Actor oriented analysis of innovation systems:

Exploring micro-meso level linkages

in the case of stationary fuel cells

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Abstract

The innovation systems approach has been successfully established as a conceptual basis for an encompassing analysis of actors, networks and institutions that influence innovation processes. Here we present an approach that concentrates on the actors in a selected technological innovation system. The intention is to specify current or potential contributions of actors, or actor groups, to innovation system performance and dynamics. This will be achieved by explicitly relating actor level characteristics such as innovation strategies and resource endowments to system level characteristics like actor configurations, system functions and performance. We illustrate the approach with a case study on stationary fuel cells in Germany.

1 Introduction

The innovation systems perspective has gained increasing importance in recent years to study the emergence and development of new products or technologies. Concepts such as innovation systems[1] or technological systems[2] account for the observation that many success factors of innovation processes are neither located within single firms nor can they be regarded as mere context conditions. Instead it is the interaction of private firms, other types of organizations and institutional structures that crucially determinates the direction and outcome of the innovation process. Firmly rooted in evolutionary theorizing, the strengths of the systems concept are, among others, that it adopts a holistic perspective and considers phenomena such as path dependency, lock-in, interdependence, non-linearity and co-evolution.[3]

Apart from the general intention to provide a meso-level framework for analyzing the complexity of innovation processes, a major motivation for scholars in the field of technological innovation systems has been to inform policy making.[4] As a precondition, methods and tools are needed to analyze system dynamics and to measure and compare system performance.[5] One approach in this respect is the assessment in terms of system functions. It has received some attention recently in conceptual[6] and empirical[7] contributions. Other innovation system studies have placed more emphasis on structural analyses, e.g. in terms of institutional structures, user-supplier linkages, innovation networks and industry structures.[8] With regard to the latter two also more formal techniques like the use of input-output tables and network analysis have been applied.[9]

A common line of argument in favor of functional analyses is that policy recommendations can only be made on the basis of system comparisons (e.g. among different countries), which again have to be based on functions because these - in contrast to structures - are directly comparable with regard to system performance. There is no unambiguous relationship between structure and performance, i.e. different structures can lead to similar performance and vice versa.[10] However, many structural analyses have as well been successfully developed towards the identification of general conditions for good system performance, often measured in ‘classical’ parameters like innovation diffusion or production output, patents, market shares etc.[11]

While much progress has been achieved from both of these perspectives at the meso level of system analysis, considerably less effort has been devoted to systematically explore the link to the micro-level of innovating actors.[12] This is despite the fact, that actors are assigned the key role in innovation system concepts[13] and empirical findings regularly report the influence of strategic decisions of particular actors[14] or the importance of entrepreneurs and prime movers.[15] With this article, we want to address this gap of a micro level foundation of innovation systems, which would contribute to a better understanding of system dynamics.[16]

In the following, we will present and empirically illustrate some core building blocks of an actor oriented analysis of innovation systems. The general idea behind this approach is to explore the link between innovation strategies and resources at the organizational level and the characteristics of innovation systems. More specifically, we propose to analyze innovation strategies and how they contribute to innovation system performance as well as dynamics. Resource endowments are interpreted as an indicator for the innovation potential of actors and a determinant of actor configuration within the system. On this basis we are able to draw conclusions with regard to system performance in terms of system functions and also with regard to future development options of the innovation system. In conceptual terms, our approach thus links structural and functional analysis.

Such an actor oriented approach goes well beyond the mere identification of system actors discussed in some of the innovation system literature.[17] Although showing parallels to existing empirical studies on actor competences,[18] it elaborates micro-meso level interaction more systematically. From a conceptual point of view, this approach has the potential to explore the boundary area, in which the literature on innovation systems and the literature on business studies and innovation management at the firm level might be fruitfully related to each other. A detailed elaboration of the bridge between those strands of literature, however, is beyond the scope of this paper.

Empirically, we will illustrate the application of an actor oriented innovation system analysis for the case of stationary fuel cells in Germany.[19] In the field of energy supply, fuel cell technology can be regarded as a radical innovation, mainly because it combines power and heat supply in decentralized applications. Though fuel cells are still in an early state of development, some countries such as Germany, the US and Japan have recently experienced significant innovation activities by various actors. Conceptually speaking, a technological innovation system has emerged, which reaches beyond national boundaries but - so far - is shaped by a few countries with a high degree of innovation activity. Given the high complexity and uncertainty of the associated innovation processes, fuel cell technology represents a challenge for the innovation management of each individual manufacturer, utility company and installation firm. We might therefore expect a rather explicit strategic consideration of the innovation for those firms that engage in fuel cell projects. In the light of these arguments, we think that stationary fuel cells represent a potentially fruitful empirical field for illustrating core tenets of an actor oriented perspective on innovation processes.

The paper is structured as follows. In chapter 2 we will present the goals and the conceptual building blocks of the analysis as well as the expected benefits. Chapter 3 introduces the empirical field - the innovation characteristics of stationary fuel cells, the major elements of the innovation system and the challenges ahead. The fourth chapter then illustrates how we analyzed innovation strategies of electric utility actors according to their impact on the functions of the innovation system. Chapter 5 deals with the analysis of resource endowments at the level of actor groups as an indicator for potential actor configurations. This includes an assessment of critical resources for the development of the innovation at hand. Chapter 6 resumes and discusses further development needs of the approach.

2 Actor oriented analysis of innovation systems

2.1 Key terms and goals of the analysis

Our point of departure is an innovation system that has emerged around a specific product or technology. We basically draw on the concept of technological systems[20], and furthermore focus on activities and processes related to the development of (radically) new technologies, not on the incremental improvement of existing ones.[21] With regard to the components of a technological innovation system, we distinguish actors from institutions. Actors are considered as those system components that perform innovation activities and pursue deliberate strategies, whereas institutions are rather passive, i.e. they are made by or evolve as a result of the behavior of actors. At the same time, institutions enable and favor particular activities, while constraining others. Actors may thus be regarded as the players and institutions as the rules of the game.[22]

In our analyses, we will concentrate on organizational actors thus leaving individuals aside. Organizational actors, in general, include companies, universities, research institutes, governmental and non-governmental agencies, associations, venture capitalists etc. More specifically, we focus on those *organizational units* that are involved in the generation, diffusion or utilization of the innovation under study. These may be departments of larger research institutes, business units within larger companies but also single business companies, which operate exclusively in the innovation field. These actors carry out a broad variety of *innovation activities* such as research and development, experimentation, field testing, market analysis, management of networks, lobbying, collaboration in the definition of standards, set up of incentives schemes etc.[23] Apart from actors, finally, we differentiate *actor groups*, which we define as those sets of actors who control similar resources.

The goal of what we call *actor oriented innovation system analysis* is to assess i) current and potential contributions of organizational actors to innovation system dynamics and ii) the range of structural alternatives that would be conceivable for producing a high innovation system performance. This shall be achieved by explicitly relating actor level characteristics such as innovation strategies and resource endowments to system level characteristics like actor configurations, system functions and system performance. An actor oriented approach may thus fruitfully complement system function approaches - in their explanatory power as well as their intention to arrive at policy recommendations. It will be of particular importance in the case of emerging innovation systems, where actor roles and networks are still very much in flux.

2.2 Conceptual building blocks

Actors are of key importance for innovation systems as they influence the pace and direction of technology development with their innovation activities. Each innovation activity contributes to one or several functions of the innovation system. The aggregated effect of all innovation activities of all actors within the innovation system will finally determine its overall performance.[24]

In order to better understand the underlying factors that lead certain actors to adopt specific innovation activities, we have to consider processes of *innovation strategy* formation more explicitly. Conventionally, strategy is regarded as the determination of long-term *goals* of an organization that guide decision making, management activities and the necessary allocation of *resources*.[25] Innovation strategy, in this simplified view, can be understood as the goal determined activation of resources available at the organizational level. The actual strategy process, however, is more complex. Activities or decisions may deviate from the goals originally formulated. Even more, organizations may show consistent patterns of activity without having formulated explicit strategic goals, in the first place.[26]

Also the relationship between strategy and resources is multifaceted. While strategy defines the resource allocation to particular activities, the choice of a specific strategy is at the same time constrained by the resources available. As not all resources can easily be acquired, imitated or transferred from one actor to another,[27] a given resource endowment of an organization will determine (and constrain) its strategic leeway, i.e. its potential to carry out innovation activities. Still, strategies may intend to enlarge or change the organizational resource base. The constraining effect of given resource endowments may even hold (at least temporarily) for a broader range of actors in the innovation system, thus leading to an entrenchment of prevailing structures, even to path dependencies or lock-in effects

If we now turn to the systems perspective, each innovation system can be characterized by a particular set of aggregated resources that need to be provided or activated, in order to support its further development. A novel environmental technology, for example, may need specific governmental support in the form of financial incentives in order to compensate for the positive externalities of its application. Or a new high-tech product may crucially depend on the skills of local service companies for maintenance and trouble-shooting. Of particular interest for the analysis are *critical resources* that are i) important for the innovation under study and at the same time ii) difficult to imitate or transfer. Critical resources are expected to be case and time sensitive.

The ‘resource needs’ of an innovation system can be matched in various ways. There may be very few actors, who control a broad range of critical resources and are thus able to dominate system structure and the direction of the innovation process. In this case, corporate innovation management will more or less be tantamount with innovation system dynamics. Alternatively, the distribution of actor commanded resources may be more variegated. Different actors may control some critical resources and no single actor is able to dominate the process. Here, co-ordination and collaboration will be essential to further the innovation process. Finally, if there are many actors with very similar and thus substitutable resource endowment profiles, imitation and competition rather than collaboration will be the dominant interaction mode. A similar situation will occur, if relevant resources can easily be acquired or transferred, i.e. if there are no critical resources.

2.3 Key mechanisms addressed by an actor oriented approach

An actor oriented conceptualization of the micro-meso link helps to better address a number of research topics in the analysis of innovation systems, which we will spell out in the following i) for the micro-level of organizational actors, ii) for an actor group and for the innovation system as a whole in iii) static and iv) dynamic terms.

First, a detailed analysis of motives, drivers, and decision procedures at the organizational level, will lay the ground for linking corporate resource endowment and strategic goals with innovation activities that contribute to innovation system functions. In relation to innovation system performance, findings from the strategy analysis could furthermore be interpreted with regard to ‘actor-related’ criteria such as entrepreneurial drive or customer competence that have been identified in comparative empirical studies.[28] The analysis can also reveal the profile of specific actors and the role they play in the innovation system. Some actors, so-called prime movers[29], who control critical resources or pursue very dedicated innovation activities, may - temporarily or permanently - exert significant influence on the trajectory of an innovation system in an early stage of development.

This represents the micro-level foundation for understanding innovation system dynamics and corresponds largely to conventional innovation management research. However, in the context of innovation systems, the influence of prevailing system structures and the assessment of performance deficits at the system level could be considered more explicitly in the strategy formation process.

Second, the resource and strategy oriented analysis can furthermore help to conduct structural analyses of innovation systems in a more systematic way. Defining actor groups on the basis of similar resource profiles represents a theoretically informed way of classifying actors compared to the often used superficially descriptive categories.

The analysis of the distribution of strategies and resources within a particular actor group can be interpreted as the (potential and actual) ability and interest of this group to assume a specific role in an innovation system. In a more dynamic interpretation, the pursuit of specific strategies by some firms may signal interesting opportunities to non-active firms of the same group. Especially in an emerging system often only a few actors will carry out innovation activities (and thus be part of the innovation system) while a majority of the firms remain passive. Such non-innovating organizations may intentionally stay away from the innovation but as well observe the development carefully in order to get involved at a later stage. Passive actors, in other words, represent a "dormant" resource of an innovation system, which could be mobilized in the future. An exploration of the 'near' actor environment of the innovation system, therefore, may indicate future development potentials.

Third, the analysis of aggregated resource portfolios of different actor groups as well as the assessment of their complementarity, transferability and criticality will allow differentiating potential actor configurations with regard to overall innovation system performance. Different actor configurations may be interpreted as being associated with alternative development trajectories of a given innovation system. Inversely alternative actor constellations (e.g. as found in different national contexts) may be used to compare the contribution of specific actor groups to overall system performance.

Furthermore, the analysis of complementary resource profiles may also be instrumental to more explicitly address the issue of *structural variety* in an innovation system, i.e. the diversity of actor groups (e.g. manufacturers, suppliers, service providers, associations, policy makers) and actor profiles (e.g. large and small firms), the distribution of different roles in the innovation system (e.g. prime movers, supporters, legitimacy producers, visionaries) or the range of innovation strategies pursued (e.g. proactive and reactive ones). Variety can be a crucial issue for a successful innovation process as it increases the potential to deal with unforeseen developments or events and will determine the degree of path dependency an innovation system will be subjected to. Variety in terms of actor structures also reduces the risk that a few actors can dominate the innovation process.

Fourth and finally, the contributions of individual strategies to innovation system dynamics may be analyzed more explicitly. Even though the actor oriented approach emphasizes innovation system structures, it also provides a basis to better assess the system in functional terms. Structural[30] and functional[31] analyses, which have been treated separately in most of the literature, may be treated in a more complementary and interrelated way. One inroad for analysis in this respect is to study the impact of innovation activities on the key functions of innovation systems.[32] In the following empirical part, for example, we refer to the earlier work of Johnson and Jacobsson who identified five basic system functions including the creation of new knowledge, guidance of the search process, the supply of resources, the creation of positive externalities and the formation of markets.[33] Innovation activities can be expected to make higher or lower contributions to the different functions, thus influencing its performance but also the direction of development. Following on this line, the assessment of resource endowments can also be used for taking a future oriented perspective with regard to potential changes of actor configurations or entries of new actors.

This may finally be used to derive policy recommendations addressing functional deficits more explicitly. Resource and mobilization deficits could be identified comparing resource needs at the system level with the prevailing strategies and aggregate resource profiles of a given actor configuration. If there are resources, which none of the innovating actors or actor groups control or can acquire, then there is a need to stimulate the entry of actors who do or can. The lack of venture capital in an innovation system with many small start-up firms may be an example of a missing resource, for which new players are needed. A similar situation occurs if very few members of a particular actor group are contributing to the field and further actors would be needed, e.g. to achieve a critical mass. A mobilization deficit, on the other hand, will occur if innovating actors are unwilling to further expand their contribution of resources beyond a certain limit. In the first case, incentives and innovation policies have to be directed towards the 'activation' of system outsiders, whereas in the second case incentives have to address already innovating actors.

Taken together these four types of analysis -- when applied to the whole set of relevant actor groups in all potential configurations -- would lead to an encompassing identification of the possibility space for innovation system dynamics. However, in the vast majority of conceivable empirical examples such an encompassing analysis would quickly prove to become intractable. However, also partial analyses may be of value for highlighting crucial aspects of innovation system dynamics, as we will show in the following.

3 Identification of the innovation characteristics and the technological innovation system for stationary fuel cells

Fuel cells are based on a chemical process, in which hydrogen or natural gas is converted into electricity and heat. The basic technology is not new; its working principle has been discovered more than 150 years ago and alkaline fuel cells have been used in space travel since the 1960s. Until the 1990s, fuel cell technology saw some progress[34] but did not receive much public attention. This situation changed when automobile manufacturers like DaimlerChrysler strongly promoted the vision of a new generation of clean vehicles powered with fuel cells. In the field of stationary energy supply, utility companies and technology developers were encouraged by the promises in the transportation sector and, at the same time, challenged by upcoming market liberalization. In this context, fuel cell technology represented an innovative, environmentally sound option for a decentralized energy supply of homes, functional buildings, public facilities, small factories etc. Up to now, however, fuel cell technology has not met the high-rising promises of the 1990s - neither in the field of transportation nor in stationary energy supply. But innovation activities have been carried on and in the field of energy supply, fuel cells are on their way to establish a stable market niche for uninterruptible power supply applications.[35]

3.1 Innovation characteristics of stationary fuel cells

Today, various types of stationary fuel cells exist, which differ with regard to the electrolyte, catalyst materials, operating temperatures, fuel requirements etc.[36] Pilot plants and prototypes cover a variety of applications. Despite this diversity, stationary fuel cells have a number of innovation characteristics in common. In technological terms, they are characterized by a high energy efficiency (even in part load operation), a favorable electricity to heat ratio, silent operation without moving parts and low air emissions. Furthermore, fuel cells can use a variety of primary fuels such as natural gas, methanol or biogas.[37] Due to a modular design, fuel cells can supply electric power from some Watts up to several Megawatts.

With regard to the innovation process, most types of fuel cells are still in an early phase of development, i.e. they are mostly operated and tested in the context of R&D projects, pilot plants or field tests. The two most important challenges for further development are to significantly reduce system costs and to improve the lifetime of fuel cell stacks. Because of the early innovation phase fuel cell based products involve a high degree of uncertainty. Together with a considerable need for financial investments this results in high financial risks for actors in the field.

The fuel cell also represents a complex innovation with a high degree of technological interrelatedness. This means that a complementary infrastructure (e.g. for fuel supply, maintenance, troubleshooting and power grid control) has to be developed and that a substantial level of collaboration and coordination between suppliers, manufacturers, utilities, installers and customers is required.

Finally, stationary fuel cells can be classified as a radical innovation if the reference case is electricity production in large, central power stations.[38] A widespread diffusion of the new technology would lead to a decentralization of electricity supply with far-reaching consequences. Moreover, fuel cells would foster an integration of the markets for power and heat supply, which are mostly separated today.

3.2 Technological innovation system for stationary fuel cells in Germany

With stationary fuel cells we place a product at the centre of the analysis.[39] In the following, we want to identify the contours of the technological innovation system empirically. More specifically, we will focus on actors, networks and institutions that have emerged in Germany in recent years. As of 2003 Germany had the largest fuel cell 'industry' in Europe with more than three quarters of all installed fuel cells and a total of 2'800 employees in 350 firms or other organizations.[40] In the sub-field of stationary fuel cells more than 500 small units (pilot and field test plants, for residential customers) and about two dozen larger units (pilot plants, for commercial customers) were planned or already installed in 2003, cf. Table 1. The majority of these stationary fuel cells is operated by utility companies, thus representing an important actor group.

< Table 1 about here >

Actors

In general, various groups of actors are active and share different innovation tasks in the field of stationary fuel cells in Germany: universities and research institutes, fuel cell manufacturers and suppliers, utility companies, installers, associations, governmental agencies, financiers and end users.[41] Research institutes such as the Fraunhofer Institute of solar energy systems (ISE), the Center for Solar Energy and Hydrogen Research (ZSW) or the German Aerospace Research Centre (DLR) are active in fields like mechanical and electrical engineering, material sciences or chemistry in order to develop and improve fuel cell design concepts, materials, system components etc. Manufacturers are involved in applied research and prototype testing. Furthermore, they design and manufacture entire fuel cell power plants, while relying on a number of up-stream equipment suppliers. German manufacturers are business units of large firms such as Siemens-Westinghouse, Vaillant or MTU, which have their core business in traditional markets for electricity generation (Siemens), heating boilers (Vaillant), or other industries (MTU). It is on this upstream part of the supply chain that linkages across national borders, e.g. to international manufacturers such as Ballard, PlugPower, Sulzer-Hexis or UTC Fuel Cells, or to the other large application domains of portable and mobile fuel cells are most abundant.

With utility companies, a third major actor group is involved in the supply chain, identifying promising market niches and developing energy services on the basis of stationary fuel cells (e.g. in the form of contracting). This means that they play a user role but also manage the interface to the end consumers of energy in most cases. In Germany, many large utility companies like RWE, E.ON, Thyssengas or EnBW but also some regional or local utilities are among the pioneers in the innovation system as they operate pilot power plants at own locations or at their customers' sites (private homes, functional buildings). Utilities often collaborate with local installation companies, which integrate the fuel cell into the supply infrastructure of the building and also provide maintenance and troubleshooting services. These installers are usually small enterprises originally specialized in heating systems.

Associations like the German Technical and Scientific Association for Gas and Water (DVGW) are involved in the development of technical norms, networking, lobbying or campaigning. National and federal governments as well as supra-national organizations have launched a variety of R&D programs to support the technological progress of fuel cells. They also initiated the set-up of (mostly regional) innovation networks and / or centers for knowledge transfer and education. On the end consumer side, we can finally distinguish a number of pioneers (private households, municipalities, hospitals and medium-sized industrial energy consumers).

Networks and relationships

The actors in the fuel cell innovation system are related in many different ways. Among firms we find user-supplier linkages but also formal co-operations, mergers and acquisitions, strategic partnerships and marketing alliances.[42] Two examples for such strategic partnerships in Germany are the Fuel Cell Initiative and the Fuel Cell Alliance. Nation-wide as well as networks have been set up for education on fuel cell related issues (e.g. Fuel Cell Education Centre, Ulm), the coordination of R&D activities (e.g. Fuel Cell Research Alliance Baden-Württemberg) or the exchange of knowledge. Furthermore, numerous inter-firm working groups have been established and more than two dozens of public conferences and workshops are organized every year.

Institutions

In Germany, institutions that are relevant for stationary fuel cells include publicly funded R&D, regulations and policy instruments, technical norms and the like. Support for research and development in fuel cells comes from the Federal Ministry of Education and Research, the Federal Ministry of Economics and Technology and the Federal Ministry for the Environment. These ministries also coordinate the national Future Investment Program, which focuses on new technologies such as fuel cells or solar. Direct financial support by the Federal Government for all fuel cell applications has reached an annual level of 15-20 million € since 2000.[43] In addition, many states (Bundesländer) have set up regional support programs, some of which are comparable to federal support in their expenses. The German law on the conservation, modernization and development of combined heat and power and the electricity feed-in law, furthermore, foresee premium payments for power that was generated by fuel cells. With regard to standardization and norms, finally, several initiatives are on their way to facilitate licensing procedures and the interoperability of fuel cells and local heat and power infrastructure.

Summing up, we may conclude that the domain of stationary fuel cells in Germany can be regarded as a technological innovation system with a broad range of actors, specific networks and institutions that deal explicitly with the technology. The innovation system, of course, is not limited to Germany but has an international reach - especially in terms of research and technology manufacturing. At the upstream level, there are also linkages to innovation activities in other technological domains like mobile or portable fuel cells. However, stationary fuel cell activities in Germany show sufficient density and intensity that typical innovation system processes can be observed.

3.3 System functions and challenges ahead

Given the large number of projects and actors, the dedicated support by states and the federal government and the establishment of formal networks at the regional and national level, contributions to the key functions[44] of the system are manifold. Research projects and pilot applications generate new knowledge, while formalized networks, inter-firm working groups or public conferences facilitate the diffusion of explicit knowledge and also enhance work force mobility, i.e. the diffusion of personal skills. Direction of search has been guided, for example, by prominent image and advertising campaigns of electricity suppliers, public commitment of utility CEOs to fuel cells, the formation of joint-ventures or other formal co-operations related to specific types of fuel cells. Public support programs have supplied additional resources but they also contribute to the guidance function as they signal passive actors that there is a promising new technology. Positive externalities have been created by centers that coordinate research, facilitate information exchange or train installers and other service providers on the particularities of stationary fuel cells. The market formation function, finally, has as well benefited from end user oriented campaigns, fuel cell exhibitions at local conventions, good coverage of fuel cell development activities in the mass media etc. Against this background, we might be inclined to say that the German innovation system for stationary fuel cells is well on track.

However, neither a systematic assessment of the fulfillment of functions at the system level has been carried out nor an overall performance analysis. Both would have required some kind of comparative approach,[45] e.g. across countries or between stationary and mobile fuel cells, which was beyond the scope of our empirical analysis. Still, we are able to point out some challenges ahead for stationary fuel cells in Germany.

Given the early state of development together with a high degree of complexity and uncertainty, fuel cell technology represents a challenge for the innovation management of each actor. We might therefore expect a rather explicit strategic consideration of the innovation for those firms that engage in fuel cell projects. This holds particularly for innovating incumbents that seem to carry many of the financial risks involved - be it as manufacturers or as intermediary users (utility companies). We may well ask for the motives that drive these potential prime movers and whether there will be back-up in the innovation system if some of these firms decide not to pursue fuel cell development any further.[46] There is also some uncertainty on how actor roles along the supply chain will develop in the future as stationary fuel cells bring together players of two sectors (electricity and heat supply) that have been separated so far. Another issue relates to the size of the German fuel cell innovation system at an international scale. While Germany is outstanding at the European level, it is way behind the US and Japan, which saw 3 and 2 times more installed fuel cells by 2003, respectively.[47] Out of 5’000 worldwide patents related to fuel cells, 400 were granted in Germany compared to 1’900 in Japan.[48]

This list of challenges is certainly not comprehensive[49] but illustrates some of the motives for the following empirical analyses, where we review the strategic considerations that drive the innovation activities of utility companies. We also analyze the variety of strategies adopted within this actor group and assess the impacts of different strategies on system functions (chapter 4). In a second step, we will focus on how resource endowments influence potential actor configurations along the supply chain (chapter 5). The combination of the two steps will serve to better assess the importance and relative role of utilities in the innovation system. On the one hand, this may ultimately serve to better circumscribe the possibility set of strategies for utilities, thus informing corporate innovation management. On the other hand, it may serve to determine incentive structures and other support policies that would have to be put in place in order to enticing utilities to mobilize more resources for the innovation system.

4 Utility innovation strategies and their contribution to system functions

In chapter 2 we have emphasized that innovation activities of specific actors have to be understood as a result of strategy formation processes and corporate resource portfolios. In the following, we identify strategy making and its impact on the innovation system for the actor group of electric utilities. We empirically concentrate on strategy identification and impact analysis, thus leaving aside the constraining effects of resource endowments for the time being.[50] Utility companies play an important role in the innovation system (cf. section 3.2) and control a broad range of resources including two very critical ones, namely reputation and existing customer contacts as we will see later in chapter 5. While this focus on a single actor group, in our view, is sufficient to illustrate our approach, a complementary analysis of innovators from other groups would be needed to capture the whole range of strategic positions and moves in the innovation system.

The empirical findings presented here were part of a broader study in 2003 on the impacts of electricity market liberalization on utility innovation strategies, which has been published elsewhere.[51] The survey was mainly based on expert interviews with employees of innovating business units. As to the selection of firms we tried to select different types of utility companies - large and small ones as well as public and private ones.[52] Interview data were complemented by the analysis of business reports, web-based information and other firm specific documents as well as broader studies on fuel cell innovation activities or articles in professional magazines.

4.1 Fuel cell innovation strategies

We conceptualize the innovation strategy of a business unit as a composition of strategic goals, innovation activities and the priority the innovation receives within the organization as a whole. Innovation activity was analyzed in terms of the innovation project portfolio and priority was assessed in terms of verbal or written commitments and resources allocated to the activities or business unit. Resource inputs included, among others, financial capital and man power as well as expertise, customer contacts and reputation.[53] Table 2 summarizes the results of the strategy analysis and Figure 1 depicts the different innovation project portfolios.

< Figure 1 about here >

The cross comparison of project portfolios shows that innovation activities were rather heterogeneous with regard to fuel cell type, size and number of installations. Nearly all actors operated small fuel cells and some firms had both, small and large units in their portfolio. The results on innovation strategies underline that there are differences in the details but some commonalities in terms of basic strategy making. Based on these commonalities three types of strategies were derived representing specific combinations of goals and priorities.[54]

In two cases, for instance, it was stated that the actor had the intention to make profit with fuel cells, to create a market and to become a leader in this field. The fuel cell innovation projects had a high priority within the company and received a high amount of resources accordingly. The fuel cell played a key role in the public relation activities of the whole firm. These two actors were classified as implementing a *'leading' strategy*. In other cases, the strategy was characterized by the goal to gather experiences with the new technology and its application in different contexts. Decision makers were interested in learning about customer preferences and to establish contacts with manufacturers and other actors in the field. The corresponding actors had quite a broad portfolio of different fuel cell systems and applications, they mostly spent a medium amount of resources and the priority was said to be higher than or similar to that of other innovations. These actors were classified as implementing a *'learning' strategy*. A third group of utility actors stressed the innovative image of the fuel cell *('image shaping' strategy)*: Their projects were mainly set up to shape the corporate image. Still, experiences and the creation of knowledge also played a role. The projects were regarded as experiments, on which to base further innovation decisions in the future. They received a medium or low priority and the investments were strictly limited.

< Table 2 about here >

Summarizing we may say that different strategy types have been chosen by the selected utilities that lead to a broad and diversified portfolio of activities. And learning oriented strategies were explicitly set up temporarily in order to be adjusted to the progress of the innovation. We also found that medium sized utilities pursued resource intensive strategies (leading and learning), which comes with higher relative 'costs' compared to large companies. As was said at the beginning, however, this aspect was not analyzed systematically.

4.2 Assessing the effects of innovation strategies on system functions

In order to address the link between the micro and the meso level we will now turn to the question how different innovation strategies affect the functions of the innovation system. Obviously, one may expect that strategies with a high degree of commitment and resource input are likely to make a high contribution. While this causality may apply in general, the details of the picture can well be different. In the following we will assess the typified innovation strategies relative to their contribution to the system functions. In our survey, we concentrated on the first function, 'creation and diffusion of new knowledge'.

We asked the interviewees i) what kind of experiences they made (thereby distinguishing technology specific and general knowledge as well as process related knowledge), ii) whether and how the knowledge was disseminated in the firm and iii) whether it was applied elsewhere in the firm (closed learning loop).[55]

The results are as follows. In all companies observed, innovation activity induced the creation of new knowledge of all three kinds. Despite different strategies, the differences in knowledge generation for each actor were rather low but learning oriented companies were slightly ahead with regard to process related knowledge. Our analysis also showed that in all cases the knowledge was spread out from the innovating units to other parts of the firm. However, many interviewees reported that knowledge dissemination could be improved. In some cases, the knowledge had also been re-applied to other projects. But again, the interviewees saw much potential for making a better use of the lessons learned. With regard to the differences in innovation strategies, we found that knowledge dissemination and application in other projects was best achieved by the actors that followed a leading strategy. Table 3 summarizes major instances of the three kinds of knowledge that were mentioned in the interviews.

< Table 3 about here >

On the basis of these findings we inferred that actors who pursued a leading strategy made a high or very high contribution to the function of knowledge creation and diffusion, while learning strategists made still a high and image oriented actors a high or medium contribution, cf. table 4. Note, that we just analyzed knowledge creation, diffusion and application at the firm level. The contribution assessment is thus based on the assumption that there are no differences to what extent this knowledge has become available at the system level.

With regard to the other four system functions the assessment was carried out similarly, though a little less comprehensively. For each function we had criteria against which the strategies, or innovation activities, were tested. In the case of market formation, for example, we took end consumer involvement (participation in field tests) and consumer information (campaigns, exhibitions, press releases) as proxies for a creation of awareness and demand.

< Table 4 about here >

Our findings show that for some functions the differences between the three strategies are striking, while they are less pronounced for others. The function ‘guidance of the direction of search’, for example, strongly benefited from the two companies that followed a leading strategy because their actual commitment combined with pronounced public statements and intense awareness campaigns represented a signal for other actors that there might be strong commercial prospects in the innovation field. Similarly, the innovation activities of the leaders and one learning oriented actor served as an orientation for the followers (image shaping) in terms of technology choice and business concept. Externalities, as another example, were created likewise by leading and learning strategies through an active exchange of knowledge in networks or public conferences, lobbying activities or the set-up of institutions like the Fuel Cell Initiative. The formation of markets, e.g. in terms of creating customer awareness for the new technology, finally, exhibited a generally lower level of contributions with one of the leading companies sticking out.

In sum, the analysis revealed that the different strategies contributed differently to the functions of the innovation system. Within the group of utility companies the two actors, which pursued a leading strategy, played a key role and can thus be regarded as prime movers that might have a decisive impact on the direction the innovation system takes. However, also innovation strategies with a lower degree of commitment were observed to make a contribution to the functioning of the innovation system as a whole. Against the background of these results we may also reflect potential developments in terms of actor configurations. The distinct strategic positioning of some utilities counteracts a potential configuration, in which manufacturers and installers, whose combined resources may be a substitute for many of those utilities control (cf. chapter 5), dominate the field. Similar assessments could be made with regard to the effects of structural changes, e.g. due to the entry of newcomers or a strategic reorientation of key players.

The empirical findings as well as the methodological propositions, however, have to be interpreted with care. First, the methods to analyze the impact of actor strategies on system functions have to be elaborated further. Here, indicators and criteria that were recently proposed[56] to support the functional analysis of innovation systems seem to be a promising anchor point. Second, and even more importantly, the analysis presented above still misses to account for the interdependencies among actor strategies but also in relation to institutions. Findings like the ones depicted in table 4 might readers entice to conclude that actor strategies, or the outcomes of innovation activities, influence system functions in a rather linear way, which, in general, is a false assumption. New experiences with a particular type of fuel cells, for example, may represent a ‘simple addition’ to the knowledge stock of the innovation system. Depending on the context, however, such experiences may also set in motion a number of reactions by different actors or even a change of institutions - for example if they were obtained as part of a larger demonstration project that received much attention from practitioners and the broader public.

5 Analysis of resource endowments at the level of actor groups

From the meso level perspective the question also arises what actor configurations can provide the resources needed for the innovation to prosper, and whether there are resource or mobilization deficits (cf. chapter 2). Here, we will illustrate the former issue. We begin with a cursory specification and assessment of the resource needs for stationary fuel cell development. This will be followed by a resource endowment analysis of three key actor groups currently active in the innovation system.

5.1 Resource needs for the development of stationary fuel cells [former 3.2]

On the basis of the innovation characteristics identified in section 3.1, resources that are needed for the innovation process can be identified and assessed in terms of whether they are difficult to imitate or transfer. Such an analysis, ideally, should be supported by thorough empirical survey. Here, we applied a more cursory approach, i.e. we started with a generic collection of resources from the management literature,[57] which we specified and ranked in terms of criticality for the fuel cell case. Then we asked two experts, a researcher and a consultant in the field, to comment on our propositions. The results are part of table 5 (first column).

As general categories, we distinguish material, immaterial and human resources. Especially immaterial resources are often difficult to transfer or imitate. Inter-firm cooperation networks, customer contacts and reputation, for example, are based on mutual trust and usually require time to get established. With regard to material resources imitation and/or transfer tend to be rather easy. It may be time-consuming, though, to establish technology specific laboratories and shops and to put them into operation.

Material resources

The development and application of fuel cells requires a large amount of financial resources (venture capital) and the ability to take the corresponding risks. In addition, a broad range of technological equipment including laboratories, shops and other facilities for manufacturing and system testing is needed. Due to the decentralized nature of the technology, local offices or branches may also be advantageous – at first for field testing and in a later phase of innovation diffusion for regular maintenance and trouble-shooting services.

Immaterial resources

In the current stage of development the new technology is not yet well known and customers might hesitate to adopt it. Thus, a good reputation as well as existing marketing and distribution channels to potential customers will be crucial. Due to the complexity of the technology, well-established contacts (e.g. inter-firm networks) to suppliers and service providers are also required. Finally, an organizational culture that embraces innovative technologies and is willing to take risks is an asset.

Human resources

Due to the fuel cells' high-tech character specialized scientific know-how is needed for technology development and the improvement of its various components. Furthermore, specific technological skills are needed for installation, operation and maintenance. In order to reduce the risk for the customer, a fuel cell based product should include a full service package or even the financing part (contracting). For that reason, experiences and know-how in fields like energy services are needed as well.

5.2 Comparison of resource endowments

The comparison of resource endowments focuses on three major actor groups: manufacturers, utility companies and installers. While this limitation is sufficient to illustrate the general analytical approach, it does not capture the innovation system completely. Moreover, assessments at the actor group level rest on the assumption that the organizations in each group are to some extent homogeneous with regard to the key dimension of analysis, which is, of course, a simplification.

The empirical findings presented here are based on the 2003 case study introduced in the previous section. Data was derived from firm specific documents and - in the case of utility companies - complemented by interviews with employees. As this in-depth verification was missing for the other two actor groups, those results were presented to and discussed with two sector experts. The findings are summarized in table 5.

Manufacturers have strengths with regard to machinery and production equipment as well as venture capital. With a high degree of technical know-how, considerable scientific expertise and laboratories they carry out a broad range of vital innovation tasks from applied research, to prototype development and even series production. Their organizational culture is rather open for new technologies although we found differences here between the firms. Firm reputation, customer contacts and marketing know-how are rated as medium; most manufacturers do not interact directly with end users. Manufacturers also lack local branches although some may compensate for this resource by collaborating closely with installers. Experiences in the field of energy services were mostly inexistent.

Utility companies show a very good resource profile as far as customer contacts, marketing, local branches, reputation and experiences in energy services are concerned. Thus they definitely represent an important gateway to pioneering customers. They also control a considerable amount of financial resources to back up the risk related to fuel cell based power plants. Innovative organizational culture, scientific know-how and technical expertise, however, are less pronounced. Rather weak scores have also been attributed with regard to laboratories and production facilities.

Installation companies, finally, are in close contact with residential or commercial customers of conventional heating systems as they operate on a local or regional basis. They provide advice with regard to the choice for a certain technology (electrical heating, conventional boiler gas vs. oil, condensing boiler for gas, heat pump, fuel cell etc.) and they have in general a good reputation. Thus, they are well positioned to influence decisions of end users. However, installers have little material resources in terms of financial capital, laboratories or fuel cell production facilities. They are weak with regard to human resources and the technical skills needed to install and operate fuel cells are not readily available. Instead these skills have to be developed if the firm chooses to become active in that field. Installers finally are often characterized by a rather conservative firm culture that is not very open to new technological developments.

< Table 5 about here >

The comparison shows that the three actor groups have rather different resource profiles. Every group has strengths in one area and weaknesses in another. Utilities and installers, for instance, have considerable strengths with regard to the customer interface (reputation, contacts), which is particularly important because these resources are critical ones. Installers, however, show a weak spot in the case of cooperation networks and innovative culture. Manufacturers are better equipped than the other groups in terms of laboratories, scientific know-how and technical skills. In sum, manufacturers but also utilities control quite a broad range of resources thus having a potential to play a leading role in the innovation system. While in the current innovation system actors from all three groups collaborate, this situation might change in the future because some critical resources are simultaneously available within different actor groups and thus redundant in a certain way. Therefore it might well be possible that - as technology matures - manufacturers and local installation companies serve the market for stationary fuel cells alone and utilities are assigned a spectator's role. Such a scenario would be very similar to the current situation in the heat market.[58]

Against this background, such a resource analysis does not only provide a first overview of strengths and weaknesses of different actor groups but can also indicate where incentives and disincentives for collaboration lie. In this vein, the analysis may serve to elaborate potential trajectories of technological innovation systems by identifying feasible actor roles and network configurations. Finally, table 5 can also be interpreted line by line. If all actors or actor groups of an innovation system were included in the analysis, it would allow identifying missing resources or drawing conclusions on the potential performance of the system. This could represent a major inroad for policy intervention and strategic development of innovation systems. For this purpose, however, the relationship between resource endowments, actor strategies and system functions would have to be specified.

In order to develop its full potential, the here presented cursory analysis of resources will have to be elaborated in many repects. These include, among others, a comprehensive determination and assessment of critical resources and their potential shift as the innovation matures, a systematic screening of potentially relevant actors (or actor groups) including a procedure of how to identify those in the 'universe of non-innovating actors', a proposition of how to assess resource endowments in detail, and the elaboration of the link between resources, strategies and innovation system functions. The last issue represents a particular challenge as it is often not the mere addition of resources but their synergetic combination in networks what makes a relevant contribution to system functions.

6 Conclusions

In the paper we outlined the contours of an actor oriented analysis of innovation systems with the goal to specify current and potential contributions of actors, or actor groups, to innovation system performance and dynamics. We differentiated innovation strategies of organizational actors and the resources they command. At the system level, we proposed to analyze actor configurations, their aggregated resource profiles and system functions. The approach claims that a thorough examination of the interplay between innovation strategies and resources at the micro level with system characteristics at the meso level allows addressing a number of core research questions of innovation system analysis more appropriately. It might be of particular importance in the case of emerging innovation systems, where actor configurations and resource accumulation are still very much in flux.

As illustrated in our case study, an actor oriented approach can be used as a tool to explore the impact of innovation strategies of specific actors on overall system performance, for instance, to identify prime movers that have the potential to significantly shape the trajectory an innovation takes. The approach can also be applied to identify strength and weakness profiles of actors in terms of resources in order to explain current or to derive potential future actor constellations. In a similar vein, an analysis of resources across actor groups may reveal missing or under-activated resources in an innovation system and therefore hint at inroads for policy makers to support innovation system performance.

More generally, an actor oriented analysis improves our understanding of the structures of a specific innovation system and their impact on innovation success. A comprehensive structural analysis, however, would require the inclusion of additional elements, in particular institutions, networks and their interaction with strategies. Also, our approach has the potential to establish a conceptual link between innovation activities, strategies and resource endowments at the micro-level with meso-level concepts like actor configurations, system functions or system performance. Finally, we may embark on relating future actor configurations or system dynamics with current strategic decisions of firms and policy makers active in the respective innovation system and thus open up the innovation system concepts to prospective uses.

However, the paper could only sketch very roughly what would be needed for a full blown micro-foundation of innovation system dynamics. A number of conceptual und methodological points could only be hinted at without fully elaborating them. A crucial issue is that an actor oriented analysis always runs the risk to view the aggregate effect of different elements in an innovation system as the mere sum of the individual contributions. It therefore risks neglecting emergent effects, which arise due to the interaction of different system elements. For that reason, actor oriented analyses have to deal carefully with this topic and empirical findings need to be interpreted on the basis of these limitations. Another aspect that requires further elaboration is that structural analysis may prove too static in situations characterized by rapid change. In particular, strategies may explicitly relate to an expansion of the resource base both at the level of an individual firm and the system as a whole. A static analysis of resources would therefore give an inappropriate impression of the relevant processes operating. One way to approach this issue may be to analyze the interaction between strategies and resources at different time scales. The analysis of conditions for strategy definition may represent another option as determinants for strategies may have a longer validity than specific innovation activities.

Apart from these major issues, a number of methodological details have to be developed further. These include, for example, the identification of critical resources and the detailed specification of the resource analysis at the firm or actor group level. Furthermore, the relationship between resources and innovation system functions needs to be addressed more explicitly. In a similar vein, the link between strategies and system functions needs to be further elaborated. The development and testing of criteria and indicators of how strategies affect functions is one possibility to proceed in this respect.

In sum, further conceptual refinements and more detailed empirical applications of the actor oriented analysis are necessary to evaluate its potential to gain insight into the current state and future development options of innovation systems. The successful accomplishment of this research agenda promises to lead towards a more integrated understanding of the interplay between micro-level and meso-level determinants of innovation success.

7 Notes and References

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17. Bergek *et al.*, *op. cit.*, Ref. 4; Carlsson *et al.*, *op. cit*., Ref. 13.

18. Cf. endnote 12.

19. Much of the empirical data presented in this paper is based on an earlier study, which dealt primarily with the question of how the innovation activities of electric utility companies contribute to technological change in the energy sector: J. Markard, B. Truffer & D. M. Imboden, 'The impacts of market liberalization on innovation processes in the electricity sector', *Energy & Environment*, 15(2), 2004, p. 201-214; J. Markard, *Strommarkt im Wandel - Veränderung von Innovationsprozessen am Beispiel von Ökostrom und Brennstoffzelle* Wirtschaft - Energie - Umwelt, ed. T. Dyllick, M. Filippini & D. Spreng (Zürich, vdf Hochschulverlag, 2004).

20. Carlsson & Stankiewicz, *op. cit.*, Ref. 8.

21. For a more detailed discussion of the distinction between radical and incremental innovation processes at the system level see J. Markard & B. Truffer, ‘Technological innovation systems and the multi-level perspective: towards an integrated framework’, submitted to *Research Policy*. In F. Malerba, 'Sectoral systems of innovation: basic concepts', in: F. Malerba (Ed), Sectoral systems of innovation: concepts, issues and analyses of six major sectors (Cambridge, Cambridge University Press, 2004), p. 9-41 a similar issue is raised with the differentiation of innovation, production and distribution systems.

22. Edquist, *op. cit.*, Ref. 3. In the following, we concentrate on actors and, for example, their impact on innovation system functions. However, institutions may also be conceptualized in a way as to influence system functions directly, not just through their impact on actors. Either way, the influence of institutions is left aside in the analysis, which is of course a simplification.

23. Note that this definition of innovation activity at the micro level is different from typologies of innovation activities that have been proposed at a more aggregated level. See Chaminade & Edquist, *op. cit.*, Ref. 4 for an overview.

24. Apart from innovation activities, institutions also have a major influence on the performance of an innovation system. Here, we largely ignore the role of institutions, cf. Ref. 22. A full fledged analysis of innovation system dynamics, however, would have to explicitly include this dimension as well as the relationships between the actors.

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29. Jacobssen & Johnson, *op. cit.*, Ref. 8.

30. See Carlsson or Jacobssen & Johnson, *op. cit.*, Ref. 8.

31. Bergek *et al.*, *op. cit.*, Ref. 4; Hekkert *et al.* or Johnson, *op. cit.*, Ref. 6.

32. Different sets of functions of innovation systems have been proposed in the literature, cf. Ref. 31.

33. Jacobsson & Bergek, *op. cit.*, Ref. 4; Johnson, *op. cit.*, Ref. 6.

34. With regard to stationary power supply, for instance, a 200 kWel phosphor acid fuel cell (PAFC) by UTC Fuel Cells, has been made commercially available in 1991. Until 2004, 270 of these units have been installed worldwide (cf. A. Baker & D. Jollie, *Fuel Cell Market Survey: Large Stationary Applications*. 2004, Fuel Cell today: http://www.fuelcelltoday.com, London. p. 21.).

35. K.-A. Adamson & D. Jollie, *Fuel Cell Market Survey: Small Stationary Applications*. 2004, Fuel Cell today: http://www.fuelcelltoday.com, London. p. 22.

36. See L. Carrette, K. A. Friedrich & U. Stimming, 'Fuel Cells - Fundamentals and Applications', *Fuel Cells*, 1, 2001, p. 5-35. for a technology overview and for a review on recent market developments: K.-A. Adamson, *Fuel Cell Today Market Survey: Small Stationary Applications*. 2005, Fuel Cell today: http://www.fuelcelltoday.com, London or K.-A. Adamson, *Fuel Cell*

Today Market Survey: Large Stationary Applications 2006. 2006, Fuel Cell today: http://www.fuelcelltoday.com, London.

37. Depending on the fuel cell type the primary fuel is either used directly or pre-processed in a reformer to extract the hydrogen.

38. J. Markard & B. Truffer, 'Innovation processes in large technical systems: Market liberalization as a driver for radical change?' *Research Policy*, 35(5), 2006, p. 609.

39. See Carlsson *et al.*, *op. cit.*, Ref. 2 or Bergek *et al.*, *op. cit.*, Ref. 4 with regard to the question of how to delineate technological innovation systems.

40. S. Geiger, *Fuel Cells in Germany – A survey of current developments*. 2003, Fuel Cell today: http://www.fuelcelltoday.com, London. These figures include all, i.e. stationary, mobile and portable fuel cell innovation activities. Organizations were dominated by research facilities (28%), manufacturers and suppliers (28%), technology users like car manufacturers or utility companies (12%) and policy makers and associations (12%).

41. For a more encompassing collection of particular actors see Geiger, *op. cit.*, Ref. 40.

42. B. Bourgeois & S. Mima, 'Rationales for cooperation between firms and States within an emerging radical innovation', in: A. Avadikyan, P. Cohendet & J.-A. Heraud (Eds), *The Economic Dynamics of Fuel Cell Technologies* (Berlin, Springer, 2003), p. 79-113.

43. Geiger, *op. cit.*, Ref. 40.

44. See Ref. 33.

45. Innovation system performance can only be assessed on a comparative basis, cf. for example Edquist, *op. cit.*, Ref. 10.

46. In 2005, for example, Sulzer, the incumbent behind Hexis in Switzerland, decided to end their commitment to stationary fuel cells. Although Hexis was a leading manufacturer in stationary

solid oxide fuel cell technology at that time, Sulzer had a hard time to find an investor. Finally, the development activities at Hexis had to be cut back dramatically before a new risk taker took over.

47. Adamson & Jollie, *op. cit.*, Ref. 35.

48. Geiger, *op. cit.*, Ref. 47.

49. A systematic identification of system strengths and weaknesses can only be carried out on a comparative basis, with two or three countries for example.

50. This restriction is related to the assumption that utility companies control a more or less comparable set of resources, on which basis they can be defined as an actor group. While this is empirically supportable in most cases with regard to the resource access, actual resource amounts in each firm may differ significantly.

51. Markard and Markard *et al.*, *op. cit.*, Ref. 19; Markard & Truffer, *op. cit.*, Ref. 38.

52. Altogether 13 interviews with utility employees in response for the fuel cell development activities were conducted in 2002 and 2003 (follow-up). Our sample included 8 companies, 6 of which were located in Germany, one in Switzerland and one in The Netherlands. The two non-German companies were included for two reasons. First, a minimum sample size was needed, e.g. in order to identify strategic similarities. Second, we wanted to check whether firms under a different institutional framework show a much different strategic behavior (which was not the case).

53. See also table 5.

54. For a more detailed description of how the strategy types were identified see Markard *et al.*, *op. cit.*, Ref. 19.

55. Here we assume that knowledge created and applied within one organization serves the innovation system as a whole. We did not check, however, to what extent the knowledge was externalized.

56. Bergek *et al.*, *op. cit.*, Ref. 4; Hekkert *et al.*, *op. cit.*, Ref. 6.

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58. Whether such a scenario will become reality is, of course, not just a question of resource endowments but also of actor strategies (cf. chapter 4) and other influences such as technology development, institutional change, external events etc.

Table 1: Overview of installed and planned fuel cell power plants in Germany by 2003 (own data)

	Number of plants	Installed capacity	Capital investment (estimation)	Share of plants operated by utility companies
Large units (>100 kW)	25	5,1 MW	22 Mio. €	88%
Small units (<100kW)	540	1,2 MW	27 Mio. €	96%

Table 2: Innovation strategies of utility companies in the field of stationary fuel cells (2003)

	Goals	Priority	Activities	Strategy type
#1	Make profit, create a market for fuel cells, relate the name of the company with fuel cells	High, fuel cell is a "CEO issue"	Concentration on fuel cells for residential buildings	Leading
#2	Make profit, become a first-mover, create fascination, gather experiences	High, Fuel cells is most important decentralized technology	Broad fuel cell innovation portfolio	Leading
#3	Gather experiences, present the company as innovative	High, fuel cell is a "CEO issue"	Broad fuel cell innovation portfolio	Learning
#4	Gather experiences with different types of fuel cells and manufacturers	Medium, fuel has same priority as other decentralized technologies	Broad fuel cell innovation portfolio	Learning
#5	Gather experiences, become an "intelligent follower"	Medium, image has some importance	Pilot power plant for commercial customers	Learning
#6	Create contacts with other utilities and manufacturers, gather experiences	Low	Pilot power plant for residential buildings	Image shaping
#7	Present the company as innovative	Medium, fuel cell is an image issue	Concentration on fuel cells for residential buildings	Image shaping
#8	Present the company as innovative	Low, fuel cell is an image issue	Concentration on fuel cells for residential buildings	Image shaping

Table 3: Examples for the acquisition of new knowledge in utilities in the course of fuel cell projects

Specific knowledge on fuel cells	Knowledge that can be of general use	Innovation process related knowledge
characteristics of fuel cells operation, e.g. typical failures or factors that influence the life time of the cell stack design of fuel cell based energy supply services, e.g. collaboration and allocation of tasks with and among different firms integration of fuel cell in existing heating system and the electricity grid remote control and steering of fuel cells	design of contracting services for customers, e.g. contract details, duration, insurance issues customer preferences with regard to energy services remote control of distributed power plants organization / improvement of troubleshooting services strategic management, e.g. integration of new products into the overall strategy of the firm	learning by doing is important and can not be substituted how to manage a systematic technology watch importance of flexible design of innovation projects importance of inter-departmental cooperation within the firm importance of innovation networks favorable cost-learning-ratio of small projects

Table 4: Contribution of different innovation strategies to the functions of the fuel cell innovation system

	Leading strategy	Learning strategy	Image shaping strategy
Creation and diffusion of new knowledge	2-3	2	1-2
Guidance of the direction of search	3	1-2	0-1
Supply of resources	2-3	2	1
Creation of positive external economies	2	2	0-1
Formation of market(s)	1-2	1	1

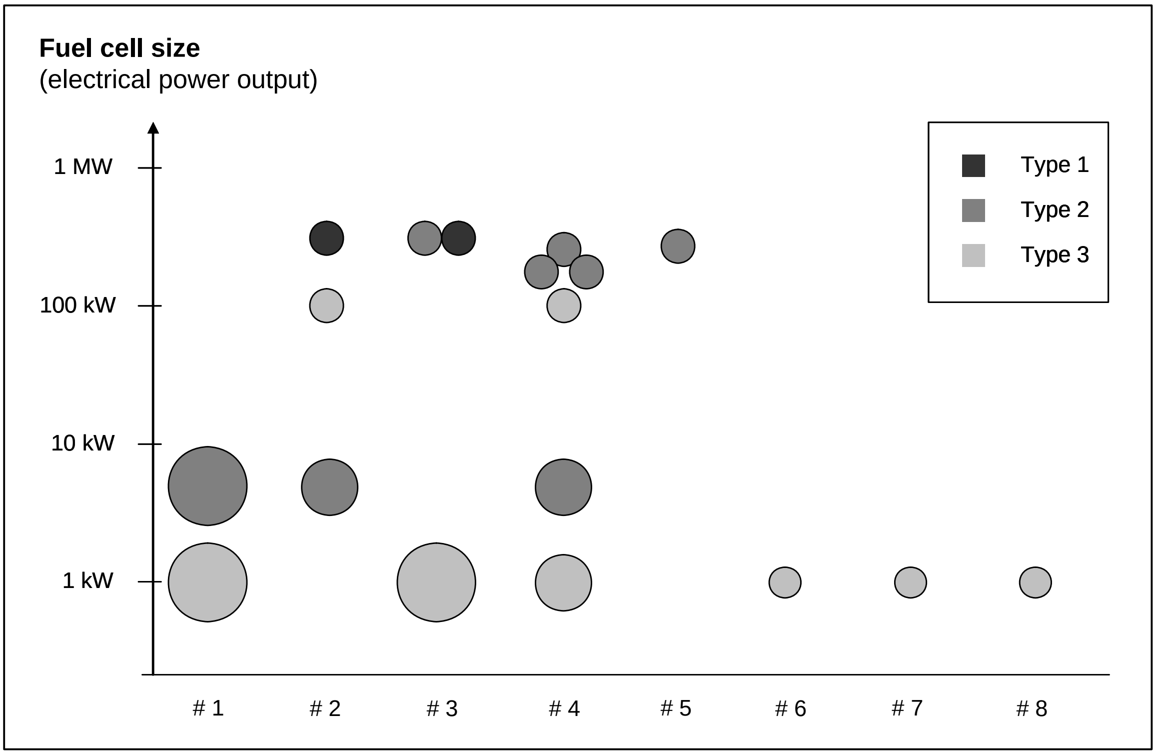
0: no or little contribution, 1: medium contribution, 2: high contribution, 3: very high contribution

Table 5: Assessing the provision of different resources by four actor groups in the stationary fuel cell innovation system

	Critical resource	Manufacturers	Utilities	Installers
Material resources				
Financial resources (venture capital)	*	1-2	1-2	0
Laboratories, shops	* *	1-2	0-1	0
Facilities for production and testing	*	2	0-1	0-1
Local offices or branches	*	0	2	2
Immaterial resources				
Reputation	* * *	1	2	2
Existing customer contacts	* * *	1	2	2
Established inter-firm co-operations	* *	2	1	0
Culture open for innovations	* * *	1-2	1	0-1
Human resources				
Specific scientific know-how	* *	1-2	0-1	0
Technical skills (installation, O&M)	* *	2	0-1	0-1
Expertise in energy services, contracting	*	0	2	0
Specific marketing know-how	*	1	1-2	0-1

Critical resources are important for the innovation and difficult to imitate or transfer: very critical ***, critical **, less critical*; Resource not available 0, available 1, highly available 2; Ranges indicate the heterogeneity within groups.

Figure 1: Project portfolios of utility companies with different types / sizes of fuel cells (2003)



Small circles represent a single or just a few pilot plants based on stationary fuel cells, medium sized circles more than a dozen and large circles more than 30 plants.