Governing Fuel Cell Innovation in a Dynamic Network of Expectations

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Abstract

Expectations and visions have been identified as a forceful element in the governance of emerging innovations. However, visions and expectations frequently change rather dynamically creating vulnerability to strategy and policy processes, which have to deal with the dynamics and tentativeness of expectations, either ex post when expectations have changed, or even ex-ante, when possible future changes in expectations are taken into account in the set-up of governance measures. In this article, we follow the dynamics of fuel cell expectations in the German policy discourse, highlighting how these fuel cell expectations were linked to a wider network of expectations, and examine if and how policy measures were discursively related to these expectations, and how policy dealt with the dynamic evolvement of expectations. We show that fuel cell expectations alone were not sufficient to trigger substantial policy support; only once they linked up with visions and expectations about the future energy system and the future socio-technical landscape, supportive policy measures were set up and expectations became materialized and institutionalized in the governance of the field. Still, despite dedicated and successful efforts to stabilize policy support for fuel cells, governance remained tentative, as it had to adapt to changes in the network of expectations, in particular the rise of expectations on battery-electric vehicles.

Keywords: sociology of expectations, multi-level perspective, fuel cells, electric vehicles, governance

1. Introduction

The emergence of new technologies is characterised by a broad array of inherent uncertainties. This holds all the more for technologies with the potential to turn into a radical innovation. These technologies typically pose particular technological challenges, they allow new ways of application, require the adaptation of regulatory frameworks; they affect established business models, and new constellations of innovation actors have to be set up. In the face of these uncertainties, actors involved in innovation and governance processes have to rely on expectations rather than on robust knowledge for developing strategies and policies. Especially collective expectations, i.e. expectations that are part of a widely acknowledged social repertoire, have been shown to be particularly influential (Bakker et al., 2012; Borup et al., 2006; Konrad, 2006; Konrad et al., 2012; Raven et al., 2008). Collective expectations act as provisional, and in that sense tentative, but forceful assumptions on the future potential and requirements of an emerging technology, and thus constitute a core element in the governance of innovation processes (Borup et al., 2006; Haegeman et al., 2012). The important role of expectations is also acknowledged by approaches dedicated to governing radical innovation processes, such as transition management and strategic niche management (Geels et al., 2008; Geels and Raven, 2006; Loorbach, 2007; Raven et al., 2008; Sondeijker et al., 2006). However, expectations often develop quite dynamically, up to sudden changes, due to developments within a technology field, as well as external developments in related sectors or competing technologies (Borup et al., 2006; Geels and Raven, 2006; Konrad, 2006; van Lente, 1993; van Lente et al., 2013). The highly dynamic evolvement of expectations creates challenges or even vulnerability for related governance processes, which have to deal with the dynamics and tentativeness of expectations, either ex post when expectations have changed, or even ex-ante, when possible future changes in expectations are taken into account in the set-up of governance measures. Thus, governance itself may become tentative in the sense outlined by (Kuhlmann et al., this volume) , either as de-facto tentative when flexibility is the outcome, or in a purposeful manner, when flexibility is actively sought.

Against this background, this article investigates how expectations on fuel cell technology developed in the German policy arena, taking into account expectations on the technology and its applications, as well as on further influential developments, e.g. related sectoral dynamics. Moreover we consider how these expectation dynamics affected the governance of the field and how governance processes and structures dealt with the uncertainty and changes in expectations. We focus on Germany, one of the highly active countries in fuel cell innovation, in the time period 1994 to 2011 (Neef, 2009; NOW, 2012). In this period fuel cell expectations were changing considerably: At the turn of the millennium many expected fuel cell technology to become widely implemented within a few years from then, for propulsion of vehicles, as combined heat and power systems at the household level (micro CHP), or as highly efficient replacements of conventional power stations. A number of companies announced the market introduction of fuel cells within the first half of the 2000s (Bakker, 2010; Konrad et al., 2012; Ruef and Markard, 2010b), and policy programmes to support the technology were initiated around the globe (Bernay et al., 2002; Neef, 2009). However, fuel cell technology did not live up to these optimistic expectations and the hype around fuel cell technology turned into disappointment (Bakker, 2010; Bakker and Budde, 2012; Konrad et al., 2012). In the second half of the 2000s, expectations about battery electric vehicles became increasingly optimistic, putting additional pressure on fuel cell expectations (Bakker et al., 2012). However, in Germany actors with stakes in fuel cell technology managed to translate the very positive expectations into stable support structures, and succeeded in maintaining these institutions – while adjusting them - in times when battery electric vehicles were generally expected to be more promising. This is in contrast to other countries, e.g. the Netherlands or the US, where fuel cell technology rather disappeared on the policy agenda, or was at risk to receive considerably less funding after the hype (Bakker and Budde, 2012; Bakker et al., 2012; Tollefson, 2010).

Conceptually, this paper draws on two bodies of literature: the sociology of expectations and the multi-level perspective of transition studies. Both literatures have shown the importance to consider different levels of, on the one hand, expectations and, on the other, 'real-world' processes, to understand the complex dynamics of innovation, up to broader sectoral transition processes (Geels, 2002; Ruef and Markard, 2010a; van Lente, 1993). Building on this, we develop a conceptual framework for the analysis of interrelated visions and expectations. Based on this framework, we analyze how visions and expectations related to different levels, such as a technology field, sectoral developments or broader societal trends, developed and influenced each other over time in the German policy discourse on fuel cell technology. Since we focus on the linkages between different expectations, we refer to these interlinked expectations as networks of expectations. Empirically we draw on a discourse analysis of German policy documents from 1994 to 2011, complemented by expert interviews.

Thus, the main research question of this paper is: *To what extent can the dynamics of fuel cell expectations and visions in the German policy discourse be explained by changes in the broader network of expectations and how have these dynamics affected policy support for fuel cell technology?*

With this paper we want to contribute firstly to a better understanding of the dynamics of expectations, which takes into account the complex interactions – or co-evolution – of collective expectations, and, secondly, to explore how policy responds to these dynamics.

The remainder of this paper is organized in 5 sections: First we present the theoretical background, and develop our concept of networks of expectations. Subsequently, we present the methodological approach, followed by an analysis of the German policy discourse around fuel cells and if and how these triggered or legitimated governance measures, be it in the form of regulatory measures, support schemes or further dedicated articulation of expectations. Finally, we discuss our main findings and assess if and in which sense the German fuel cell policy can be characterized as tentative.

2. Conceptual background

Expectations are specific assumptions about future developments or states, which are assigned a certain likelihood. Whereas in the sociology of expectations, expectations are often confined to "real time representations of future *technological* situations and capabilities" (Borup et al., 2006, p. 286), for the purpose of this article we reopen the scope of expectations to be considered to real time representations of future situations. We take into account non-technological expectations, since expectations concerning the future socio-economic environment or the institutional framework conditions can have a major influence on the technological innovation itself (Budde et al., 2012; Geels and Raven, 2006). We furthermore define the related concept of a vision as a coherent set of expectations, which usually have a normative connotation, for instance as imaginations about a desirable future (Berkhout, 2006; Eames et al., 2006).

Visions and expectations are a major driver of innovation activities. Although from different backgrounds and perspectives, a number of literature strands, such as science and technology studies, institutional theory, strategic niche management, foresight studies and innovation economics have scrutinized the role of visions and expectations for innovation processes (Barney, 1986; Borup et al., 2006; Brown and Michael, 2003; Geels, 2004; Haegeman et al., 2012; Kemp et al., 1998; Rosenberg, 1976, 1995; Swanson and Ramiller, 1997; van Lente and Rip, 1998). Some of these focus on the management of innovation in organisations, whereas our particular interest resides with the governance of innovation at the level of innovation fields. Hence, we focus in the following on two, partly overlapping bodies of literatures related to science and technology studies, which discuss the relation between expectations and the governance of innovation: The literature on transition studies (Geels et al., 2008; Markard et al., 2012) and the literature on the sociology of expectations (Borup et al., 2006). The literature on sustainability transitions emphasizes the role of expectations for the governance of long term transitions and particular innovations which may contribute to a transition. The sociology of expectations literature is concerned with the performative role of expectations on the one hand, and with the shaping and dynamics of expectations on the other.

Together these two strands of literature suggest a complex set of relations between expectations, innovation and the governance of innovation. The remainder of this section first discusses the insights from both strands of literature before proposing an integrated approach.

<u>Governing transitions: the role of visions and expectations</u>

The multi-level perspective analyses the development of radical innovations and major structural changes in established socio-technical systems, so-called transitions, as the outcome of processes at different levels and their interactions: the level of established socio-technical systems (regimes), of protected spaces, where radical innovations which are difficult to integrate in established regimes can develop (niches), and the level of broader societal developments, influencing the development of regimes and niches (socio-technical landscape).

The multi-level perspective and, in particular, related governance approaches like transition management and strategic niche management emphasize the crucial role of visions and expectations in guiding and coordinating transitions (Geels et al., 2008; Kemp et al., 2007; Späth and Rohracher, 2010). Strategic niche management regards the alignment and successive articulation of expectations and visions as one of the three key processes for the successful development of a niche (Geels and Raven, 2006). The development of such niche-related expectations has been shown to be influenced both by learning processes within the niche, as well as by niche-external developments in related sectors or competing technologies (Budde et al., 2012; Geels and Raven, 2006).

For the transition management approach, vision building processes are key to develop visions guiding transition processes (Kemp et al., 2007; Späth and Rohracher, 2010). However, the dedicated construction of a guiding vision has also been criticized by some as either not likely to be forceful enough, or prone to be captured by particular interests (Berkhout, 2006; Schot and Geels, 2008). While visions can be the result of dedicated vision-building processes, they may also emerge in discourses and turn into 'collective' visions, thus becoming part of a widely acknowledged discursive repertoire. Still the challenge remains that these visions are often 'moving targets', showing ups and downs and changes in meaning.

Several studies of past transitions have been performed, which allow to identify the eventual outcome of a transition by hindsight (Geels, 2002, 2006; Hofman and Elzen, 2010; Raven, 2004; Verbong and Geels, 2007). It is, however, considerably difficult to identify - and even less so to predict - specific transition processes ex-ante, since ongoing transformation processes may or may not result in fundamental transitions. Moreover they may unfold into different directions and multiple transition processes may interrelate (Konrad et al., 2008). In addition, the different visions and expectations circulating in discourses might appeal to different actor groups, making it difficult to identify a single guiding vision (Budde et al., 2012). Especially technologies considered important in sustainable transitions are often embedded in several diverging visions of projected transitions in the discourses that provide legitimacy and guidance to the actors involved in the transition process (Raven and Verbong, 2007; Ruef and Markard, 2010a). A single technology may thus link up with different visions of projected transitions. These links to different visions of projected transitions are a result of diverging normative considerations about the most desirable transition, as well as to the inherent uncertainty of the on-going transformation processes (Farla et al., 2010). As a result, the embedding of expectations about a technology in a specific vision is frequently only tentative and may change over time. The changing linking of expectations about a specific technology to broader economic or societal challenges on the one hand, and the necessity to deal with dynamic, potentially inflated technological expectations on the other, raises the challenge for governance to deal with this uncertainty.

The sociology of expectations literature

As has been shown in various studies, expectations, in particular widely acknowledged collective expectations, play a key role in mobilizing, legitimating, guiding and coordinating innovation activities and consequently in the governance of new and emerging technologies (van Lente 1993; Borup et al. 2006; Konrad et al. 2012; Budde et al. 2012). At the same time expectations are themselves shaped, coordinated and mobilized, and in this sense governed in various ways by diverse actors, be it in rather formalized procedures as technology assessment or roadmapping exercises, or in the form of contributions to public and other discourses by publications, talks etc. (Konrad, 2010; McDowall, 2012). To understand this important role of visions and expectations for innovation processes, Van Lente and Rip (1998) suggest to interpret expectations as “prospective structures”, since expectations about future social structures may function in a similar way as if they had materialized already, and they may eventually result in self-fulfilling prophecies. Thus, expectations have a mediating role between actors and structure. Actors try to shape expectations (prospective structures), which may eventually have an impact on the real structures (van Lente and Rip, 1998). It has been emphasized that struggle and power relationships play an important role in the shaping of these prospective structures; actors try to “colonize the future” by articulating expectations corresponding to a future desirable from their perspective (Berkhout, 2006; Brown, 2000). Thus discourses about the future reflect the contested nature of expectations with diverging and often opposing perspective on the future stated by different actor groups, since discourses are crucial in the mediation and shaping of expectations (Konrad, 2006; Wyatt, 2000). As shown by several studies, actors may consciously stimulate or even inflate expectations about a technology they have stakes in (Alkemade et al., 2011; Bakker and Budde, 2012; Bakker et al., 2012; Brown, 2000; Konrad et al., 2012; Petersen, 2009).

This tendency, as well as possible learning, e.g. about unexpected hurdles, and changes in the environment of an innovation field (see above) contribute to the dynamics of collective expectations, with phases of quickly increasing and spreading expectations, up to hype, phases of disappointment and shifts in what is considered as most promising options at a time (Alkemade and Suurs, 2012; Bakker, 2010; Bakker and Budde, 2012; Brown and Michael, 2003; Ruef and Markard, 2010a). As an implication, while potentially becoming a quite forceful element in the governance of innovation, as indicated in the concept of prospective structures, particular collective expectations can fulfil this role only tentatively.

So far, studies in the sociology of expectations have focused on the role and dynamics of expectations among researchers, industry actors or in media discourse. Although many activities are aimed to mobilize policy actors, policy actors respectively policy discourses have received less attention (for exceptions see Bakker et al., 2012; Beynon-Jones and Brown, 2011; Eames et al., 2006). This raises the question about the particular role of policy actors. In general, we expect policy actors to be rather in a position of observers and possible 'selectors' of expectations promoted by others, for instance particular innovation communities. Therefore, they are likely to follow to some extent the dynamic evolvement of expectations, even though certain policy actors may at times also turn into spokespersons for particular options (Bakker and Budde, 2012; Bakker et al., 2012), and decisions for support measures and public funding programmes can feed back on the development of expectations. At the same time, being in a selector position implies that we expect policy actors to 'follow' the expectation dynamics around an emerging technology only as far as these are able to link up with policy priorities, for instance relevant societal needs (Bakker et al., 2012).

Similar to transition studies, several authors have emphasized the importance of considering multiple levels of expectations and their mutual interactions, though making slightly diverging distinctions. Mostly they refer to a level of technology- or project specific expectations, to expectations referring to the perspectives of a technology field, and to broader societal developments (Geels and Raven, 2006; Ruef and Markard, 2010a; van Lente, 1993). Drawing on the multi-level perspective, Truffer et al. (2008) have furthermore differentiated between expectations referring to developments at the niche, regime and landscape level.

A multi level perspective on expectations:

Thus, both strands of literature provide insights in the complex relation between expectations and visions and innovation processes, and the governance thereof. We build on these insights and suggest a framework which, in line with Truffer et al. (2008) uses the levels of the multi level perspective (niche, regime, and landscape) not only to distinguish processes and activities, but also to classify expectations. What is more, we suggest drawing on the MLP as a heuristic for identifying possible interrelations and interactions between expectations and visions.[1] 'Real-world' niche,

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[1] Budde, B., Weber, K.M., Alkemade, F., 2012. Expectations as a key to understanding actor strategies in the field of hydrogen and fuel cell vehicles. Technological Forecasting & Social Change 79, 1072-1083. studied the relevance of visions and expectations related to the different MLP levels for actor strategies, but not how visions and expectations as such interact across levels.

regime and landscape developments can support and reinforce or contradict and weaken each other leading to complex dynamics (Geels, 2002; Geels and Schot, 2007; Schot and Geels, 2008; Smith et al., 2005). In principle, the same holds for expectations and visions; expectations at the landscape level, for instance an expected shortage of fossil energy resources, may support visions and expectations at the regime level, such as the vision of an energy system based on renewable energies. Following the argumentation by Van Lente and Rip (1998), changes in the structure of the field can be mediated by visions and expectations, in the form of prospective structures which eventually lead to actual structural changes. Thus, we expect structural similarities between the patterns of interactions, of activities at different levels (e.g. niche-regime) and the interaction of expectations and visions related to different levels. Besides the one already mentioned, further patterns of interaction well-known in transition studies may occur between visions and expectations at one or different levels. Expectations regarding landscape developments may support expectations about promising niche innovations. Expectations on niche innovations may align with a specific or even with several different visions related to the regime level. These can be competing visions on potential transformations of a specific regime, or visions regarding different regimes the innovation may align with. The latter corresponds to interactions and dynamics of multiple regimes as described by Konrad et al. (2008) and Raven and Verbong (2007). Finally, expectations on different niche innovations may compete or support each other, comparable to real-world multiple niche dynamics. Accordingly, the relations between these visions and expectations can be analysed as a *network of expectations* with a vertical and a horizontal dimension. On the one hand, there may be linkages and interactions between visions and expectations related to niche, regime and landscape level (vertical), on the other hand, linkages and interactions of visions and expectations occur at the same level, such as complementary or competing niche expectations and regime visions (horizontal).

While we expect to see similarities in the ways expectation networks and 'real-world' processes interact, it is important to consider the differences as well. Certain 'real-world' states or processes constitute structural, constraining or enabling conditions for other 'real-world' processes, in particular at lower levels. Expectations as "prospective structures" may work as a sort of functional equivalent to structural constraints, but need to be perceived as such, so will hardly work as hidden structure. Furthermore, in general 'prospective structures' will be more fragile and destabilize more easily – thus exhibiting a high degree of tentativeness. This can for instance be seen in the case of strong hype-disappointment cycles and the sometimes very sudden destabilizing of certain expectations if related expectations and visions, which so far created a protected space are shifting (Konrad, 2006). Furthermore, the fact that competing 'prospective structures' can co-exist simultaneously, has no straightforward equivalent in the real-world. Thus, while we assume that the multi-level analogy is helpful for identifying dynamic processes within expectation networks and relating them to real-world processes, there are also limitations of the analogy.

3. Data and methodology

We apply the suggested framework for analyzing the dynamics of fuel-cell related visions and expectations in the German policy discourse as represented in the German parliamentary documentation system, and we examine how these expectations were discursively related to policy measures. We start our analysis in 1994, when fuel cells are mentioned for the first time in our sample reaching back to 1990, and continue up to 2011, covering a number of changes in both expectations and policies.

We decided to focus our analysis on the discourse in the German parliament, the *Bundestag*, which is very well documented in the "Parliamentary Material Information System" (DIP, Dokumentations- und Informationssystem für Parlamentarische Vorgänge). The DIP database contains information and protocols of all activities in the German *Bundestag*, including stenographic protocols and all other printworks such as strategy documents of the government (DIP, 2013). While the plenary protocols, parliamentary inquiries and strategy documents represent only a part of the wider policy discourse, it allows identifying the major discourse phases and the main argumentation lines, it shows what is widely agreed or an issue of contestation, and links with debates on and decisions about policy measures become apparent.

Our discourse-based approach allows examining how expectations and visions are discursively related to policy measures, for instance legitimating certain policy measures. It is however not possible to follow the policy-making process in all its facets. Accordingly, our study allows to observe only some forms of tentativity in the governance of fuel cells, for instance in the form of de-facto tentative governance (Kuhlmann et al., this volume) when policy measures are adapted to changing expectations. Furthermore, intentional tentativity may come to the fore, if for instance the need for flexibility or reversibility is explicitly discussed in the discourse, or if uncertainties are reflexively taken into account. A more comprehensive analysis would also address considerations and steps during the policy-making process, but this is mostly beyond the scope of this paper. Still, in order to cross-check if our analysis covered the most important processes, and to learn about some of the considerations of key fuel cell actors involved in the policy process as well, we complement the discourse analysis with data from a series of semi-structured interviews conducted with key actors in the field of fuel cell technology.[2]

We created our sample by using multiple steps. Firstly, we searched for all documents assigned to the keyword/topic fuel cell ("Brennstoffzelle"), as pre-defined in the database. However, after a manual screening we had to sort out a number of documents, where no relation to fuel cells was apparent. Furthermore, the pre-defined keyword/topic was not available for the whole period of investigation. Thus, for the remaining years we used a full text keyword search for fuel cells including relevant truncations, followed by a manual screening of these documents.[3]

In a first step we compiled a summary of the main lines of argumentation. Subsequently, we identified expectations and visions (following the definition mentioned above) explicitly mentioning fuel cells, as well as further expectations and visions which were discursively related to them, e.g. if used for justification of fuel cell expectations. In addition, we classified them according to the level they referred to. Expectations referring to the future development of fuel cells and the surrounding socio-technical arrangement were coded as niche expectations. Expectations and visions about the future mobility or energy system were coded as regime level expectations, for instance expectations about the future role of privately owned cars in contrast to car sharing models, assumed common preferences of future car users, future emission regulations for vehicles or the role of renewable energy in the future energy mix. Expectations about relevant aggregated developments external to niches and regimes, such as climate change, the depletion of fossil energy resources or the further general economic development qualified as landscape level expectations.

4. Expectation networks in the German policy discourse

In this section we apply our framework to follow the development of fuel cell expectations in the German policy discourse, and examine how the development of expectations related to policy measures targeted at fuel cell innovation. In particular, we examine how fuel cell expectations were

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[2] These interviews mainly served to analyze the interaction between strategy-building and dynamics of collective expectations which were in the focus of a further step of our research project (Konrad et al. 2012; Budde et al. 2012).

[3] The keyword used was "Brennstoffzell*" (fuel cell*). In total 268 printworks (plenary protocols, parliamentary inquiries, legislative texts incl. drafts thereof, strategy documents, technology assessment reports, etc.) were identified as being relevant. However, the number of documents does not necessarily correspond to level of activities related to fuel cell technology, since a plenary protocol of intensive discussions counts as one document, while a parliamentary inquiry and the answer by the government are two separated documents in the database.

linked with and influenced by expectations and visions related to future regime or landscape developments. As we will see, the dynamic development of fuel cell expectations was not only a result of processes within the fuel cell niche, but as well affected by developments in related expectations. Furthermore, changing linkages in the network of expectations introduced additional dynamics.

Period 1: First discussions on the future potential of fuel cell technology (1994 – 1997)

In 1994, fuel cells caught attention in the German parliament for the first time. A member of parliament raised the question how the government assessed activities concerning stationary fuel cell technology (in particular Phosphoric Acid Fuel Cells, PAFC) in the USA and Japan (DIP, 1994). The responsible secretary of state in the ministry for research and technology responded that these activities were not considered as promising for German industry due to the advance of US and Japanese industry, and thus observing activities would be sufficient for German industries. (DIP, 1994). This lack of interest may be interpreted against the background of collective fuel cell expectations at the time. While optimistic expectations about the commercial potential for large-scale stationary applications of (PAFC-)fuel cells circulated in the international scientific discourse, attention in public media as newspaper and professional journals was still low (Budde & Konrad, (to be) submitted). The hype around mobile and small-scale stationary applications of fuel cells, which approximately lasted from 1997 to 2000 for mobile, and from 1999 to approximately 2003 for small-scale stationary applications, was yet to come. Actually, the parliamentary discourse on fuel cells took off from 1997 onwards, with a focus on stationary applications, now based on emerging fuel cell technologies such as Molten Carbonate Fuel Cells (MCFC) and Solid Oxide Fuel Cell (SOFC) (DIP, 1997b). In 1997, mobile applications, in particular for car propulsion, were discussed for the first time, referring to the first prototype cars presented by the automobile company Daimler[4] in previous years. However Proton Exchange Membrane Fuel Cells (PEMFC) – supposed to be the most promising fuel cell technology for the application in vehicles - were considered as too expensive for commercial purposes at the time. Still, a potential market introduction in 2005 was discussed (DIP, 1997a).

Thus, the policy discourse in this early period shows some reflection of the incipient rise of expectations on the future technological and economic potential of fuel cell technologies, with two streams, concentrating on either stationary or mobile applications. However, these niche level

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[4] The corporate name of Daimler changed several times between 1990 and 2010. From 1926 to 1998 the official company name was Daimler-Benz, which changed into DaimlerChrysler from 1998 to 2007 and Daimler from 2007 onwards. Nevertheless this paper refers to Daimler to maintain clarity, since the major share of the fuel cell activities within the corporation were conducted at the European Daimler facilities

expectations were not explicitly linked to expectations referring to developments at the regime or landscape level, and no need for active governance measures was deduced.

Period 2: Linking up with visions and expectations about (decentralized) energy systems (1998 – 2002)

In 1998, mobile fuel cell technology was increasingly mentioned in relation to the regime level vision of a future hydrogen-based energy system, a hydrogen economy. In an economy based on the universal use of hydrogen as an energy carrier, fuel cells would be the ideal technology to transform hydrogen into electricity for the propulsion of vehicles (DIP, 1998). However, this link of fuel cell technology to the vision of a hydrogen economy did not strengthen fuel cell expectations in the German policy context at the time. An intensive discussion in 1998 revealed that the government was very critical about the future use of hydrogen. Criticism focussed in particular on the high costs of hydrogen technologies which would require substantial subsidies over a long time period (DIP, 1998). The German government stated that the widespread use of hydrogen was not expected until 2030 to 2050 (DIP, 1998). So, due to the link with the vision of a hydrogen economy, which was expected being a prerequisite for the diffusion of fuel cell technology, fuel cells for transport applications were not perceived as a technology ready for deployment on the short or medium term.

Still, the development of fuel cells as a technology was explicitly discussed as a promising field, and stationary applications were presented as more promising due to higher flexibility in the fuel to be used, which – besides hydrogen – could also be natural gas, biogas, or coal gas (DIP, 1998). Thus, expectations concerning stationary fuel cell systems were not only linked to expectations about an upcoming hydrogen economy, but were also perceived as compatible with other possible future energy systems, relying on different energy carriers. Against the background of these discourses and diverging expectations about fuel cell technology (mobile, stationary, link to a hydrogen economy) the Office of Technology Assessment at the German *Bundestag* (TAB) conducted a comprehensive technology assessment project , which was, however, not reflected in the documented parliamentary debate (TAB, 1997).

Even though in the public media fuel cells for mobile applications were presented as highly promising at the time (Bakker, 2010; Konrad et al., 2012), there was hardly any mentioning of fuel cells in the following years in the policy discourse. Only from 2001 on, the attention for fuel cell technology in the policy discourse was rising again, coinciding with a swing of attention and expectations towards stationary applications in public media, in particular small-scale combined heat-and-power systems for single houses. The minister of economic affairs and technology stated that he expected stationary systems to be introduced to the market between 2005 and 2010 (DIP, 2001c). In particular, the question whether stationary fuel cell systems should be entitled to receive support as combined heat and power (CHP) systems under the German CHP law was debated intensively (DIP, 2001b). Thus expectations concerning fuel cell technology got linked with an ongoing governance process (CHP law), which was strongly related to the regime level vision of a decentralized energy system.

In 2002, a second report by the Office of Technology Assessment at the German *Bundestag* (TAB), building on the first one mentioned above, was at the core of an intensive debate about fuel cell technology and its future potential. The report was initiated with the explicit aim to provide a "realistic, holistic and differentiated picture of the state of development and future perspectives concerning a widespread use of fuel cell systems and its consequences [translated from German by the authors]" (DIP, 2002a, p.7). Finalised at the end of 2000, the report was first discussed within the committee on education, science, research, technology and technology assessment. All parties expressed agreement with the key findings of the report, that fuel cell technology would be in a "decisive phase" in which it was time for "setting the course for innovation [Weichenstellungen]" (DIP, 2002a, p.6). Furthermore, development activities around the world undertaken by large enterprises and public funding schemes "document the expectation, that fuel cells have significant market potential and could provide solutions for the transport sector and the energy industry" (DIP, 2002a, p.6). Despite the general optimism, the TAB report mentioned a number of hurdles, such as "numerous technical barriers, yet to overcome" and high production costs of fuel cells. In addition, the need to take into account competition with established conventional and other emerging technologies was stressed (DIP, 2002a). The report assessed stationary fuel cell systems as a promising technological option, in light of the expected decentralisation of the energy system. In a decentralised energy system, fuel-cell based CHP would be able to supply heat and electricity to households. Furthermore, these systems could provide electricity to the grid and visions of large numbers of stationary fuel cell systems operating as coordinated virtual power plants were discussed intensely. Thus such virtual power plants would facilitate the reliable operation of electricity grids, in an electricity grid which would be increasingly reliant on wind and photovoltaics. In contrast, the prospects of fuel cell vehicles (mobile applications) were contested, in particular with regard to the production of hydrogen and technical problems concerning the on-board storage of hydrogen (DIP, 2001a). The main findings of the report appeared to be shared by the different parties represented in the *Bundestag*, however the parties derived different policy implications:

Referring to the technology assessment report, the opposition party FDP (liberals) argued in favour of more dedicated public funding for fuel cell technology, which was opposed by the government parties SPD (social democrats) and the Green party. The latter called for a more balanced view taking into account the whole energy system (DIP, 2002b). Furthermore, the government parties argued that they had initiated already important funding schemes to support fuel cell R&D in previous years which would be continued. One of the most important sources for these funding schemes was the so called Future Investment Program ZIP (Zukunfts-Investitions-Programm). The ZIP was financed by the revenues the state generated from the auction of the UMTS mobile communication licences and enabled different future investments, among those fuel cell research (60mio EUR from 2001 to 2003) (DIP, 2002b, p.6 & p.88-90).

Whereas the potential of fuel cell technology was not disputed, initial discussions within the committee focused on the question of energy carriers used to operate fuel cells. In particular the production of hydrogen from nuclear power was controversial and led to different perspectives on the future of hydrogen. The Green party strongly opposed the use of nuclear power to produce hydrogen, because of low efficiency and called for the use of biomass to produce hydrogen (DIP, 2002a, p.8). In addition, expectations about the potential impact of fuel cells on the energy system were disputed: While the government parties expected a decentralisation of the energy systems (including more combined heat and power (CHP) systems), other parties expected the use of nuclear power, thus a more centralised energy system, to produce hydrogen to power fuel cells (DIP, 2002b).

To summarize, most expectations concerning fuel cell technology were strongly linked to expectations at the level of the future energy regime, either a hydrogen economy in the case of mobile applications, or a decentralized energy system in the case of stationary fuel cell technology. Different from the previous phase, the link of fuel cell expectations with the vision of a decentralized energy system enabled the community around stationary fuel cells to link up with an ongoing governance process (reform of the CHP law). However, in the case of mobile applications, the regime vision of a hydrogen economy was arguably too controversial to trigger further governance measures to support the technology. The link to landscape expectations was emerging, but still rather weak. With respect to the governance *of* expectations, in this period we now see dedicated efforts for the further articulation of expectations in the form of technology assessment studies.

Period 3: Fuel cells: promising, but one technology among others (2003-2005)

After 2002, attention for fuel cells decreased within the parliamentary discourse, with fuel cells being mainly discussed as a side-issue in more general discourses about industrial/technology policy (DIP, 2003a) or export of military technology (fuel cell systems for submarines) (DIP, 2003b). In 2004, the government initiated the development of a German fuel strategy (Kraftstoffstrategie), as an element within a German sustainability strategy. Based on a stakeholder process, different options on how to reduce the use of fossil fuels, increase energy security, and reduce greenhouse gas emissions were assessed. Hydrogen and fuel cell technology were assessed positively, but only on the very long term (DIP, 2007g).

In 2004, the opposition party CDU/CSU (Christian Democrats) launched a parliamentary inquiry on climate change and future energy resources including 73 questions to the government concerning its expectations about climate change impacts, future energy resources, energy efficiency, the future development in different sectors (e.g. transport, buildings, and industry), future technologies and how the government assessed these technologies at the time. Among others, the inquiry raised the question when the government expected mobile respectively stationary fuel cell technology to be ready and competitive for a widespread application (DIP, 2004b). Furthermore, the Christian Democrats proposed to focus governmental activities on concepts for the build-up and operation of a hydrogen infrastructure and the production of hydrogen (DIP, 2004a).

The government eventually answered the parliamentary inquiry in 2005, stating that new technologies would broaden the portfolio of technological options to cope with climate change and the expected energy scarcity. Among these technologies, carbon sequestration ("clean coal"), hydrogen and fuel cell technology and technologies to increase the efficiency of fossil fuel technologies were mentioned. The use of hydrogen for transport was regarded as an "important field of application" of new technologies referring to the ongoing strategy processes for new energy carriers for transport, and the clean energy partnership (CEP), a large hydrogen demonstration project in Berlin (Bonhoff, 2008; DIP, 2004a). However the government clearly stated that the efficiency and desirability of fuel cells and hydrogen would depend on the primary energy source (DIP, 2005b). Hydrogen was discussed as a promising universal energy carrier to store energy from different sources, with renewable energy sources being the most desirable option to produce hydrogen. However a large share of electricity from renewable energy sources would be available on the long term only, when fluctuating energy sources such as wind or solar energy would provide large shares of electricity in the grid. Consequently, the decisions concerning "investments in the infrastructure for [energy] storage [were] significantly influenced by the development of fluctuating energy sources. An authoritative forecast [was] not possible." (DIP, 2005b, p.10). Furthermore, an "assessment concerning the broad application in mass markets" did not seem possible either. (DIP, 2005b, p.12). According to some speakers, the use of nuclear power would have negative effects on new innovative technologies, such as gas turbines, renewables or fuel cells (DIP, 2005c). Thus, fuel cells were regarded promising, but as one technology among others.

While in the previous period fuel cells had been positioned mainly in relation to the visions of a hydrogen economy and a decentralization of the electricity system, in this period these visions were complemented by expectations and visions about an energy system based on renewables, which were at least to some extent shared by the parties. However, due to the long term horizon and perceived uncertainties, the governmental actors did not identify an immediate necessity for an intensification of support measures in the field of fuel cell technology. Expectations concerning the landscape level, in particular with respect to climate change, became more relevant, but not closely linked to the regime and niche level expectations. Policy measures rather focused on a combination of dedicated expectation-building and strategy-building in the form of the German fuel strategy process.

Period 4: Fuel cells, competitiveness, jobs & climate change (2005-2007)

The fourth period is characterized by the recurrence of attention for fuel cell technology, the creation of a strong link with a discourse on competitiveness as well as the issue of climate change, and the decision to launch a large fuel cell and hydrogen support programme.

In 2005, Germany saw a preponed change in government, a grand coalition of Christian Democrats and Social Democrats replaced the previous coalition of Social Democrats and the Green party. In this year, the liberal party called for a climate protection initiative 2006 (Klima-Schutzoffensive 2006) promoting policy action on the international and national level, aimed at furthering the Kyoto process and the reduction of greenhouse gas emissions. As one of the key points, policies were to be developed that would establish "Germany as a high tech region to focus its forces, in order to maintain and further develop a technological leadership role in energy technologies" (DIP, 2005a, p.3). The further development of fuel cell and hydrogen technologies and the erection of a hydrogen infrastructure was advocated, as a way "to make sure that renewable energies, beyond fuels based on biomass, will be a viable and economic option in the transport sector" (DIP, 2005a, p.3). At the same time, the government aimed at developing policies to improve industrial competitiveness and address societal challenges, in particular energy security and climate change (DIP, 2005d). In parallel, the committee on education, science, research and technology and technology assessment of the German *Bundestag* contracted the TAB to prepare a report about future transport technologies, which could contribute to a significant reduction of CO2 emissions. This report was eventually published and discussed in 2007 (DIP, 2007c, see below).

The new government emphasized the role of technology and innovation to maintain and improve the competitiveness of the German economy; from 2006 onwards the government initiated lighthouse projects to strengthen the position of "Germany as a hotspot for technological innovation", including the field of fuel cell technology (DIP, 2006d). In order to support growth and new jobs, the government developed a "High Tech Strategy" (DIP, 2006b, c), as part of which six billion EUR were allocated for implementing different measures and initiatives. New energy technologies were chosen as one focus area, in light of the expected societal challenges of climate change and the depletion of fossil energy resources (DIP, 2006c). Hydrogen and fuel cell technologies among others were part of the list of promising technologies to be supported. The goal, that on the long term the ideal and most sustainable option would be the use of hydrogen produced from renewable energy sources, remained unchanged, and the further development of renewable energy technologies was declared as another area with high priority in the high-tech strategy (DIP, 2006c). In general, the vision of a hydrogen economy was discussed with a more positive attitude now, as it would create new opportunities for renewable energy technologies such as wind and photovoltaics.

In 2006 the government announced the launch of a ten year national innovation programme (NIP) on hydrogen and fuel cell technology, financed by funds from the High Tech strategy (DIP, 2006b). The aim of the NIP was to maintain and enhance the competitiveness of German research and development actors in the field, and to accelerate market introduction (DIP, 2006b). A budget of one billion EUR was assigned to the programme, 500 million EUR provided by the government, and at least another 500 million EUR by the industry (DIP, 2006a). Following the commitment of the industry actors, it was agreed that the programme would be managed by a specifically established organization, the National Organization Hydrogen and Fuel Cell Technology (NOW), supported by an Advisory Board, thus staying in close collaboration with key stakeholders (Expert 2; Expert 3; Garche et al., 2009). The programme primarily aimed at accelerating and supporting the market entry and diffusion of mobile, stationary and portable fuel cell applications, but it was acknowledged that one of the “fundamental questions to be answered” was how to provide the necessary amounts of hydrogen in an efficient and environmentally sound way (DIP, 2006c, p.36).

According to a key industry expert involved in the setup of the NIP, research and industry actors convinced policy actors that hydrogen and fuel cell technology needed more time and stable framework conditions, and to move “away from the expectation to deliver results in three or five years [...] the call for a ten year programme [was] chosen in order to avoid immediate euphoria, and to avoid a negative twist in case public opinion changes in three years. To avoid throwing out the baby with the bathwater [translated from German by the authors]” (Expert 1).

To summarize, while still being seen as part of a portfolio of promising options, fuel cells were more and more emphasized as one of the key technologies of the future. Fuel cell expectations remained strongly linked with the vision of a hydrogen economy, which gained in attractiveness, the more it was linked with renewable energies. Jointly, expectations about fuel cell and hydrogen technologies linked up with expectations referring to the landscape level, in particular expectations about climate change and the expectation that fuel cell technology would maintain and improve the competitiveness of German industry players and support the creation of new jobs appeared to be important. This linking to expectations at the landscape level appeared to be stronger than in previous phases. The expectation that hydrogen and fuel cell technology would contribute to greenhouse gas emission reduction was used frequently, as the issue of climate change became increasingly important in the parliamentary discourse. According to one of the industry experts involved in the set-up of the programme, the promise to be able to reduce CO2 emissions of houses by 30% using stationary fuel cells in small scale CHP systems (micro CHP), was one of the main arguments to convince policy to grant the support programme (Expert 2) .

In contrast to the years before, this period saw the emergence of dedicated policy support for fuel cell technology, with the establishment of the NIP. This policy measure was facilitated by the change of government, which created an opportunity structure to position the outline for a support programme, recently developed by a network of fuel cell actors. Actually, the decision to create a fuel cell support programme was part of the coalition negotiations (Expert 1; Expert 2; Expert 3). On the discursive level, the emergence of a strong link between fuel cells, hydrogen and the topic of economic competiveness in an increasingly globalising world and climate change, was supportive as well. This linking to current expectations in line with current policy priorities was actively sought, as reported by two major fuel cell actors involved in the development of the programme outline (Expert 2; Expert 3). Remarkably, the launch of the 10 year NIP was intended as a means to deal more reflexively with the expectation dynamics experienced in the recent past. The creation of such a long term programme and a dedicated hydrogen and fuel cell organisation was an attempt to “stabilize” the governance of fuel cell technology and reduce the uncertainties, at least with regard to national RTI policy in the field.

Period 5: Climate change, renewables and the rise of electric mobility (2007-2011)

In this period, fuel cell expectations were on the one hand strengthened, due to a number of the supportive expectations in the network gaining in importance, and at the same time challenged by the emergence of optimistic collective expectations on battery-electric vehicles.

Climate change action remained, if not even increased as a major priority on the parliamentary agenda. With respect to the transport area, a report published by the office of technology assessment in 2007, emphasized that transport was the only sector with increasing CO2 emissions in previous years, requiring further action (DIP, 2007c, p.4). The report provided an overview on technological options for alternative drivetrain technologies and fuels. The market introduction of fuel cell vehicles was expected earliest 15-20 years in the future, since the “euphoria of the 1990s has [had] cooled down” (DIP, 2007c, p.6). Still, the technology was considered as promising, though dependent on the future production of hydrogen and the progress of renewables. The hype around fuel cells was reflected even more critically in a further technology assessment report on demand oriented innovation policy: “Communication activities for fuel cell systems gave the impression that already tomorrow whole fleets of clean vehicles would be on the road [...] These communication activities raised counterproductive expectations, which could not be fulfilled considering the state of the technology, causing scepticism regarding fuel cells.” (DIP, 2007e, p.102) Apparently, this scepticism was not shared by the authors of the report, who called for additional supportive policy measures (demonstration projects, regulations, etc.). They furthermore emphasized the importance of vision building processes, roadmaps and the like: “The importance of such consensus- and communication processes cannot be overestimated, because they provide orientation for private and public investment decisions and reduce uncertainties” (DIP, 2007e, p.14). In line with this, key stakeholders and policy actors developed a fuel cell roadmap, the national development plan (Strategierat Wasserstoff und Brennstoffzellen, 2007), which became the key orientation point for the NIP providing detailed information about supported topics, time scales and budgets – the “bible”, as it was positioned by one of the experts involved in the NIP (Expert 2).

Expectations on stationary fuel cells and the electricity system more broadly did not change substantially in this period. Expectations concerning climate change and emerging markets for new technologies remained closely linked, as manifest in terms as “future market climate change” circulating in the discourse (DIP, 2007f). Hydrogen and fuel cell technology were particularly discussed as possibly going to play a key role for storing excessive electricity from renewables as (off shore) windparks and photovoltaics, or as virtual power plants (DIP, 2007b, 2008b).

Alongside the discussion of fuel cells, very positive expectations concerning (battery) electric vehicles emerged in the public discourse at the time, and were reflected as such in the parliamentary discourse. The green party called for the formulation and implementation of a comprehensive climate protection strategy and the support of alternative drive train and storage technologies in vehicles, going “beyond fuel cell and hydrogen technologies, to support batteries, plug in hybrid technologies and pure [battery] electric vehicles” (DIP, 2007a, p.3). Subsequently it was discussed if the title of the NIP should be extended to cover hybrid and electric vehicles as well, however this proposal was eventually rejected by a broad majority (DIP, 2007d).

In 2008 (battery) electric vehicles were gaining more momentum and four ministries decided to set up a coordination platform and to develop a national development plan for “electric mobility” (DIP, 2008c, d). Expectations on “electric mobility” were, just like hydrogen and fuel cell expectations, linked to the anticipated need to balance supply and demand in the electricity grid, resulting from an increasing share of renewables. “The battery of the electric vehicle can provide an important contribution to [an efficient] management of the grid. [...] [The government] aims to focus and increase its activities in the field of electric mobility [...]" (DIP, 2008d, p.96).

In addition, some disappointment concerning hydrogen and fuel cell technology was articulated in 2008, when an inquiry led by the Liberal party was referring to the "sluggish" development in the area of hydrogen and fuel cell technology and a "dynamic" development in the field of battery technology (DIP, 2008a, p.1). Also here, large parts of the network of expectations sketched around battery electric vehicles was congruent with the one around fuel cells: CO2 reduction, "efficient use of renewable energy, since electric vehicle promise to provide an option to store electricity from fluctuating sources" (DIP, 2008a, p.2). In 2009, the Green party argued likewise calling for more support for electric vehicles due to the expected complementarities with renewable energy sources (DIP, 2009b). Although electric vehicles would be on the market on the short term, research funding in Germany was considered to be modest in comparison with other countries like Japan and "still" focussed on fuel cell and hydrogen technologies (DIP, 2009b, p.9). However, the Green party expected fuel cells to play a role in the long term as range extenders for electric vehicles [5], referring to prototypes by General Motors and Daimler (DIP, 2009b, p.9). This perspective, of fuel cells being part of the vision of electric mobility, was emphasized by the government, stating that all electric propulsion systems such as hybrid, battery and fuel cell vehicles had great potential to reduce emissions and to reduce the dependence from fossil fuels. Furthermore the government shared the expectation that electric vehicles would help to integrate more renewable energy in the electricity grid (DIP, 2009a).

Consequently, the government launched a 500 Mio. EUR stimulus package which included new funding schemes to support electric engines, hydrogen and fuel cells and energy storage, since "Germany cannot afford to bet on a single technology", reflecting the high level of uncertainty at the time (DIP, 2009a, p3.). In addition, the government set the target of having one million electric vehicles on the road in Germany by 2020 (DIP, 2009a). This figure included both battery and fuel cell electric vehicles. Among these measures from the stimulus package was the setup of a programme respectively funding scheme for model regions for electric mobility (DIP, 2009c, p.49). Remarkably, it was decided that the program would be managed by the National Organization Hydrogen and Fuel Cell Technology (NOW), the organisation initially founded for the management of the hydrogen and fuel cell innovation programme.

[5] Fuel cells were envisioned to charge the batteries of an electric vehicle to enable a range of up to 600km.

Despite these activities by the government, the Green party raised doubts if these policy initiatives would be sufficient and identified a lack of knowledge concerning battery technology in Germany. Furthermore the Green party doubted if hydrogen and fuel cell technologies were still promising, given that major automobile companies as Ford or BMW had reduced their involvement in development of fuel cell and hydrogen technologies (DIP, 2010b, p.8). The government answered that "electric mobility [was] used frequently in a restrictive way and synonymously with battery electric vehicles. The term electric mobility, however is [applied] overarching for all approaches electrifying vehicles and includes electric, hybrid and fuel cell vehicles" (DIP, 2010a, p.2).

In 2011 minor adaptions of the NIP were implemented. Still, the government repeatedly emphasized that there would be a role for hydrogen fuel cell vehicles supplementing battery electric vehicles, not the least because of their superior range, provided that hydrogen would be produced from renewable energy sources (DIP, 2010c, 2011). Thus, fuel cell vehicles were reframed as being part of the vision of an electrification of transport.

To conclude, in the fifth period fuel cell and battery vehicle expectations took a very similar position within the broader network of expectations, which predestined them to a competitive position in relation to each other. While the two technologies were indeed mostly perceived as competing (Bakker, 2010), the German policy discourse *and* the supportive governance arrangements were adjusted in such a way, that these technologies were rather reframed and positioned complementary in relation to a broader regime level vision of an electrification of transport, even though this was not uncontested. Figure 2 provides a summarizing overview of the main linkages between expectations and visions at different levels.

As in the period before, we see indications of a reflexive governance of expectations, which tries to respond to the perceived and potential future dynamic evolvement of expectations. The main strategic thrust pointed towards stabilization, be it in the form of the set-up of a robust, long-term funding programme, or the crystallization and fixation of expectations in a roadmap, arguably as a response of the hype-disappointment dynamic which took place within the fuel cell niche. However, stabilization alone was not sufficient to respond to the 'external' dynamics of the rise of battery-electric vehicle expectations; now adaptation took place as well.

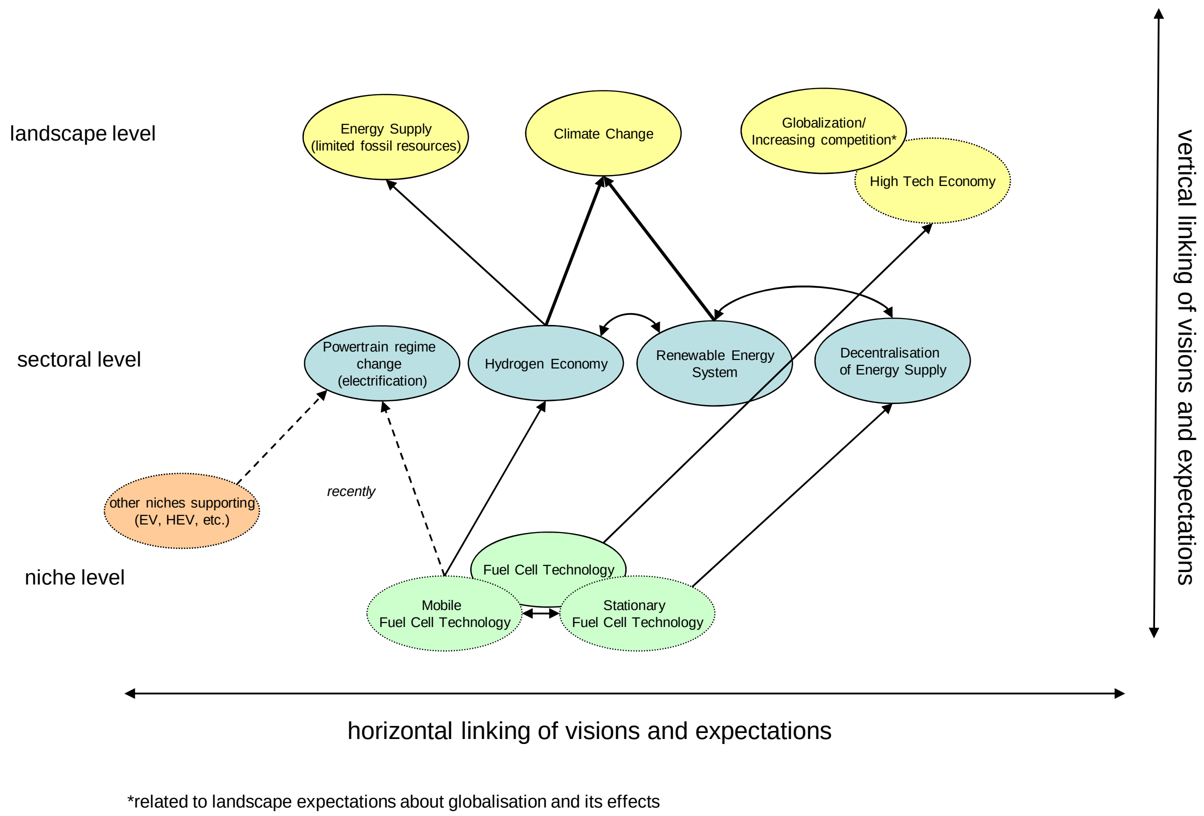

Figure 2 Networks of vision and expectations in the German policy discourse

5. Discussion and Conclusions

In this article, we set out to follow the multi-level dynamics of fuel cell and related expectations in the German policy discourse, to examine if and how policy measures were discursively related to these expectations, and how policy dealt with the dynamic evolvement of expectations.

Our analysis showed that collective niche expectations were an important reference point in the policy discourse. However, it became also clear that niche expectations alone were not sufficient to trigger substantial policy measures, as exemplified by the fact that the hype around mobile fuel cell applications did not result in immediate policy action. Apparently, only once and as far as expectations about fuel cell technology linked up with visions and expectations at the regime and landscape level, they were able to facilitate the setup of supportive policy measures. In addition, but not surprisingly, linking to regime and landscape level expectations was only supportive, if these were widely shared and assessed positively across the policy spectrum, or the governing parties at the time.

The types of links and interactions we observed within this dynamic network of expectations reflect the broad variety reported in the literature of strategic niche management and transition studies for 'real-world' processes. We identified more or less supportive links between niche and regime expectations, supportive linkages between niche and landscape expectations, and competing and complementary linkages between expectations concerning different niche technologies. Niche expectations were related to multiple regime expectations and visions, both in the form of expectations referring to multiple systems a niche may relate to, such as visions regarding the electricity and the mobility system. Furthermore niche expectations were related as well to competing visions about the future of a particular system, for instance visions about a hydrogen economy based on renewables or nuclear energy, or a mobility system based on fuel cell versus battery-electric vehicles or – in the case of battery electric vehicles - to an overarching vision of an electrification of transport. These linkages are not stable, but change over time. A further dynamic element is introduced due to changes in the assessment of linked visions, as in the case of the vision of a hydrogen economy, or the assessment of battery-electric vehicles.

Dynamics do not only include reshufflings of the network of expectations. In addition, we observed a successive articulation of expectations – mainly in the later periods -, largely by way of dedicated expectation-building measures within working groups, which were initiated by actors of the "fuel cell community" (Expert 2), but joined by policy actors and became increasingly institutionalized. In parallel, the expectations qua content got more and more institutionalized as well, starting with discussions in working groups, and then getting inscribed into strategy papers, a roadmap and eventually turning into a "national development plan" providing guidelines for a funding program. In this way, the increasingly articulated expectations served to mobilize policy support, and to coordinate and guide concrete support measures. Dedicated articulation of expectations was, however, not only limited to the fuel cell community, but also initiated by policy actors in the form of technology assessment studies, which mostly became important reference points in the parliamentary discourse.

Thus, this network of expectations functioned indeed as a prospective structure, which increasingly materialized in the governance of the field – including regulatory measures, support schemes and organizational structures - and with actors working actively towards stabilizing both the prospective-discursive and the material structures. At the same time, the discursive structures proved to be prone to change, and these changes led to adaptations of the governance structures, thus creating an element of tentativeness.

A case in point are the emerging links of expectations regarding fuel cell technology and battery electric vehicles under the regime level vision of an electrification of transport, which could be traced in the organizational structure of the field as well, as the example of the NOW above shows, which broadened its scope from a dedicated fuel cell and hydrogen support organization to administrating both fuel cell and battery-vehicle support schemes. Moreover, this joint regime vision allowed fuel cell and hydrogen technology to remain high on the agenda of the German government unlike in many other countries where fuel cell and hydrogen actors were struggling to maintain or restore (networks of) expectations concerning these technologies (Bakker et al., 2012). Therefore, the governance of fuel cell innovation can be characterized as dynamically stable. A similar phenomenon can be found on the regional level where the fuel cell initiative in Lower Saxonia ("Landesinitiative Niedersachsen") turned into the fuel cell and electric mobility initiative ("Niedersächsische Landesinitiative Brennstoffzelle und Elektromobilität"). More recently the initiative changed its name again to an energy storage and –systems initiative, responding to the perceived need of future energy storage technologies (Landesinitiative Niedersachen Energiespeicher und -systeme, 2013).

While these adaptations of support schemes following the discursive dynamics constitute a form of de-facto tentative governance, responding to the dynamics within the network of expectations when they occur, we observed reflexive strategies trying to cope in an anticipatory way with the dynamics of expectations as well. The hype-disappointment cycle around fuel cells at the turn of the millennium was reflected within technology assessment studies and by key stakeholders. As a response, stakeholders worked towards a supposedly more robust governance structure for supporting fuel cell development, by stabilizing expectations in roadmaps and a long-term funding scheme. Thus, future dynamics and uncertainties were taken into account, yet the intended response was only partly flexibility, but also stabilization in the context of a dynamic environment. However, apparently anticipation of further dynamics of expectations focused on dynamics of niche expectations, whereas the rise of battery expectations created dynamics on top of what was anticipated. This created a pressure to respond not only to the prolongation of time horizons (which could be responded to by a long-term program), but also to respond to the shift in expectations, which led to the described expansion of the scope of support programs.

Thinking beyond this paper, our framework could be further developed and applied for a reflexive approach of dealing with the dynamics within networks of expectations. The multi-level analysis of expectations may serve to identify weak, latent or potential future relations and interactions of visions and expectations, which may affect future discourses and ultimately governance processes. Thus this paper emphasizes the importance of taking into account expectations and visions related to all three levels linking up to emerging discussions among experts in the German fuel cell community, that higher level expectations were not taken into account sufficiently in previous expectations work (HyTrust, 2013) . Thus an analysis based on the insights of this paper could eventually contribute to a reflexive governance approach, which does not only respond ex post to shifts in expectations and expectation networks, but tries to anticipate to some extent possible future dynamics and reshufflings of expectations, for instance as a result of changes in related expectations or due to the intensification o so far weak or latent links.

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