avoidance of peak hours for commuting which implies changes in the predominant use form. Travel time will increasingly be used for work related activities with consequences for the willingness to use and own a car. We might also experience a growing virtualization of work flows and of professional networks (social embedding).

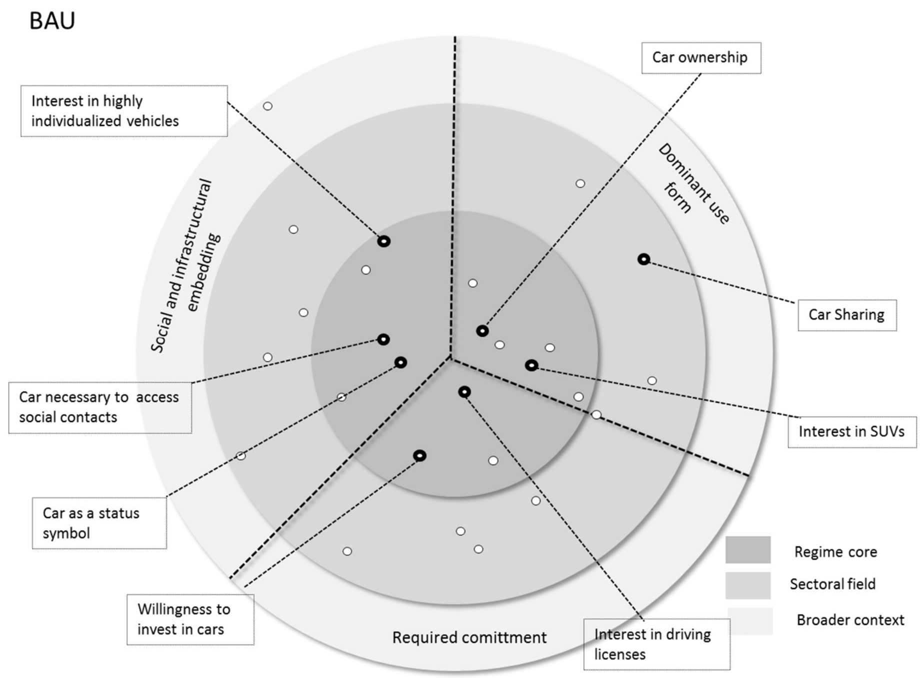

Fig. 2. Characteristics of user related institutional structures in the German automobile regime. At the same time, this configuration is assumed to remain constant in a business-as-usual (BAU) scenario.

3.3.5. Cocooning

The trend cocooning goes back to the megatrends identified by John Naisbitt (1988). It is linked to the idea that cars will become even more a sort of "third place" (NRZ, 2015), in addition to domicile and workplace. "Cocooning" relates to the need to protect oneself from the harsh, unpredictable realities of the outside world. Security and safety become top-priorities in daily life as well as in long-term planning. We assume that as a consequence intimate spaces are increasingly valued. In its extreme, this means that people try to avoid the public sphere, and as a consequence also public transport. Again, all three institutional dimensions might be affected. People want to have full control of cars as personal space and there is need for safe infrastructures (e.g. supervised parking lots). Referring to dynamics in cognitive-normative institutions, (Wells and Xenias, 2015), 106) argue that "cars as cultural objects have shifted from embodying the ideological philosophy of personal freedom to that of cocooning". The authors illustrate that such a cultural shift might lead to a "continuing commitment to mass car ownership and use" (Wells and Xenias, 2015), 108.

3.3.6. Virtualization/online shopping

Online sales are extending their market shares. At the same time, new services for fast delivery are emerging such as Amazon's "green delivery". All age-groups participate in this development. It is well imaginable that in the future less mobile people will be more and more familiar with (and dependent on) internet services. As a consequence, online-services may become the dominating form of shopping and the share of private transport dedicated to shopping will decrease substantially. Accordingly, there would be less need for large trunk space, which goes along with less commitment to invest in large cars. Furthermore, urban structures may be affected by the increase in delivery services.

3.3.7. Sharing economy

Rifkin's books on the upcoming "sharing economy" (Rifkin, 2001, 2015) predicts a general shift in paradigm towards the "Zero-Marginal-Cost-Society". Remarkable are recent developments related to the most expensive investment decisions in an ordinary person's life: housing (buying a house or not) and car usage (buying a car or not). Airbnb has become the symbol for sharing living space. In Germany, car-sharing experiences stable growth rates since 20 years. More recently, growth rates increased heavily due to the market entrance of free-floating car-sharing schemes of larger car companies (e.g. car2go, DriveNow). In 2015, the total number of car-sharing users exceeded one million and further growth is expected by many experts. We assume that over the next decades this development could lead to a flexible use of different car types and to a disinterest in ownership as dominant use form and in technical features of cars. Trust in internet based services is likely to increase and new mobility providers will appear who develop multi-modal journeys. The willingness to spend time and resources in car-ownership and usage may be reduced.

3.3.8. Urbanization

As in many other countries, the number of people living in urbanized areas is continuously growing in Germany and this trend is expected to continue. New business models related to sharing economy have a much larger potential to change the dominant use form in urban areas than in rural areas. We assume that together with individualization, decreasing number of persons per household, the space for living per persons is increasing and space is becoming a scarce resource in many urban regions. Different ideas about how to use this space in order to create a livable city will compete and affect the institutional dimension "societal embedding". Larger cars such as SUVs may increasingly be prone to criticism and small car may become fashionable.

3.3.9. Peak car

Numerous analyses and empirical studies show that many industrialized countries experience slower growth rates in car use per head (e.g. Goodwin, 2012; Kuhnimhof et al., 2013; Van Dender and Clever, 2013). To a certain extent, these slower growth rates seem to be due to a change in transport behavior of young urban adults (Puhe and Schippl, 2014). A decrease in both rate of car ownership and distances driven by car can be observed; this is accompanied by a decrease in driving license rates (Delbosc and Currie, 2013; Grimal et al., 2013; Kuhnimhof et al., 2012). A growing number of younger people show a

Table 3
Selected megatrends and their assumed impacts on institutional dimensions.

Megatrend	General impacts	Assumed impacts on user related institutional domains		
		Predominant Use Form	***User Commitment***	***Societal Embedding***
Climate sensitivity	Leads to different developments that foster less GHG-intensive modes of transport	Tendency to choose the car and the use form which fits ideally with personal needs	Willingness to invest in eco-efficient mobility	Acceptance of regulations to reduce GHG; "Ultra-efficiency" as "norm" and status symbol
Ageing Demographics	More active older people travel more and many of them are still able to drive by themselves	Even more variations in mobility preferences (and attitudes)	Higher service orientation	Changes in settlement structures
Individualization	More variations in settlement structure and mobility choices imaginable	Less need for large vehicles, more variations in preferences	More variations in willingness to invest in car-mobility; More versatile transport options required	Variations in settlement structures and parking spaces; different access points to communities
New work	More interest in virtualization; strong need to combine work and travel	Flexibility, avoiding peak hours	Flexibility/travel time used to do work	Increasing virtualization of work flows and of societal embedding
Cocooning	Will strengthen car transport and individual ownership	Protection against feelings of insecurity in public spaces	Full control of car as personal space (car as a "third place")	Safe infrastructures, many parking lots needed
Virtualization	Reduced interest in going to real shops	Reduced need for large trunk space	Less commitment to invest in larger cars	Extension of delivery services affects urban structures
Sharing economy	Reduced interest in personal car-ownership	Flexible use of different car types	Disengagement with car ownership, disinterest in technical matters of cars	Proliferation and widespread trust in internet based services
Urbanization	In urban areas space is a limited resource; challenge to ensure high quality of live in densely populated areas	In dense urban areas cars areas small as "possible"; many car trips are replaced by other modes	Less commitment to invest in large cars	Increasing societal interest in "livable" cities
Peak Car	Cars less affiliated with status symbols; different car fleet might emerge	Demand for a broader mix of means of transport	Alternative budget items (e.g. smart phones) compete with cars in household budgets	Number of "conventional" cars declines, impact on price and support infrastructure

more pragmatic attitude towards cars and car ownership than the generation before (user commitment). The importance of cars as status symbols is decreasing (Puhe and Schippl, 2014). The dominant use form appears to be changing since young people in urban areas seem to become more flexible in their mobility behavior and more open to new forms of transport (Infas and DLR, 2010; KIT, 2010). One of the major drivers of this shift is that budgets of young people get devoted to other expensive consumer items like smart phones or streaming services. We assume that this trend leads to a higher demand for multimodal options and a decline in the number of "conventional" cars and, thus, to significant changes in all three institutional dimensions.

3.4. Scenarios of future user-related regime structures

After having identified nine trends that could shift the positioning of institutional elements in the regime set-up, we have to interrogate what sort of institutional alignments could develop in the regime core of the future. Analyzing Table 3, we identify a number of shared features of all trends, namely an increasing need for flexibility in car use, a stronger service orientation, a renunciation of large SUVs, and a potential substitution of at least some formerly automobile based activities by internet based services. However the overall outcome for individual mobility is not entirely determined by these developments. For example, whether or not car ownership will still be strong depends on which of the nine trends will dominate in the future.

Not all potential impacts listed in Table 3 are pointing in the same direction, though. We see two major scenarios. A first one (blue cells) builds on trends of virtualization, sharing economy and peak car. Here the main development lies in a shift towards multimodal transport that goes along with dissociating car-ownership and car use. In this scenario, the number of kilometers traveled per capita does not have to decrease nor do the different designs of automobiles have to change too dramatically. The second scenario puts emphasis on the trends of cocooning and new work conditions (green cells). Here we would expect a multiplication of the number of cars per capita as car ownership will even increase its importance as dominant use form. But on average the individual vehicles might be smaller, as they have mostly to guarantee the transportation of one or two people over short to medium distance (mainly commuting or leisure activities).

Institutional variation I: Sharing and inter-modality become dominant in the institutional core

In this variant, the main trigger is the strongly growing importance of the sharing economy, which is becoming an overarching economic paradigm in Europe and in many other countries. The new institutional configuration is strongly pushed by changes in the predominant use form of cars.

Most people consider cars a means of transport, which is just needed for transport from A to B in situations where there is no more convenient alternative available. In the beginning it was the smaller group of younger adults in urban areas, which were not willing to commit themselves to car ownership with its large upfront investments and/or long lasting financial burden in form of credits and also maintenance. This trend has spread to other user segments. Users of the transport system meanwhile can choose from broad range of attractive alternatives to car ownership: Highly sophisticated car-sharing schemes are accessible also in many smaller cities and they are well connected to public transport options and cycling system. Car companies but also many public transport operators extended their portfolio towards car-sharing and bike-sharing systems. This is accompanied by various taxi-sharing systems. The highly integrated range of options fits well with the major preferences for a flexible and easily usable transport system, which enables working and/or networking while travelling. Culturally, driving is considered a waste of time, and cars are not associated with social status. Trips that take more than one or two hours are usually done by trains or busses. Because of online-shopping cars are not often needed to carry private goods. Those people, who still need a private car (e.g. for commuting) usually buy a cheap one in a supermarket or via internet. The market mainly requires smaller and robust cars (SAR) for car-sharing purposes. The variety in models is heavily reduced, only a few standard-models are needed. The total number of cars in operation declines heavily.

Institutional variation II: cocooning and climate concerns determine transport needs

In this variant, ownership remains the dominant use form. This is strongly triggered by tendencies towards cocooning. People try to avoid public transport and prefer their own, individualized environment to move from A to B. Besides individualization there are security concerns induced by riots and terrorist attacks that nourish the interest in individual transport.

Ongoing individualization leads to diversification of belief systems, attitudes and perceptions. Not for all, but for many citizens cars are still a status symbol. This is mirrored by growing interest in different individualized vehicles. In general, brands and individualized products are highly relevant. The number of vehicles and of car-based person kilometers increases. The share of households with a second or third vehicle is strongly growing.

Driven by the alarming impacts of climate change energy and resource efficiency has become an overriding paradigm of economy and society. Citizens are not willing to abandon their individual vehicles. But public acceptance for environmental regulations has grown strongly. Increasing eco-efficiency of cars is unavoidable for reducing CO_2 emissions from personal transport. Amongst the consequences are speed limits of 130km/h on highways and strong regulations pushing towards smaller, energy efficient vehicles. There is a large market for vehicles below the size of conventional cars (bicycle, e-bikes, scoters, small cars) – in particular in the many households with a second and a third car. The well-established preference for cycling and public transport in many urban transport plans is replaced by policies that foster the usage of smaller cars. One effective measure are small parking lots. Widely established urban congestion charging strongly prefers smaller vehicles and the tariff structure tries to enable a more evenly usage of urban road networks over the day. Flexible working hours help to avoid too heavy peak hours. Most people do not need larger cars for pragmatic reasons, since they do not have children beyond 16 (which is the age you are allowed to drive smaller cars) and everybody who can effort it prefers to have its own vehicles anyway (to "cocoon" in it). Usually, there is no need to carry goods since nearly 100% of all goods is ordered online and brought by delivery services. A counter-trend to the SUV fashion sets in, the corresponding cars are labeled as SSE (small, smart, efficient). However, a smaller but still significant number of households with only one car and an interest in a "Rennreiselimousine" remain.

Cars are well-equipped with information technology and communicate with intelligent urban transport systems. The strong willingness to use cars and the density in urban areas triggers urban sprawl. A self-reinforcing effect sets in: alternatives to cars are becoming relatively less attractive, and, in consequence, these alternatives are less interesting for investments what leads again to an increase in the relative attractiveness of cars. The public transport system is reduced to those elements that are unavoidable and highly frequented such as underground systems and some central tramway lines. Further, some long-distance trains and air traffic are still in good shape.

Summarizing the analysis of regime level institutional changes, we may represent the two alternatives scenarios by radar plots that highlight the major shifts in the core institutional elements of the current regime configuration (see Fig. 3).

The main institutional changes in scenario I are that car ownership is moved out of the regime center and replaced by car-sharing and multimodality; induced by these shifts, other institutions are changing their position as well, such as the willingness to invest in cars or the interest in SUVs. Actually all the institutions we mapped in scenario I are showing a strong change in position and a completely new socio-technical configuration is emerging. In the second scenario, the shift in the positioning of institutions are not as extreme, but still some significant changes can be observed. Main triggers appear to be that the interest in highly individualized cars is moving even more into the center. At the same time, the interest in SUVs is replaced by a high interest in SSEs. All that leads to some other smaller but visible movements, e.g. the interest in car ownership is even growing and also the willingness to invest in cars is further increasing. Car-haring, however, is not affected by this movements and, thus, not changing its position at all in the second scenario.

4. Interactions between institutional variants and technical designs

The potential future user-related regime structures should not be read as predictions about future market contexts. They summarize possible development trajectories in (one specific domain of) institutional structures that might interact with specific technological trajectories. We will therefore in the following analyze in how far specific technological designs might interact with these institutional development trajectories and by this create integrated socio-technical dynamics.

4.1. Recent developments in the innovation field of electric mobility in Germany

As we are particularly interested in trajectories of BEVs, we will briefly sketch the specific context of BEV policies in Germany. As in other countries, the German government has implemented ambitious strategies to foster R & D activities as well as market growth of BEVs. The "National Development Plan Electric Mobility" was initiated by the

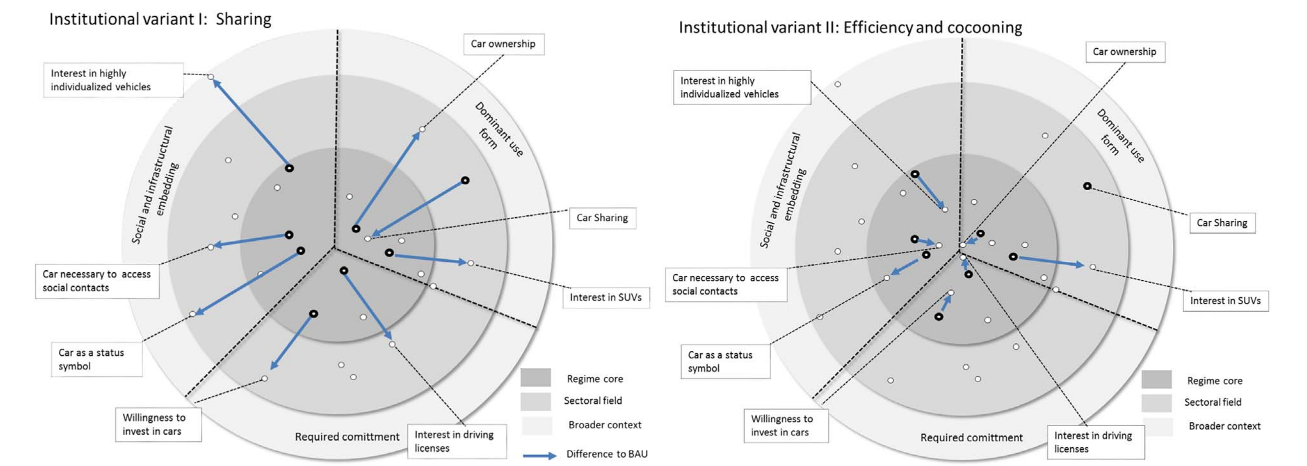

Fig. 3. Changes in core institutional elements of the two institutional scenarios. Arrows represent shifts in positions relative to the BAU scenario represented in Fig. 2.

federal government. Approved in the year 2009, it has set the goal of having one million electric vehicles (BEVs and plug-in hybrids) running in the country by 2020. Germany should become a lead market and leading supplier of electro-mobility to stabilize the strong competitive position of the German automotive industry and related jobs. The target is highly ambitious. However, current developments do not yet live up to the expectations: in 2015, less than 30.000 BEVs or plug-in hybrids were running on German streets. In contrast to countries such as Norway or Netherlands, so far there is nearly no direct support for the purchase of electric cars. Only in spring 2016, the German government agreed on supporting electric vehicles and plug-in electric hybrids by subsidies (4000 €) in case of purchase, by stronger tax reductions and as well by intensified roll-out of charging infrastructure. Recently, local governments were enabled to introduce incentives such as access on bus lanes or reduced parking fees in inner cities. Up to now it is not clear to what extent German cities will make use of these options.

The technological variations in the electric car field are quite broad. This indicates that no dominant design could yet be established and there is still an increasing number of suppliers for alternative designs (Sierzchula et al., 2012). Table 4 shows which electric cars were mostly sold in Germany in 2014. The patterns reflect already a smaller segment of the car fleet. But some plug-in SUVs with smaller electric ranges (15–25 km) are available on the market, for example the BMW X5 xdrive40e or the Porsche Cayenne S-Hybrid.

4.2. Design implications: the co-evolution of institutional and technological characteristics

Based on the possible and potentially disruptive changes identified in the trend analysis, we may now spell out potential alignments between three user-related regime scenarios (business as usual, multi-modal sharing and individual efficiency) and a range of technological design characteristics (Table 5). These relate to key performance criteria such as range, charging requirements, integration in smart grids, relevance of purchase cost or maximum speed. Different developments in the user-related institutional structures may either support or hinder specific technological development trajectories.

The BAU describes and perpetuates the current situation. BEVs have to compete with ICEs under market conditions as we know them today. Required are long ranges and a dense public network of high-voltage fast charging infrastructures in order to simulate the long ranges of ICE vehicles. There is a strong interest in cars that are usable for very different purposes, SUV and Off-road vehicles remain very popular. There is currently an increasing demand for these car segments as is shown in Table 2. Compared to the current (BAU) regime structures, the two institutional variants vary considerably regarding design implications. In general, flexibility for covering transport needs shifts away from all-purpose vehicles towards either simple and robust cars suitable for car-sharing contexts (Scenario I) or towards an enlarged variety of individualized, smart, small and efficient vehicles (scenario II). Regarding technical performance characteristics, designs providing long range are less important in both alternative scenarios compared to the situation today. In scenario I, longer distances are covered by public transport and scenario II would privilege range extended BEVs and/or rental services (e.g. for some holiday trips).

In scenario I, vehicles will be flexibly selected depending on the best fit with the travel purpose. As a consequence, only a limited number of different models is needed. Cars also don't have to fulfill the role of status symbols anymore. Like trains or busses, the brand of a vehicle is rather insignificant to the users; the quality of the integrated services matters. Regarding emotional attachment, scenario I goes along with product designs that accept a pragmatic attitude towards the means of transport.

In scenario II, most cars are used for shorter distances compared to the BAU. The need for extremely efficient vehicles leads to preferences of cars that are fit for the most frequent use patterns, which are usually clearly below 100km a day. However, it is quite common to have a contract with dealer garages that enable access to longer-distance cars for a certain period in the year. In general there is a higher willingness to pay for sophisticated technology, but it has to be eco-efficient. Owning advanced technology is highly attractive. Most cars are sold in smaller segments and a broad range of highly diversified variations is emerging in this field. Highly expensive vehicles are on the market, but at the same time there are cheap models for lower-income groups. Regarding emotional attachment, in scenario II the ability of providing

Table 4
Frequently newly registered electric vehicles in Germany in 2014 and 2015 differentiated by car model and vehicle type (source: *www.electrive.net; **Kraftfahrt-Bundesamt (KBA) - Federal Motor Transport Authority; ***about 2230 of these vehicles were licensed in Germany but then immediately transferred to Norway (Weigel, 2015).

Automobile segment	Brand	Sales 2014	Sales 2015	Sales 2014 + 2015
Mini/E-motorbike	Renault Twizy*	573	435	1008
Mini	Smart ForTwo ED*	1.589	672	2261
Mini	Volkswagen E-Up*	1.354	547	1901
Subcompact	BMW i3**	1213	2271	3484
Subcompact	Renault Zoe**	1.498	1787	3285
Compact	Nissan Leaf**	812	948	1760
Compact	Volkswagen E-Golf*		1099	1099
Luxury	Tesla Model S**	814	1582	2396
Van	Kia Soul (Mini Van)**	0	3839	3839***
Van	Mercedes B-Class (Mini-Van)*	132	485	617

Table 5
Design implications of the user-related institutional variations (Assumed relevance of the criteria for purchase/usage: + + highly relevant, + relevant, **0** neutral, - not so relevant, - - not relevant at all).

Design implications	Assumed BAU –case (business as usual)	Institutional variant I: multimodal sharing	Institutional variant II: individual efficiency
Range	> 700 km + +	100–200 km - -	Variable (100–500) **0**
Fast charging	Dense public network + +	Very dense public network +	Only loose network required **0**
Purchase costs	High range (low – very high) + +	Low-medium, low range **0**	High range (very low–high) +
Flexibility in design of cars	Low - -	Middle **0**	Very high + +
Functional variability of a car	Very high + +	Insignificant - -	Middle **0** (very variable)
Size	Small - SUV + +	Mostly small, some L – XL -	Mostly small, some L–XL **0**
Max speed	medium – very high + +	slow – high -	130 km/h max. speed **0**
Status-oriented design	Demonstrative (design-related) + +	Not visible/required - -	Visible (technology-related) **0**
„Third Place“ character	Mostly demanded +	Not demanded -	Strongly demanded + +
Connection with other vehicles / transport services	Medium, with other cars and some other modes + +	High intermodal connectivity (controlled by operator) -	car2car connection (decentral control in the cars) **0**
Infrastructural integration (incl. smart grid)	moderate demand +	Not required -	Broad integration demanded + +
Summary	***All-purpose cars/SUVs***	***Simple and robust (SAR)***	***Variety of SSE cars***

safe private space (“a third place”) will be decisive for market success. As regards the connection with other vehicles and/or transport services in the BAU there is a continuing connection of increasingly intelligent cars with infrastructure and with other cars. In scenario II, the cars are even more intelligent and highly integrated into the transport systems with its infrastructures and vehicles. But in scenario I, the car itself is rather dull and isolated; the users have their highly intelligent smart phones or similar mobile devices to guide their journeys.

Scenario I, relies on a highly intelligent transport system, integrated and connected. The individual cars need rather limited capabilities. Providers of sharing services are interested in fast charging facilities, since cars should run as much as possible and not be immobilized by long charging times. Charging at home is not very strongly needed, as there is little willingness to invest in any privately owned car infrastructure. This is mirrored by a high demand for a public charging infrastructure. Utilities might run such an infrastructure and start offering car-sharing or rental as well. Frequently used car-sharing cars are usually not connected to electricity supply; there is not much opportunity to use the car battery as buffer for the electricity network.

Scenario II supports infrastructure buildup strategies that cover a wide range of recharging requirements. People would probably prefer charging facilities at home and/or at the workplace. There are some public charging stations in public space as fallback options, but also in this case the public sphere is avoided as long as possible. Electric vehicles might profit from being integrated into smart grid concepts to further increase the efficiency of the energy system. On a private basis and for operators of company fleets, smart grid integration is an option to reduce the cost of individual mobility. Charging time would not be too relevant, since the cars are usually only used over a small period of the day.

The different regime scenarios also have quite dramatic implications for the size of the market for future automobiles. Scenario I would go along with declining sales numbers. As car-sharing develops into a widely accepted mode of access to transport options, fewer vehicle will be needed in total. The opposite is true for the developments depicted in scenario II. Here the number of vehicles sold is likely to be larger and more diversified than today. Users would prefer highly individualized types of vehicles. However, due to the increasing range of requirements, economies of scale are likely to be lower, which could translate into lower profit margins for the automobile industry. Also a vital second hand market is likely to emerge as people change their vehicles quite often. In scenario I, there is only a small second hand market since there is nearly no private ownership.

As regards the development of land-use patterns, in scenario I urban concentration processes continue mainly along the most comfortable public transport and cycling networks. Space is not too limited in urban areas since the number of cars has decreased to a rather low level. Scenario II, sees an interaction with urban sprawl that further reinforces the need for privately owned cars. In particular in larger urban agglomerations, space would be an more pressing problem. The development of BEVs markets is likely to start in smaller cities and in rural areas, where households have access to a second or even a third vehicle and a private parking place to install charging equipment.

Some hints for both scenarios can be clearly identified today in the mobility regime. The share of electric vehicles in some car-sharing fleets (car2go and drive now) is significantly higher than the share in the total fleet and the share in new sales. This fits well with the movement of core institutions in scenario I. Also conventional ICE-car-sharing fleets generally differ from the overall fleet composition in Germany presented in Table 2. Many car-sharing schemes cover a broad range of vehicles, but in general there is a clear dominance of smaller and medium sized vehicles. SUVs and Off-Roaders are usually not integrated into car-sharing schemes. However, so far car-sharing seems not to take too much influence on the design of cars; usually cars in car-sharing were not purpose built for that specific pattern of usage. An exemption might be the full electric Bluecar of the French Company Bolloré, which is mainly used in the electric car-sharing scheme Autolib’ in Paris.

On the other hand, recent analyses show that smaller electric vehicles, including the Renault Twizy, are popular amongst the early adopters of BEVs (Frenzel et al., 2015). This might be taken as an indicator for a development towards scenario II. However, for the moment there is not enough data to clarify whether this tendency towards smaller electric vehicles is a result of changes in institutional settings or just reflecting the fact that the few larger electric vehicles and plug-in hybrids on the market are still very expensive.

5. Conclusions

The paper aimed at proposing a framework to address coupled dynamics in socio-technical systems for the purpose of technology assessment. We elaborated a method that addresses potential dynamics in deeply sedimented institutions and their interaction with future technological trajectories and applied the example of electric mobility in Germany in order to illustrate that changes in core regime elements may lead to significant implications for the technical design of electric vehicles. The operational dimensions depicted in Table 1 as well as the radar plot provide useful tools to analyze institutional structures in the context of TA processes. Two institutional variants were developed that represent different dynamic selection environments for future technology development. This way of constructing socio-technical trajectories broadens the scope of potential future options and it provides additional entry points for policy options.

The example of electric mobility illustrates that the approach is able to reveal plausible trajectories that differ from traditional technology-centered analyses regarding results and the line of reasoning. Many debates about the future of the transport system discuss whether the car regime in its current shape will persist over the next decades, or if it will be replaced by a transport system, where access to cars is more dominant than ownership (Canzler and Knie, 2012; Geels et al., 2012; Schippl and Puhe, 2012). The latter option is showing several overlaps with our scenario I. However, coming from an institutional analysis it becomes obvious that a “third way” is plausible as well: as illustrated in scenario II, electric mobility might co-evolve with an institutional setting that leads to even more cars but to a significantly different car fleet than the current one. The focus on variable institutional settings reveals currently taken for granted presuppositions may change under certain plausible circumstances. For instance, the strong preference of German customers for all-purpose cars and the current trend towards SUVs and Off-Roaders seems to be more volatile as it would have seemed from a perspective where institutional settings were taken as rather static.

These outcomes may also have implications for policy advice and consulting practice: Carmakers and public authorities would need specific strategies to cope with the developments described in the two institutional scenarios. As illustrated in Table 2, the current car fleet is covering a broad range of different segments of vehicles that would align with the alternative regime structures. None of the segments is dominating. Strongest is the “compact class” with 25%. SUVs and Off-Road vehicles combined show the highest growth rate (> 20%). Strategies for a diffusion of full electric vehicles might firstly address the smaller segments, however, in order to successfully enter the growing markets for SUVs and Off-Roaders significant progress in battery technology and/or a focus on plug-in electric hybrids would be needed. Such strategies are currently observable. A roll out of electric mobility in scenario 1 would mean to concentrate on a limited number of simple but robust vehicles, while the majority of new sales would be in the smallest segments. The larger segments will significantly lose market shares. Public support strategies may be needed to implement the required fast-charging infrastructure. Early adopters of electric vehicles are organizers of car-sharing schemes rather than private persons. The idea of handing over “company cars” as an incentive for employees is losing attractiveness.

In the second case, there will as well be a strong concentration in the smaller segments. But the diversification inside these segments will need to be increased to meet the highly variegated demand structures of the customers. In urban agglomerations, roll-out strategies will further need to rely on privately owned infrastructures enabling slower charging. Given that space is a scarce resource in larger agglomerations, planning strategies may include the building of private parking lots in the form of underground parking facilities. However, early adopters and the early majority of BEV users might rather consist of households with more than one car who have the possibility to install charging facilities on privately used parking areas. Such households can be found more easily in smaller cities and rural areas rather than in densely populated urban centers.

The approach presented in this paper enables to address a range of societal developments that are important for the socio-technical configuration in the core of the regime. An increasing public sensitivity for climate change, for instance, might lead to a strong emphasis on energy efficiency in transport and support a trend countering the current rise in SUV sales. However, this does not necessarily mean that the overall number of cars is reduced, particularly when trends such as cocooning or individualization push car-ownership even deeper into the core of the regime. Neither does it imply that SUVs and/or all-purpose cars are just replaced by smaller vehicles. Such simple predictions would not sufficiently account for the complex interplay in the core of the regime. The two scenarios show that changes of some institutions might lead to movements of other core institutions as well and new configurations might emerge with their own preference structures and specific technical requirements.

The results prove that the approach provides a valuable amendment for technology assessment. The systematic and transparent variation of institutions in socio-technical systems meets core requirements of TA. The approach is successful in opening up TA-approaches for a broader perspective by laying stronger emphasis on potential variations in the highly sedimented institutions, and hence, in a way, decenter technology from the TA analysis. This perspective is also likely to inform other future oriented technology approaches such as foresight or FTA. Related to policy implications for policy makers, our approach helps to identify institutional changes, which are likely to critically influence transition dynamics. These may be carefully observed by policy makers and industrial strategists to better anticipate the future course of transitions and, last but not least, to identify suitable entry points for policy interventions.

Further research can be suggested in three fields. Firstly, it could be elaborated whether other plausible institutional trajectories can be mapped consistently for the field of electric vehicles. Secondly, the TA-process could be completed by applying sustainability assessment criteria to the scenarios and by developing more specific policy recommendations. Thirdly, the scheme could be applied to other typical TA cases. Nearly ideal candidates in the field of future transport options are the introduction of personal air vehicles into the transport system as well as the potential diffusion of technologies for autonomous driving. In both cases, it is argued that not the technologies themselves but rather regulative, cognitive and normative institutions are decisive for the future development of these approaches (Fraedrich and Lenz, 2014; Meyer-Soylu et al., 2014). In both cases it will be important to assess institutional trajectories and corresponding socio-technical dynamics. The approach proposed here may prove to be suitable.

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