The Governance of Innovations in the Energy Sector:
Between Adaptation and Exploration

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The field of electricity supply has slowly evolved over a long period of time. Electricity supply constitutes an example of a large technical system resistant to sudden changes or reorientations. The essential incentives for changes have come from the so called oil-price shocks in the mid ninety-seventies of the last century, the Chernobyl accident and the resulting critical attitude towards nuclear energy in many countries, the liberalization of markets driven forward by the European Commission, discussions about climate change and finally the Fukushima catastrophe. Such external events can lead to changes in governance structures. The standard operating procedure is to have the incumbent actors deal with external challenges in the established way of doing things (structures and actors). We assume that changes in the governance structure are not an immediate reaction to external shocks, but rather these external shocks have to be interpreted, mediated by new, skilled actors and perceived as a chance to see things differently and organize and build coalitions around these new frames. For a successful transformation, a change in the relevant power constellations which supports the incumbent governance structure is required. Processes of change in the end deal with the following question: which actors can achieve what aims under what conditions? The article will analyze four prominent cases in the energy sector to illustrate this point: the governance of the carbon dioxide capture & storage technology in Germany and Norway and the governance of photovoltaics development in Japan and Germany.

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Governance of Innovations: Structural Stability and Change

Over the last couple of years, research on governance has made much progress. We are now better able to understand how markets work, what mechanisms account for the functioning of industrial sectors and how technological developments come about and influence industrial activities (Ugur, 2013). In all these areas, coordination problems have to be solved in order to allow for a smooth operation of activities (Hall & Soskice, 2001; Beckert, 2009). Coordination problems are dealt with by a varying mix of private and public actors in a more or less organized manner. Governance in this context can be defined as all forms and mechanisms used for the coordination of actors, whose actions are interdependent, i.e. they can support each other in achieving specific aims or prevent them from happening (Benz et al., 2007: 9). The reflections on the importance of governance structures are theoretically usually informed by institutionalist thinking (Werle, 2012) and predominantly analyze specific regulatory structures (Mayntz, 2004). Research has thus been concentrated on the more static and structural aspects of governance. Most of the governance literature focuses on the internal operation of governance structures and presupposes that they are working in a more or less self-sufficient manner. At least as important, however, is the challenge to analyze the *change* of existing governance structures. It has been sufficiently discussed that structures, institutions as well as organizations are characterized by a specific immobility (Scott, 2001). Path dependence - among other factors - plays a significant role in making more radical change difficult (see Fuchs, 2012; Fuchs & Shapira, 2005). Verbong and Loorbach (2012) have recently established that especially in the field of energy infrastructures, "transition" to a new state is hard to come by. This is the effect of the inertia inherent in established governance structures. If we assume that to fight climate change, significant changes in the way our established system of electricity generation works have to be made, it is paramount to ask, whether the existing governance structures are fit for that task or whether we need to look for new forms or structures of governance to ensure a transition towards a more sustainable infrastructure. Studies employing an institutionalist framework or studies that are informed by one or the other strand of evolutionary theory have repeatedly and successfully attempted to show that changes especially of a fundamental nature will be the result of "external" demands (Meyer & Rowan, 1977) or major crisis and shocks emanating from the environment (Gould, 2002). Fundamental changes furthermore are not driven forward by the incumbent actors in a specific field, sector, organization or policy domain, but by challenger groups. The transformation of a field is linked to the successful realization of radical innovations as opposed to incremental innovations. Incremental innovations improve on existing ways, activities, conceptions and purposes of doing things, while radical innovations change the ways things are done. Under this definition, the key to classifying something as a radical innovation is the degree to which it reverberates out to alter the interacting system of which it is a part (cf. Padgett & McLean, 2006). How do radical innovations then come about and can we analyze the preconditions of stability and change with the same analytical apparatus? The present paper tries to make the suggestion that the Theory of Strategic Action Fields provides just such an analytical approach (Fligstein & McAdam, 2011; 2012). The potential usefulness of the approach will be demonstrated by four case studies from the field of electricity supply.

Analyzing Technologies and Sectoral Transformation

Earlier research within Science and Technology Studies and related fields has developed different analytical approaches to study sectoral transformation. Some of these will be briefly discussed here to help better understand the theoretical option we are advancing. One important line of reasoning can be associated with the so called "transition" literature heavily influenced by the work of Frank W. Geels (2005; 2011; 2012). It claims to have an analytical apparatus that would help us both understand as well support infrastructure transitions towards a more sustainable state. Research done in this tradition meanwhile shows an amazing breadth (see Truffer, 2012). Nevertheless, it faces some shortcomings. It has an implicit normative character, arguing that transition processes will and should develop in a direction towards more sustainability. We actually see transition processes as being open-ended. The outcomes of these processes are the product of a struggle between actors who define sustainability in different ways and favor different strategies and methods. A cornerstone of the transition approach is furthermore its emphasis on niches. Niches are important since they contain the seeds for transition processes. Niches therefore have to be protected, and new technologies have to be experimented with in these niches until they are ready to help transform the system. We share the view that transformation or radical change from within a system or sector is unlikely. We doubt, however, whether the niche concept provides the best analytical concept for understanding transition processes. Niches by themselves do not necessarily transform a sector. Niches are to be found everywhere. There are niche markets which thrive on the simple fact that they concentrate on niches, e.g. by offering very high-quality or specialized products or services which are relevant only for a tiny minority. Radical change in sectors such as telecommunications on the other hand was not driven forward by niche actors but by political decisions and powerful actors from outside the field. The niche argument ultimately tends to underrate actors' aspirations and strategies which may or may not aim towards sectoral transformation.

Another line of reasoning is represented by the Technological Innovation System (TIS) approach. Again, this approach has produced an impressive number of valuable studies over the recent years and we can benefit from their results (Coenen & Lopez, 2010). Pioneering work on TIS was carried out by Bo Carlsson and Rikard Stankiewicz (1991). They define TIS as follows:

> network(s) of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion and utilization of technology. Technological systems are defined in terms of knowledge or competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks. (Carlsson & Stankiewicz, 1991: 111.)

Given that technology is the common denominator in TIS, a framework can be used that is geared to studying how the configuration of actors, networks and institutions changes over time as the technology develops (Carlsson, 1997). Recently, the emphasis on a dynamic analysis of TIS has received considerable impetus by explicitly focusing on the functions, activities or processes taking place within the system of innovation (Hekkert et al., 2007; Bergek et al., 2008). It remains somewhat ambiguous, however, how exactly the boundaries of a technological domain are set in relation to its geographical and sectoral embeddedness. Markard and Truffer (2008) remain critical of the inconsistent way that empirical studies of TI systems have delineated the system, using it either in a rather descriptive way as a synonym for sector or just as a catchword. From a sociological point of view, the uses of the systems metaphor and its more or less arbitrary listing of functions as well as its treatment of the concept of institutions have been criticized.

Recent theorizing in the social sciences in general has stressed the importance of the meso-level and especially of meso-level social orders where actors (who can be individual or collective) interact with knowledge of one another under a set of common understandings about the purposes of (in our case) a specific sector, a field, the relationships there (including who has power and why) and the sectors' rules (cf. Martin, 2003; 2011). This is an interesting parallel to the Multi-Level Perspective, which has a similar aim. Observing actions in meso-level social orders has already been implied in the various versions of institutionalist thinking. Meso-level orders have been called sectors, organizational fields, games, fields or networks. Most of this theorizing, however, is very static. It is difficult to use the insights produced by these studies to investigate change. Concepts like, for example, "institutional" or "organizational logic" are well suited for analyzing periods of stability, but not for the study of processes of (potential) transformation.

Interdisciplinary innovation research, finally, has also stressed the importance of the meso-level. One important strand of research has been done under the label of "Sectoral Systems of Innovation" (Malerba, 2004). This research, however, also suffers from an under-conceptualization of processes of change and transformation. In the institutional tradition, processes of transformation are described as "periods of mismatch" (Dosi et al., 1988: 11) or as "periods of considerable confusion" (Henderson & Clark, 1990: 12). Thus a more thoroughgoing analysis is necessary that highlights the interplay between incumbent, stabilizing and changing forces.

In our view, the Theory of Strategic Action Fields (TSF) provides an analytical framework that enables the analysis of dynamic developments, is not normatively based and is also not technology-centered. We conjecture that a strategic action field is dominated by a set of incumbent actors who share a common belief about what the field is all about, how specific positions are attributed to actors, what the aims of the field are and the legitimate ways to pursue these aims. From a plentiful supply of empirical evidence and theoretical considerations, we can safely assume that incumbent actors will try to oppose demands for change that will destabilize their position in the field and the dominant ways of doing things. Change will therefore be driven forward mostly by challenger actors, less powerful actors within the strategic action field under analysis or from outside actors "invading" the field. The success of the challenger actors depends on their ability to frame the problems the field is concerned with in a novel manner, to organize around this new frame and implement new innovative measures, which eventually might change the rules of the game into their favor. These groups of actors can benefit from developments apart from the field, which are of relevance to internal field processes. The developments could concern political decisions such as the Energiewende decision in Germany or the liberalization of energy markets; changes in macro-cultural discourse such as the growing awareness of the dangers of climate change; or widespread external opposition against specific technological options such as nuclear energy. For significant change to take place, these external developments have to pose significant threats or provide opportunities for the realization of collective interests. Those delivering the threats or opportunities must have command over sufficient significant resources in order to be able to generate and sustain action. Under normal conditions, the formidable resource advantages – material, existential/symbolic and political – enjoyed by incumbents are simply hard to overcome on the basis of internal dynamics alone. Significant changes to a field will also require the use of innovative and new – possibly previously prohibited – forms of collective action. The role of individual or corporate skilled actors is paramount. They need not only to fight for a new interpretation of what the field is all about, but they will also have to forge new coalitions and compromises reaching beyond the initial set of challenger actors. Analyses of processes of sectoral transformation have shown that such processes as well as their outcomes are difficult to predict and might take different forms, such as: (a) a re-imposition of the old regime with some adjustments; (b) the breakdown into unorganized social space; (c) the partitioning into several spaces (e.g. renewable vs. traditional electricity generation); (d) the development of a wholly new regime (cf. Mahoney & Thelen, 2010; Fligstein & McAdam, 2011). We reserve the term "transformation" for the last option.

The theory of strategic section fields shares many concerns and ideas with the Multi-Level Perspective as developed by Frank W. Geels. One main difference is that the theory of strategic action fields aims to be a general social theory that should be able to be applied to the analysis of a wide array of sociologically relevant problems and thus communication across the many sub-fields of social sciences could be made easier. From an STS point of view, the challenge is to show whether the approach can also be usefully addressed to the analysis of technology-related problems. To help with this task, within the theory a set of hypotheses have been formulated that can be tested by doing quantitative as well as qualitative studies. A hallmark of the theory without any doubt is its concept of fields and the linkages to the present vibrant discussion in sociology on this topic (cf. Martin, 2011). Epistemologically, the TSF in its empirical analyses tends to follow a realistic approach. Aspirations of actors are taken as a starting point and the limits of fields, which might develop out of these activities, are determined not abstractly but by the problem-oriented activities of the actors themselves.

New Technologies, Governance and the Energy Sector

In most developed countries, the organization of electricity supply in the past had been shaped by a small group of industrial actors along with political and regulatory decision makers (Viktor, 2002). Electricity supply constitutes a prime example of a large technical system (Mayntz & Hughes, 1988; Mayntz, 2009) characterized by a substantial degree of institutional inertia. The more intensive the organizational needs and the more complex and empowered a socio-technical system's structures are, the more demanding and protracted a substantial transformation will be. This is especially true for the tightly knit networks and the capital-intensive organization that exist in the electricity supply system. In many countries, decisions on the use of specific technologies (e.g. nuclear energy, renewable energies) have not been the result of the activities of profit-maximizing economic actors. The essential incentives for changes in the energy sector have come from the so called oil-price shocks in the mid ninety-seventies of the last century, the Chernobyl accident and the resulting critical attitude towards nuclear energy in many countries, the liberalization of markets driven forward by the European Commission, the Fukushima catastrophe and discussions about climate change. Large energy infrastructures are the precondition for economic development. But the dominant ways of generating electricity by extracting it from fossil fuels (coal, oil, gas) have been made responsible for the human-induced part of climate change. Insofar an important element of fight against climate change is the improvement of old technologies to make them more climate-friendly or the development of new technologies, which promise to be climate-neutral from the start. The variety of existing technological solutions can be aligned on a continuum between adapting existing technologies and exploring new ways of generating electricity. In the following I will analyze the so called Carbon Dioxide Capture and Storage (CCS) technology as an example for the "adaptation" option, which is aiming at making conventional power plants work more climate-friendly. The CCS technology is considered by the International Energy Agency as the only viable and available technological option if societies want to continue to use and build conventional power plants and reduce CO2 emissions at the same time. A more decisive challenge for the existing governance structure is coming in the past, present and future from the area of renewable energies. The traditional way of generating electricity has as its backbone a centralized structure with big electricity generating units, which are run by a small group of potent firms. Renewable energies on the other hand are not only vying for attention with the claim to develop a new, climate friendly and secure way of electricity generation, but also favor a decentralized design, demanding and offering new roles for entrepreneurs as well as consumers. A totally new form of governance seems possible.[1]

Applying the Theory of Strategic Action Fields, we aim to show that the success of the technologies in transforming the given field of electricity generation in order to make it more sustainable is dependent on the ability of actors from outside the field to destabilize the dominant system and organize political support. Concerns about environmental sustainability and energy security have made sustainable energy transitions a prominent political question in industrialized countries. Previous research in these areas has confirmed that external shocks and positive reinforcement dynamics are central to understanding transitions (Unruh, 2000; Jacobsson & Lauber, 2006; Lipp, 2007). Similarly, the literature on the domestic responses to international shocks emphasizes that international pressures influence national politics in variegated ways (Gourevitch, 1978; Ikenberry, 1986). However, these theories do not offer insights into the political strategies that underpin or impede sustainable energy transitions. Energy transitions linked to climate change argumentations in principle require global decarbonization (Unruh, 2000). As of yet, there is no "global solution" to be expected. One reason is that the costs of achieving emissions reductions without improved energy technologies or an overall switch to new technologies is high (Barrett, 2009). According to many commentators, a sustainable energy transition is not possible in a society unless the government intervenes by imposing binding constraints on carbon emissions, either through direct regulation or by using price instruments (Unruh, 2002; Fischer & Newell, 2008) and develops suitable frameworks for the development of new technologies. From this vantage point, sustainable energy transitions are fundamentally political.

The Development of CCS in Germany and Norway

Using the example of CCS, we will analyze what governance of technology-oriented incremental innovations in the energy sector looks like and how different actor constellations and structures in a similar sector can lead to major differences in outcome and performance: a stalling development in Germany on the one hand

and a successful implementation based on a broad social consensus in Norway.

CCS in Norway

For generating electricity, Norway uses nearly exclusively water power. The significant domestic oil and gas reserves are mainly used for export purposes. Owing to this, the discussion on CCS in Norway was advanced by actors who did not have a significant role in the domestic electricity providing system as such. Leading actors for the development of the technology and a suitable governance structure had been the oil company STATOIL and research institutes like SINTEF and the Technical University of Trondheim (NTNU). In our terms, these were not proper incumbent actors in the field. Already in the 1980s, the idea of capturing and storing CO2 had been fancied. At the same time Norway's minister president Gro Harlem Brundtland chaired the *World Commission on Environment and Development* of the United Nations. Under her chairmanship, a comprehensive report on sustainable development was published. In 1991 Brundtland in line with her thinking on sustainability introduced for Norway a CO2 tax for fossil fuels and fossil-fuel-using sectors. This tax helped increase efforts over the 1990s to push forward plans for the capturing and injection of CO2 into oil and gas fields. Initially, this happened as a pure research effort, but gradually also in the form of projects testing whether the procedure was commercially viable. The interest of the oil and gas industry is derived from two activities linked with the CCS technology: the so called EOR (Enhanced Oil Recovery) and the EGR (Enhanced Gas Recovery). By both methods CO2 is injected into off-shore oil and gas fields in order to improve the efficiency of exploitation. This framing of the technology quickly brought other actors onto the playing field and the developing actor network. Norway's biggest industrial plant constructing company Kvaerner and international oil companies contributed to the research efforts. The driving force in Norway thus has been the oil and gas industry which started R&D activities as well as partnerships with scientific institutes. Its prime interest was the injection and storage of CO2 in nearly empty oil and gas fields. The industry joined forces with the government who looked upon CCS as a way towards demonstrating that Norway cares about the environment in spite of the fact that they are a major producer of fossil fuels. The government in turn was joined by a number of NGOs who interpreted the technology of CCS in a similar way. In this way, we can see a successful example of coalition building among actors from outside of the field of electricity generation. The government's sustainability agenda did fit well with the expectations of the oil and gas industry and its industrial partners. The coalition was further enlarged by NGOs, who also evaluated CCS as a technology very favorably.

Starting in 1996 Statoil began with the first commercial use in the gas field Sleipner West in the North Sea. From 1997 onward, research activities for CCS also got public support money from the KLIMATEK program sponsored by the Norwegian government. After Kvaerner had been successful with starting its first pilot installation of a CO2 capturer, Norway's second biggest technology company, Aker, also invested in R&D for CO2 capturing. Only later on did CCS become of greater significance and interest to the Norwegian system of electricity generation. Growing electricity demand could no longer be matched by domestic water power alone and environmental concerns were discouraging the building of new water dams. At this moment, the Norwegian energy provider Naturkraft acquired a license to construct two new gas fired power plants. A lively debate on the construction of these new power plants emitting CO2 ensued. Influential environmental organizations were favoring the implementation of the CCS technology for the new power plants. It seemed to be the only option, if attempts to decrease energy consumption were not successful and if on the other hand the government wanted to stick to the political aim (in the meantime also laid down in the Kyoto Protocol) of reducing CO2 emissions.

After the private R&D activities, the Norwegian policies as well as the geological storage potentials made ever bigger research efforts possible, which were now also supported by the European Union (in spite of the fact that Norway is not a member of the EU), and CCS gained solid support among the Norwegian public and most of the active NGOs. The initial debate on whether to build new gas fired power plants turned into a debate about the pro and cons of the CCS technology (cf. van Alphen et al., 2009: 49), which was initially won by the supporters of CCS coming from different camps. In 2011 the official Norwegian policy was guided by the idea that no new concessions for gas fired power plants will be granted if the CCS technology is not used.

Norway is a world leader in CCS development. It, however, features not only the technological capacities to implement it, but also in principle the political will and the public support. That CCS is still nevertheless no success story is related to the unclear financing of the technology (how much subsidies should come from the state?) and the unclear development on the world markets that seem to make it unlikely that Norway will be able to export this technology worldwide. Insofar the industrial partners as well as the oil and gas industry have become more reluctant in supporting CCS.

In conclusion, it can be said that CCS in Norway was driven forward by a growing and broad coalition of actors coming from politics, industry and the civil society. The pressure to use this technology for electricity generation did not come from the field proper but from actors and decisions external to the field. The development of the technology did not lead to a disruptive change, but was inclusive, oriented towards existing actor coalitions and broadening them in a largely consensual manner. The government succeeded in framing the problem as one of caring for sustainable development, it largely financed the development of CCS and constructed a suitable regulatory framework. It built a broad coalition of industrial and civil society actors supporting the CCS technology.[2]

CCS in Germany

An analysis of the governance of innovation for CCS in Germany gives a strikingly different impression. First of all, coal (absent in Norway) still plays an important role for electricity generation in Germany. 24% of the energy generated in Germany has brown coal as its source; an additional 18% is derived from hard coal (UBA, 2011). The brown coal used comes nearly exclusively from domestic sources and is at the same time the only competitive domestic fossil material used for electricity generation. After a period of stagnation, coal-fired power plants are again expanding in the German market, i.e. most running or planned construction projects are coal-fired power plants (cf. Pahle, 2010). As buyers of power plant technologies, the German utilities have a substantial interest in technological innovation that would allow them to continue running the coal-fired plants and build new ones. This refers to a further improvement of technology already in use to increase efficiency, but it also elicited an interest in CCS, which could significantly lower CO2 emissions. In the early years of the new millennium, politicians, industry and research shared the conviction that the pressure to reduce emissions would continue and this belief was further strengthened by the fact that the German Government committed the country to an ambitious climate policy (40 % CO2 reduction target by 2050 announced by the Federal Government). CCS therefore seemed to be a suitable solution if one wanted to continue running coal-fired power plants and reduce emissions at the same time.

The importance of coal is also highlighted by the fact that Germany is considered to be a worldwide leader in the development of technologies relevant for the running of coal-fired power plants (Weimer-Jehle et al., 2010). If CCS was to become a technological development with a worldwide appeal (especially in countries like China and India), German industry and research needed to jump on the bandwagon. Innovation activities in the area of coal-fired power plants and CCS in Germany were executed by a limited number of predominantly big actors. These were multinational companies like Siemens, Alstom and Hitachi Power Europe, which as dominant constructors of power plants build technically highly developed components like turbines, boilers and generators, producing them in a more or less identical manner for the German as well as the world market. Innovations are driven forward in clusters of research networks in which extra-university research institutions (e.g. Research Center Jülich), big university institutes, the R&D departments of the producer companies and the R&D departments of the customers, usually the four big energy providers RWE, E.ON, Vattenfall and EnBW are represented (cf. Rogge & Hoffmann, 2009: 7) – sometimes all of them at the same time. Driving actors in the development of CCS and the spread of its idea in Germany therefore are the firms constructing power plants, the domestic brown coal industry and the big energy providers, which operate the majority of the German coal-fired power plants and who were worried about the emission trade schemes and resulting increased costs. The support coalition included the government, which was concerned both with CO2 reduction aims and the competitiveness of the domestic industry. It was a coalition consisting of the incumbent actors in the field. These were the same actors which already in the past had worked in a cooperative manner to establish a stable field.

Given the importance of construction firms from an industrial policy point of view, early R&D activities were supported by the Federal Government, as mentioned. The leading actor in this respect was and still is the Ministry of Economic Affairs (BMWi). Within the so called COORETEC initiative for the promotion of research and development of future oriented power plants with fossil fuels, research projects and pilot installations for the capturing of CO2 were supported. At the site *Schwarze Pumpe* in Brandenburg, a big and traditional brown coal extracting area, the worldwide first trial installation for a CO2-poor brown-coal-fired power plant based on the Oxyfuel procedure was built. The pilot installation started to work in 2008 and was run by the energy provider Vattenfall. The aim was to test and further develop the technology in order to make it commercially viable. In a parallel effort Vattenfall also developed a 300 MW demonstration project, which was supposed to start operation in the years to come. It was planned to be again situated in Brandenburg, this time at Jänschwalde. In contrast to the Norwegian situation, the driving forces for the development of CCS clearly came from the incumbent actors of the field. Insofar innovation activities followed an established incremental course typical for this type of field, based on the interests of the incumbent actors and their networks. It soon became clear, however, that the second step in the CCS development process (looking for suitable sites to store the captured CO2) ran into difficulties. For this part, no established mechanisms were available and the approval of other actors became necessary, which hitherto did not play any role in the calculations of the coalition driving forward CCS. The commercial exploitation of CCS at the end had to cope with severe acceptance problems which threatened the success of the whole innovation process. Massive resistance against the exploration of possible storage sites became organized. Various citizen initiatives came into existence, which gradually gained the support of environmental organizations, but also of other associations, like the Farmers‘ Association and the Association of Water Power Companies (Schulz et al., 2010). After massive protests, the regional (state) governments became reluctant in their support for the Federal Government’s plans to push CCS. Especially the resistance of the state government of Schleswig Holstein made it impossible to pass a federal law on CCS. As a consequence, the energy provider RWE stopped its plans for building a demonstration power plant using the CCS technology in Hürth (Northrhine Westphalia). Even before this decision RWE had failed in its attempt to gain EU support for the project. The EU gave as a justification for its decision the public opposition against the search for storage sites in Germany. The only existing legal approval for the exploration of potential commercial CO2 sites, two sites in the state of Brandenburg, was based on state regulations, given the absence of federal rules. The permission was granted, however, with the expectation that a new federal law would soon be passed, which would then grant legitimacy to the state’s actions. Since the federal law did not materialize, the state government announced that the exploration permit can only be considered as temporarily valid. After long negotiations a new federal law was finally passed. It put the responsibility for accepting the technology in the hands of regional governments, which for political reasons at the moment do not have any interest in supporting CCS. Lobbying by the incumbent actors for a different solution was hardly visible. This was due to the changing field environment: neither the worldwide spread of CCS nor the expected attempts to charge CO2 emissions materialized. Insofar there is now not a national nor a world market for the technology and in addition no political will for regulatory actions. It is no wonder that at the moment (2014) Germany is increasing its CO2 emissions and burning more coal then before. As such the technology implementation process looks doomed.

In sum, the technology development process was advanced by established industrial actors, based on political decisions favoring the technology. Unlike in Norway, however, CCS did not succeed in building a solid support coalition reaching beyond the established field actors. Decision-making took place in closed circles until the necessity arose to go public in the search for storage sites. Local protests against CCS storage sites became quickly organized, national NGOs became active in the opposition against CCS and soon there was a vibrant nationwide discussion. The field of CCS in Germany at the moment can thus be best described as an unorganized social space. Actors are unsure what to do and how to proceed.

The Governance of Photovoltaics in Germany and Japan

Contrary to the more incremental innovations for coal and gas fired power plants, the development and diffusion of renewable energies includes a variety of new actors – especially in Germany. These new actors encompass new producers, electricity traders as well as owners of decentralized electricity generating units. Discussions about global warming and general environmental concerns have led to political attempts to create and manage a new energy market and the newly developing energy mix. New political instruments were developed and at least in Germany new actor constellations can be observed, which in consequence have led to the development of a specialized governance structure for renewable energies.

Photovoltaics (PV) Development in Japan

The beginnings of PV research in Japan date back to the 1960s. The company Sharp was engaged in the development of solar cells for space research. As a result of the oil crisis in the 1970s, which struck Japan fuels especially hard due to its near complete dependence on the import of fossil, the government in 1973 initiated a first political program, the so called "Sunshine Program", with the aim to explore possibilities to reduce the dependence on energy imports. A small part of the overall program, ca. 6 million USD, was devoted to PV research for terrestrial applications.

At the center of the Japanese innovation system is a small number of big, vertically integrated as well as diversified companies that specialize in incremental innovations in products and production processes. The second-most important actor for the governance of innovation is the government. It is much more directly involved and makes more direct attempts to coordinate innovation processes than its counterpart in Germany, for example: "Japan and Germany clearly display different social systems of innovation and this is why these countries showed contrasting patterns of evolution during the last quarter of the twentieth century" (Boyer, 2003: 148). Vogel points out that

> the German government merely facilitates private-sector coordination, whereas the Japanese government organizes and guides the private sector more directly. The German government has codified its economic model into law, whereas the Japanese model relies more on informal norms and standard practices. (Vogel, 2006: 308)

The Japanese government has interfered actively in the development of the energy sector with a variety of measures and strategies. This can be shown for the energy sector in the whole but also very clearly for the case of PV. Following the 2nd oil price shock of 1979, the government in 1980 created the *New Energy Development Organization* (NEDO) with the aim of reducing Japan's dependence on foreign oil. NEDO is an adjunct to the Ministry for International Trade and Industry (MITI), which was also responsible for energy questions. In 1988 NEDO was renamed to the *New Energy and Industrial Technology Development Organization* and thus stressed even more its coordinating role for the industry (cf. Ristau, 1998: 81). Members of NEDO were recruited from the state apparatus but also from the industry. As such, the energy provider *Tokyo Electric Power Company* for example played an important role in the formulation of the energy policies and strategies of the organization.

Over the 1980s, NEDO fulfilled two important functions for the development of PV. On the one hand, it sponsored research projects for the improvement of the efficiency of solar cells. On the other hand, NEDO became also the biggest buyer of commercially produced solar cells. In the 1980s, there was neither a domestic nor an export market for PV applications. The state-sponsored demand was a decisive benefit for the Japanese industry, which was aiming at developing a world leader position in the development of this technology. With the eventual development of a world market for PV, Japan was able to satisfy the growing demand and expand its market share on the world market substantially. “In 1983 23% of the worldwide sales of modules originated in Japan. Two years later the European Solar Association calculated that the contribution had grown to 45%.” (Ristau, 1998: 81; translation by author.)

The strength of the Japanese innovation system is not only to be seen in the type of cooperative policy support, but also in the political instruments used for technology diffusion (e.g. the financing of demonstration projects, incentive programs). In order to give the industry incentives to expand production capacities, MITI initiated in 1994 the so-called 70,000 roofs program (*Monitoring Program for Residential PV Systems*; Shum & Watanabe, 2009: 3536). It was implemented by the *New Energy Foundation* (NEF). Within the scope of this program, the government financed 50% of the installation costs for PV modules of private households. Under specific conditions firms could also participate in the program. The financing of the overall program was done with the help of a surcharge on regular electricity tariffs. The energy providers furthermore were obliged to buy PV-electricity at market prices. In 1997 a new energy law was passed (*Law on Special Measures to Promote Use of New Energies*). It consisted of a broad mix of subsidies and other policy measures to support the spread of PV and other renewable energies. A clear target for the expansion of PV was also stated. PV was supposed to grow from 500 MW to 5,000 MW before the year 2010 (*Long-term Energy Supply/Demand Outlook*). Other laws naming targets for the spread of PV ensued as well as a number of projects, which were especially supposed to boost public demand for PV (e.g. installations on public buildings). The Ministry of Education for example passed the *ECO School Project*, the Ministry for Infrastructure Development the *Green Government Office Project* and between 1992 and 1998, a *Field Test Project on Photovoltaic Power Generation for Public Facilities* was carried out, which later on was merged into the *Field Test Project on Photovoltaic Power Generation for Industrial and Other Applications* (Anderson et al., 2006: 26). The public expenditure for the support of PV in the 1990s was significantly higher than in all other comparable nations. The public budget in 1997 for the support of PV amounted to 150 million Euro. In Germany at this time no public money of any significance was spent on this purpose. Less than half of the Japanese support money went into R&D support; the bigger part was used for the stimulation of demand (Ristau, 1998: 92). Since 1997, the support was extended with a further *Program for the Development of the Infrastructure for the Introduction of Residential PV Systems*. In the following years (from 1997 to 2001) the support grew from 11,11 milliard Yen to 23,5 milliard Yen (Shum & Watanabe, 2009: 3536). The technology developed and implemented in Japan resembled a standardized mass product without any significant adaptations to the needs of specific customer groups (Shum & Watanabe, 2009: 3540). The dominant Japanese type of an integrated innovation process can thus be observed for the case of PV. This included the integration of the “last mile”: the installation or de-installation of PV modules by artisans and architects. Shum and Watanabe refer in their analysis of the Japanese governance of PV innovations to the image of a “closed development” (Shum & Watanabe, 2009: 3540).

The development of PV in Japan therefore resembled other comparable innovation processes in Japan. In the center of attention is the cooperation between the incumbent actors from government and industry. They are aiming at developing products that can also be exported and sold on the world market and thus help the domestic industry. For the realization of the aim, PV development established channels and methods of cooperation were used, in order to push the innovation forward in an incremental and piece-meal fashion. In spite of the first-mover position of Japan with respect to technology and commercial development, a position which Japan could hold on for quite some time, the amount of installations realized in Japan was not overwhelming. Up to the Fukushima accident, the contribution of renewables to the overall energy mix actually decreased. In this regard, it is important to understand that Japan did not succeed in creating a real domestic market for PV installations. PV installations are primarily to be found on public buildings. The incumbent actors, the same companies that were doing for example nuclear power development, were also installing PV, but had their prime orientation towards exporting products and did not favor a significant change of the domestic technology mix. The composition of the coalition deciding on the further development of the energy sector remained stable, new challenger groups (e.g. from civil society) did not play a significant role and as such more wide-ranging changes were not envisioned. In Japan, the type of coordination used for PV therefore resembled the established patterns in the electricity-generating field. The development was towards a technological add-on option, but was not intended or used to break up the existing practices. The actors concentrated on strategies that would not endanger their existing position and business models, which were dominantly oriented towards developing and using nuclear energy.

PV Development in Germany

The German PV development in contrast to the Japanese case is characterized by severe conflicts, radical innovations and marked breaks and changes in governance. In the already discussed examples (CCS and PV), we detected more or less continuous efforts to sustain R&D and support efforts based on coordinated and cooperative efforts of the main actors from government, science and industry. The German PV picture looks different. In Germany, government support was and is again rather reluctant, difficult to predict, liable to sudden changes and shifting priorities. In contrast to Norway and Japan as well as the CCS development in Germany, the momentum for the development of PV was kept alive by so called non-conventional actors. In this case the social movement character of governance change becomes clearly visible.

As a result of the oil crisis, Germany started first programs related to PV and other new energy options in the 1970s. At this point in time, the responsibility for promoting PV was with the Ministry of Research and Technology. With the ensuing decline of oil prices and following a change in the composition of the federal government – it was now led by the conservative party - the programs to support PV were severely curtailed. The first programs for PV nevertheless had certain successes. The big industrial partners (AEG-Telefunken, Siemens-Solar) having received most of the public money, succeeded in establishing a competitive expertise and technological prowess. The German PV research could be established and gained an internationally leading position along with Japan and the US. Unlike in Japan, however, the little public money available was widely dispersed, experiments with various technologies and procedures were supported and universities as well as applied research centers like the Fraunhofer Institute for Solar Energy Systems (ISE) (founded in Freiburg in 1982) participated. Research projects became financed that were not evaluated from the side of the funding institution with respect to what technological option would be the most desirable one and what would be the best option for industry, society or both. In the end, the efforts were seriously hampered by the fact that technologies were developed up to a pre-market stage, but given the lagging or non-existent domestic demand combined with little political interest in supporting an uptake of the technology, this led to a stalemate and no significant role for the technology in electricity generation could be established. On the contrary: the further development of the technology was opposed by the incumbent actors of the electricity supply system, equipped with good networks and contacts to political and administrative decision-makers. Clear policy guidelines were furthermore difficult to establish due to conflicting positions of key relevant ministries. In particular, the Ministry for Economic Affairs claimed responsibility for market-oriented support schemes and until the present day sees PV very critically, while the Ministry for Research and Technology had and has a more favorable view of PV (Ristau, 1998: 44ff.).

The general support for technology development therefore was rather weak and divided. The support coalition for PV mainly consisted of concerned scientists who wanted to develop an alternative way of generating electricity. Their engagement very often had grown from of an opposition to nuclear energy. The Association for Solar Energy (DGS) (founded in 1975) tried to pool their interests and became more important due to external events. The Chernobyl accident in 1986 made nuclear energy very unpopular and initiated a new search for alternative energy resources and discussion about the future outlook of the energy system as a whole restarted. Within two years, the opposition against nuclear energy among the population at large rose from 50 to 70% (Jahn, 1992). The scientists favoring PV tried to influence the public discussion and put PV on the agenda as a possible new option, as an important element of a transformed energy system. PV was labeled as a clean, environment-friendly source of energy. This made it possible to merge the interests of different social groups: the anti-nuclear power movement and environmental groups could quickly agree on such an option, which made it also possible for them not only to be against something, but to be in favor of a true alternative option. In comparison to other countries, the social movements and the general opposition to nuclear energy after the Chernobyl accident was more wide-spread and also found a political support in the green party Die Grünen. Given this changing environment, the federal government felt obliged to offer some carrots in the form of a first, small market-oriented program for supporting PV. In 1991, the *1,000 Roofs Program* began. It was financed by a state controlled bank (Kreditanstalt für Wiederaufbau) and offered loans to private households interested in participating in a big test of PV installations connected to the electricity grid. NGOs like the aforementioned DGS as well as the Association for the Promotion of Solar Energy and Eurosolar used this situation to influence the political agenda. They developed various models for the financial support of PV and the technical options for connecting decentrally generated solar energy to the general grid.

Besides these national developments, other institutional innovations on the global and the European level were important and affected the German PV scene. On the European level, the deregulation of the energy system was driven forward by the European Commission. The global discussion about climate change led in its turn to the Kyoto protocol (1997). Both shifts altered the framework within which PV could be developed. The groups favoring solar energy became more firmly organized and built up new political coalitions especially on the local and regional levels. On the federal level, however, things looked different. After the heavily over-subscribed 1,000 Roofs Program was terminated, the demand for PV installations plummeted again and decreasing energy prices seemed to make PV an economically unviable solution. The market nearly disappeared and the relevant industry threatened to or actually left Germany to move to locations that would provide a more stable regulatory framework. It became clear that without a long-term regulatory strategy and support scheme, no significant demand for PV could develop in Germany.

In this situation, the role of non-conventional actors proved again decisive. Greenpeace paid the independent public Ludwig Bölkow Foundation for doing a study on the feasibility of constructing a production facility for PV modules in Germany. The study came to the conclusion that it would in fact be economically viable to produce and use PV modules in Germany. Considering economies of scale and an automatisation of production processes, the price for PV installations could be reduced by 40%. Even a small production unit with the capacity to produce only 2,000 PV units would be able to work profitably. These results were used by Greenpeace to look for people interested in helping to finance such a plant. Within a short period of time, 4,000 people showed their interest. Greenpeace then put adverts in leading newspapers to look for entrepreneurs to realize their plans and suitable persons actually showed up. The major importance of Greenpeace's activities was in sensitizing to the potential demand of PV and showing ways for a viable implementation of a PV production strategy. It had become clear that PV installations could be produced more cost-efficiently than previously thought and the discussion thus also gained an industrial policy component (cf. Fuchs & Wassermann, 2012).

Once it had become clear that PV modules could be produced more cost-efficiently than initially thought, medium sized companies in particular became interested in PV – such as RAP Microsystems in Wernigerode or the Solar Factory in Freiburg (Ristau, 1998: 57). The new small and medium-sized PV companies concentrated from the beginning on grid-connected installations. They began to produce modules, mounting frames for roofs and inverters. In this way the activities instigated by the various social movements, mentioned above, led to the development of a new innovation path and strengthened the specific characteristics of PV development in Germany (Jacobsson & Lauber, 2006: 266). Many of the new PV startups had their origins in PV research institutes. The close networking between science, environmental groups and small, initially environmentally and energy politically motivated entrepreneurs was especially valid in the case of PV.

In 1998, the development received a new push. A change in the composition of the Federal Government brought a red-green coalition into power. The window of opportunity was now wide open and the expanding PV support coalition saw its chance. It no longer needed any lobbying work from the outside. Members of the PV coalition could now effectively influence policies from the inside. The aim that resulted was an institutionalization of the support for renewable energies. The red-green coalition in fact initiated two new policy instruments for the support of PV. Firstly a successor to the terminated 1,000 Roofs Program was started, now called *100,000 Roofs Program*, demonstrating the new emphasis and importance of promoting PV. The program was passed in 1999 and it was again administered by the bank KfW. It offered cheap loans covering a period of ten years. In 2000, secondly, a new electricity feed-in law was passed (*Renewable Energies Law*). It set conditions under which generated electricity could be fed into the grid and also regulated the issue of financial compensation. The Federal Government was trying to establish a broad support for the new law, but nevertheless some of the energy providers and their trade associations went to the courts and tried unsuccessfully to block the law. When the 100,000 Roofs Program terminated in 2003, a new amendment to the Renewable Energies Law increased the compensation for individuals generating electricity from PV modules, making PV even more interesting from a commercial point of view. When in 2005 a new shift in the composition of the Federal Government took place (now a coalition led by the conservative party with the social democratic party as a junior partner), no fundamental changes were put in place. Originally opposed to PV promotion schemes, the conservatives at least for some time looked more favorable to PV. This was essentially due to the influence of regional politicians from the Eastern parts of Germany, where most of the new PV companies had set up business and were also attracting foreign direct investment.

The next political change in 2009 (a conservative-liberal coalition took office) has made the further development of PV unpredictable. Various regulatory changes were implemented and opinions – especially voiced again from the Ministry of Economics, the four energy providers and network operators – gained importance, claiming that PV is not a suitable option for the German electricity system. Prior to the Fukushima catastrophe, the operating times for nuclear power plants were prolonged and contracts made by the previous governments were cancelled – damaging the prospects of PV. After Fukushima, an end to nuclear energy was proclaimed, but up until now the conditions for the promotion of PV have not become stable and calculable again. Just like in the mid-nineties the German PV industry is suffering both from the uncertain regulatory environment and new competitors especially from China. PV modules which constituted a small niche market in the late nineties have now become a mass market in which economies of scale are important.

Conclusion: Governance of Innovations in the Energy Sector

In this contribution, we have traced the development of two technological innovations in three countries. The emphasis, on the one hand, was on analyzing how technological developments are embedded in specific national and sectoral contexts for which we used the concept of governance. On the other hand, we have put the emphasis on a process perspective. The process perspective is informed by the Theory of Strategic Action Fields by Neil Fligstein and Doug McAdam. We started with the assumption that a change in governance structures has to find its expression in a change within the dominant actor constellations. Changes in actor constellations are the product of a period of contention. Actors from neighboring fields or the state attempt to change the existing field consensus and thus the position of the incumbent actors. Incumbent actors (like the four big energy providers in the German PV case) will try to defend their position and to damage the position of the challengers. The outcome of such a process cannot be easily predicted. It depends on the ability of the actors to frame the situation in a light that is beneficial to their strategy, to organize around this frame and develop (innovative) instruments for pushing forward their aims even against resistance. For the case of Germany, we could show that the development of PV was dependent on the establishment of a new support coalition, which against the opposition of incumbent actors and interests, created a new form of governance for the promotion of renewable energies. The support coalition gradually broadened and consists meanwhile of a diffuse group of actors. We can observe the development of a governance structure from bottom up.

The CCS technology in Germany on the other hand was supposed to be executed "from above" with the help of the established actors and networks consisting of energy providers, research institutes, hardware producers and political actors. They tried to push through a technological option against growing public opposition. The eventual failure to commercialize CCS is signified by the successful attempts of the opponents of CCS to organize and a lacking capacity of the established actors to co-opt them (like in Norway). The result is unorganized social space. In Norway, the CCS development was driven forward by a broad coalition of actors which initially came primarily from outside the electricity-generating sector. Successful co-optation strategies brought together a coalition of actors from neighboring fields, the general public and the incumbent actors.

PV development in Japan was on the one hand successful insofar as the main aims for spreading PV within Japan were realized. The aims were to promote the use of PV without any fundamental changes to the governance structure and the position of the incumbent actors. Of prime interest was to develop a new technology for export, which for establishing a point of reference, was also to be used in Japan. The effect, however,

Table 1. Summary of results.

	CCS/Norway	CCS/Germany	PV/Japan	PV/Germany
External event	Brundtland report, oil and gas industry business options	CO2 reduction targets, potential world market developments	Oil price shock, search for new export markets	Anti-nuclear movement, Chernobyl accident
Coalition	Government, NGOs, industry	Government, incumbent industry actors	Government, incumbent industry actors	Concerned scientists and citizens, local politicians
"Innovative" actions	Tax, funding of research	Funding of research and demonstration projects	Coordinated technology development, public procurement	Local experiments, law on renewable energies
Role of government	Regulatory activism	Arbiter	Coordinator	Enabler
Field development	Proactive adaptation	Unorganized social space	Adaptation	Transformation
Technology development	Preconditions available	Stopped	According to plan	Dynamic

has been a constant, but comparatively slow development of domestic PV. PV before Fukushima played a negligible role for electricity generation in Japan and no stable new market developed.

Within the scope of this article the case studies could only be presented in a highly stylized way. They hopefully served the purpose, nevertheless, to show the validity of a new analytical approach to study energy transitions.

References

Alphen, van, K., J. van Ruijven, S. Kasa, M. Hekkert & W. Turkenburg (2009) 'The Performance of the Norwegian Carbon Dioxide, Capture and Storage Innovation System,' Energy Policy 37(1): 43-55.

Anderson, K., L. R. Nottage, L.T. Wolff & W. Yamanaka (2008) 'Japan's Gradual Transformation in Corporate Governance,' Research Paper No. 08/29 (Sydney: Sydney Law School).

Beckert, J. (2009) 'The Social Order of Markets,' Theory and Society 38 (3): 245-269.

Benz, A., S. Lütz, U. Schimank & G. Simonis (eds) (2007) Handbuch Governance. Theoretische Grundlagen und empirische Anwendungsfelder (Wiesbaden: VS Verlag).

Bergek, A., S. Jacobsson & M. Hekkert (2008) 'Functions in Innovation Systems: A Framework for Analysing Energy System Dynamics and Identifying Goals for System-Building Activities by Entrepreneurs and Policy Makers,' in T. Foxon, J. Köhler & C. Oughton (eds), Innovation for a Low Carbon Economy: Economic, Institutional and Management Approaches (Cheltenham: Edward Elgar): 111-79.

Boyer, R. (2003) 'The Embedded Innovation Systems of Germany and Japan: Distinctive Features and Futures,' in K. Yamamura & W. Streeck (eds), The End of Diversity? Prospects for German and Japanese Capitalism (Ithaca: Cornell University Press): 147-183.

Carlsson, B. (ed) (1997) Technological Systems and Industrial Dynamics (Boston, Dordrecht, London: Kluwer Academic Publishers).

Carlsson, B. & R. Stankiewicz (1991) 'On the Nature, Function and Composition of Technological Systems,' Journal of Evolutionary Economics 1(2): 118-93.

Coenen, L. & F. J. Diaz Lopez (2010) 'Comparing Systems Approaches to Innovation and Technological Change for Sustainable and Competitive Economies: An Explorative Study into Conceptual Commonalities, Differences and Complementarities,' Journal of Cleaner Production 18(12): 1149-1160.

Dosi, G., C. Freeman, R. Nelson, G. Silverberg & L. Soete (eds) (1988) Technical Change and Economic Theory (London, New York: Pinter).

Fligstein, N. & D. McAdam (2011) 'Toward a General Theory of Strategic Action Fields,' Sociological Theory 29(1): 26-1.

Fligstein, N. & D. McAdam (2012) A Theory of Fields (Oxford: Oxford University Press).

Fuchs, G. (2012) 'Path Dependence and Regional Development: What Future for Baden-Württemberg,' in G. Schryögg & J. Sydow (eds), The Hidden Dynamics of Path Dependence. Institutions and Organizations (Houndmills: Palgrave Macmillan): 178-196.

Fuchs, G. & P. Shapira (eds) (2005) Rethinking Regional Innovation (New York: Springer).

Fuchs, G. & S. Wassermann (2012) 'From Niche to Mass Markets in High Technology: The Case of Photovoltaics in Germany,' in J.M. Bauer, A. Lang & V. Schneider (eds), Innovation Policy and Governance in High-Tech Industries (Berlin, Heidelberg: Springer): 219-244.

Geels, F.W. (2002) 'Technological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective and a Case-Study', Research Policy 31(8-9): 1274-1257.

Geels, F.W. (2005) Technological Transitions and System Innovations: A Co-evolutionary and Socio-Technical Analysis (Cheltenham: Edward Elgar).

Geels, F.W. (2012) 'A Socio-Technical Analysis of Low-Carbon Transitions: Introducing the Multi-Level Perspective into Transport Studies', Journal of Transport Geography 24: 471-482.

Gould, S. J. (2002) The Structure of Evolutionary Theory (Cambridge: Harvard University Press).

Hall, P. & D. Soskice (eds) (2001) Varieties of Capitalism (Oxford: Oxford UP).

Hekkert, M., R. Suurs, S. Negro, S. Kuhlmann & R. Smits (2007) 'Functions of Innovation Systems: A New Approach for Analyzing Technological Change', Technological Forecasting and Social Change 74(4): 413-432.

Henderson, R. & K. Clark (1990) 'Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Existing Firms', Administrative Science Quarterly 35(1): 9-30.

Jacobsson, S. & V. Lauber (2006) 'The Politics and Policy of Energy System Transformation – Explaining the German Diffusion of Renewable Energy Technology', Energy Policy 34(3): 256-276.

Jahn, D. (1992) 'Nuclear Power, Energy Policy and New Politics in Sweden and Germany', Environmental Politics 1(3): 383-417.

Mahoney, J. & K. Thelen (2010) 'A Theory of Gradual Institutional Change', in J. Mahoney & K. Thelen (eds), Explaining Institutional Change: Ambiguity, Agency, and Power (Cambridge: Cambridge University Press): 1-37.

Malerba, F. (ed) (2004) Sectoral Systems of Innovation (Cambridge: Cambridge University Press).

Markard, J. & B. Truffer (2008) 'Technological Innovation Systems and the Multilevel Perspective: Towards an Integrated Framework', Research Policy 37(4): 596-615.

Markusson, N., S. Shackley & B. Evar (2012) The Social Dynamics of Carbon Capture and Storage: Understanding CCS Representations, Governance and Innovation (London: Routledge).

Martin, J. L. (2003) 'What is Field Theory', American Journal of Sociology 109 (1): 1-49.

Martin, J. L. (2011) The Explanation of Social Action (Oxford: Oxford University Press).

Mayntz, R. (2004) 'Governance Theory als fortentwickelte Steuerungstheorie', MPIfG Working Paper 04(1) (Max Planck Institut für Gesellschaftsforschung: Köln).

Mayntz, R. (2009) 'The Changing Governance of Large Technical Infrastructure Systems', in R. Mayntz (ed), Über Governance: Institutionen und Prozesse politischer Regulierung (Frankfurt, New York: Campus): 121-150.

Mayntz, R. & T.P. Hughes (eds) (1988) The Development of Large Technical Systems (Frankfurt a. M.: Campus).

Meadowcroft, J. & O. Langhelle (2011) Caching the Carbon. The Politics and Policy of Carbon Capture and Storage (Cheltenham: Edward Elgar).

Meyer, J.W. & B. Rowan (1977) 'Institutionalized Organizations: Formal Structure as Myth and Ceremony', American Journal of Sociology 83(2): 340-63.

Padgett, J. & P. McLean (2006) 'Organizational Invention and Elite Transformation: The Birth of Partnership Systems in Renaissance Florence', American Journal of Sociology 111(5): 1463-1568.

Pahle, M. (2010) 'Germany's Dash for Coal: Exploring Drivers and Factors,' Energy Policy 38(7): 3431-3442.

Ristau, O. (1998) Die solare Standortfrage. Der technologische Wettstreit zwischen den USA, Japan und Deutschland (Bad Oeynhausen: Bröer-und-Witt-Solarthemen).

Rogge, K. & V. Hoffmann (2009) 'The Impact of the EU ETS on the Sectoral Innovation System for Power Generation Technologies – Findings for Germany,' Paper submitted to DIME Workshop on Environmental Innovation, Industrial Dynamics and Entrepreneurship May 10–12 2009 (Netherlands: Utrecht).

Schulz, M., D. Scheer & S. Wassermann (2010) 'Neue Technik, alte Pfade? Zur Akzeptanz der CO2- Speicherung in Deutschland,' GAIA 19(4): 287-296.

Scott, W.R. (2001) Institutions and Organizations. 2nd edition (Thousand Oaks, CA: Sage).

Shum, K.L. & S. Watanabe (2009) 'An Innovation Management Approach for Renewable Energy Development – The Case of Solar Photovoltaic (PV) Development,' Energy Policy 37(9): 3544-3535.

Ugur, M. (ed) (2013) Governance, Regulation and Innovation. Theory and Evidence from Firms and Nations (Cheltenham: Edward Elgar).
Verbong, G.P.J. & D. Loorbach (eds) (2012) Governing the Energy Transition: Reality, Illusion or Necessity? (New York: Routledge).

Victor, D.G. (2002) 'Electric Power,' in B. Steil et al. (eds), Technological Innovation and Economic Performance (Princeton: Princeton University Press): 385-415.

Vogel, S.K. (2006) Japan Remodeled: How Government and Industry are Reforming Japanese Capitalism (Ithaca: Cornell University Press).

Werle, R. (2012) 'Institutions and Systems: Analysing Technical Innovation Processes from an Institutional Perspective,' in J. Bauer & A. Lang & V. Schneider (eds), Innovation Policy and Governance in High-Tech Industries (Heidelberg, Berlin: Springer): 23-47.

Notes

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2 More detailed accounts of the CCS story can be found in Meadowcraft and Langhelle (2009) and Markusson et al. (2012).

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