



Creating innovation systems: How resource constellations affect the strategies of system builders

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ABSTRACT

Novel technologies require the support of larger technological innovation systems (TIS). A key feature of innovation systems are system resources - collective structures such as common standards, support programs, shared expectations or testing facilities all actors can use. System resources emerge either uncoordinated or as a result of strategic action by 'system builders'. In this paper we explore the conditions of system building. Taking a strategy perspective, we analyze how system building depends on resource constellations at a certain point in time. Drawing from research in the field of stationary fuel cells in Germany, we identify three generic modes of system building: a) the "single mode", in which a system builder uses its own organizational resources to create a system resource, b) the "partner mode", in which a system builder joins forces with partners in order to co-create system resources, and c) the "intermediary mode", in which a system builder collaborates with other actors to set up an intermediary organization, which then works towards the creation of system resources. We show that the modes were chosen depending on i) what resources were initially available and ii) how they were distributed in the innovation system. Our paper contributes to a more differentiated understanding of system building in the TIS literature and beyond.

1. Introduction

Technological innovation systems partly develop without much strategic coordination, e.g. as a consequence of more and more actors joining and business models, expectations and standards emerging (Bergek et al., 2008). At the same time, systems and system resources may also be intentionally created by innovating actors (Musiolik and Markard, 2011). Such strategic system building may provide benefits and/or coordinative effects for a wide range of actors thus eventually fostering technology development.

System building is an emerging and central topic in the literature on technological innovation systems and entrepreneurship more broadly (Hellsmark and Jacobsson, 2009; Musiolik and Markard, 2011). Scholars have pointed to visionary individuals such as Edison that create entire systems (Hughes, 1979), influential champions jointly orchestrating the development of broader innovation networks (Fichter, 2009; Klerkx and Aarts, 2013) or entrepreneurial activities, in which actors develop increasing commitment over time as they join forces for market creation (Sarasvathy and Dew, 2005). All these approaches put emphasis on strategic interventions and coordinated collective action in a

so-called broader innovation community (Lynn et al., 1996). At the same time, researchers have also highlighted the distributed, or just indirectly coordinated, nature of system formation (Garud and Karnøe, 2003; Garud and Karnøe, 2005). Similarly, Lundgren (1995) has explained the emergence of new industrial networks by rather uncoordinated activities (Lundgren, 1993; Lundgren, 1995). Strategic system building and an emergent formation of system structures do not exclude each other but co-exist. And while our study concentrates on the former, we do not intend to depreciate the latter.

In the technological innovation systems literature a better understanding of the formation of TIS structures and the role of actor strategies is needed (Farla et al., 2012; Markard and Truffer, 2008a). Several studies have meanwhile explored strategic system building and have described the underlying processes (Hellsmark and Jacobsson, 2009; Kukk et al., 2015; Musiolik et al., 2012). However, more research is needed to understand the options different actors have when faced with system building challenges.

With this article we want to provide a better understanding of the conditions under which different system building strategies can be applied. We follow up on earlier ideas on resource-based system

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building (Musiolik et al., 2012) and explore how different constellations of resources affect different approaches, or modes, of system building. The central idea is that they way in which system builders pursue their goals depends on i) whether (input) resources are available and ii) how they are distributed among different actors in the system.

Our study draws on an extensive literature review and empirical research on the TIS of stationary fuel cells in Germany. The review mobilizes insights from the literatures on large technical systems (Hughes, 1979), emergence of industries (Gustafsson et al., 2016), institutional entrepreneurship (Leca et al., 2008), as well as entrepreneurship and innovation management (Howell and Higgins, 1990; Sarasvathy and Dew, 2005). Based on typical resource constellations identified in these strands of literature, we selected seven cases for an in-depth study and conducted interviews with key actors who were engaged in system building activities. The results of our study provide insights into the process of strategic system building and reveal three modes typically used by system builders. A better understanding of these modes is especially important for policy-makers who want to support system builders, e.g. to foster a rapid market introduction of clean technologies, as well as for managers of technology firms who need to understand and assess viable system building strategies.

The paper is structured as follows: Sections 2 and 3 review and compare different streams of literature on system building and introduce our analytical framework. Section 4 describes the methods. Section 5 presents the findings from seven selected system building cases, discusses typical modes of system building, and describes the influence of initial resource constellations on the application of the modes. Section 6 discusses the findings and concludes.

2. Theoretical perspectives on innovation system building

The term “system building” is gaining increasing attention in the literature on technological innovation systems (TIS) (Hellsmark and Jacobsson, 2009; Kukk et al., 2015; Kukk et al., 2016; Musiolik et al., 2012). The TIS concept builds on the idea that determinants of innovation and technological change do not only reside in organizations but are also located in the broader innovation system which supports, guides and also constrains the activities of these organizations (Jacobsson and Bergek, 2004). A TIS can be defined as a “set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilization of variants of a new technology” (Markard and Truffer, 2008b, p.611). The TIS includes various kinds of actors such as suppliers, technology developers, service providers, lead users or industry associations and the various networks and linkages between them. Through their interaction, they create, maintain and also change technology-specific institutional structures such as norms, standards, support programs, collective visions or technology legitimacy. These institutional structures often represent critical system level resources for innovating firms (Musiolik and Markard, 2011).

When TIS scholars started to highlight the role of key processes and TIS functions (Bergek et al., 2008; Hekkert et al., 2007), processes in which innovation system structures are formed or changed were described as emergent and uncoordinated (Bergek et al., 2008). Positive externalities at the system level, for example, were conceptualized as side effects of new actors entering the TIS, thereby increasing variety and technology legitimacy: through their interaction, firms and other actors create – almost by default – the resources, competences and legitimacy needed (Bergek et al., 2008).¹

As a consequence, the TIS literature back then was criticized for paying little attention to the influence of agency² and strategic action

(Markard and Truffer, 2008a). Hence, a micro-level perspective with a clear focus on actor strategies and resources based agency was suggested (Musiolik et al., 2012; Musiolik and Markard, 2011). Central to this new perspective is a strategic view on innovation system building, which has been conceptualized as “the deliberate creation or modification of broader institutional or organizational structures in a technological innovation system carried out by innovating actors” (Musiolik et al., 2012, p. 1035).

In connection with system building we suggest using the term “system builder”, which was originally introduced by Hughes, 1987.³ While Hughes focused on influential individuals we view system builders more broadly as ‘actors who are technically, financially and/or politically powerful and commit themselves to initiate to innovation system building aimed at the diffusion and further development of a new technology’ (Jacobsson and Johnson, 2000, p. 630). Various empirical studies indicate that next to influential individuals (Hellsmark and Jacobsson, 2009) other types of system builders exist: firms (Jacobsson and Bergek, 2004), associations, consultants or other intermediary organizations (Kivimaa, 2014; Klerkx and Leeuwis, 2009), alliances and formal networks (Hellsmark, 2010; Musiolik and Markard, 2011) or even more complex collectives of actors (Klerkx and Aarts, 2013; Musiolik et al., 2012; Van de Ven, 1993a).

Despite the increasing number of studies, we are still at the beginning of understanding the conditions for successful system building. Musiolik et al. (2012) revealed that system building (as well as other strategic actions) generally depends on the availability of different resources. Actor coordination and embedding might be a key system building activity as it increases the available resources (resource-driven system building). Consequently, a TIS actor or innovation community might be less emergent as indicated in many TIS studies. Scholars are still at the beginning of understanding the underlying mechanisms and the importance of strategic entrepreneurial interventions (Klerkx and Aarts, 2013). How system builders proceed in different settings, what system building depends on or whether there are typical strategies is still unclear. That is why we review related strands of literature below.

2.1. Other meso-level approaches to system building

The literature on large technical systems (LTS) was developed in response to technological determinism. It addresses the role of human agency in shaping large systems such as electricity production and distribution or telecommunication infrastructures (Hughes, 1979; Hughes, 1987; Summerton, 1994). Attention has focused on the broader technical, economic and political factors that trigger the evolution of infrastructure systems.⁴ System evolution critically depends on so-called reverse salients, i.e. elements which are out of phase with other components and hamper system performance (Hughes, 1987). Powerful individuals are able to identify and define key sets of these critical bottlenecks and shape the various interrelated components of large technical systems while identifying and solving reverse salients. Following these ideas, system building is about key individuals who control the necessary resources (concentrated agency) to solve critical problems and carefully steer the evolution of interconnected parts of a large technical system.

The literature on the emergence of industries also contributes to the understanding of system building (for a review see Gustafsson et al. (2016)). The emergence of industry-specific elements has been

¹ The same holds true for the emergence of specific labor markets, service providers or knowledge spillovers, which are also explained by an enlargement of the actor base or co-location effects (ibid).

² Note that we define agency as the capacity of an agent (individual person or entity) to act independently in the world, i.e. to create and shape its surroundings. Agency is linked to and depends on power, i.e. the resources an agent controls.

³ The innovation management and entrepreneurship literature draws on a similar concept of innovation champions (c.f. Section 2.2).

⁴ Large technical systems consist of technical artifacts such as generators, mental frames and broader supportive structures such as laws. These elements are interconnected.

explained in a general way by the interplay of different sub-processes, i.e. developments in technology, markets, activity networks and industry identity (ibid.). However, there are also more elaborated explanations. According to Garud and Van de Ven, industry emergence is a larger social process which builds upon the efforts of a broad collective of actors (Garud and Karnoe, 2003; Van de Ven, 2005). Concepts such as ‘distributed agency’ or the metaphor of innovators who ‘run in packs’ are utilized to explain the emergence of system elements (so-called ‘infrastructure for entrepreneurship’). In particular, the process of interactive emergence⁵ is central and the idea of path creation is introduced to explain system building (Garud and Karnoe, 2003; Garud and Karnoe, 2001; Van de Ven et al., 1999). Distributed resources and inputs of actors are harnessed through a rather uncoordinated interplay of innovating actors. Garud and Karnoe (2003) labeled this process as bricolage in contrast to top down design approaches. Similarly, Lundgren describes the emergence of the field of image processing technology in Sweden as a rather emergent uncoordinated process characterized by a sequence of imbalances and partial solutions. He thus denies strategic actions and orchestrated collective strategies in the sense of a “great design of new technological fields” (Lundgren, 1993; Lundgren, 1995).

To conclude, the aforementioned meso-level approaches have a focus on the interplay and emergence of supportive system structures. These technology-specific components provide externalities, reduce uncertainties and thus facilitate innovation activities for a broad range of actors. Second, system formation can be coordinated and actively managed in an entrepreneurial way or it can be largely emergent, i.e. without any traceable strategic intervention and coordination of actors. While the TIS and the literature on industry emergence pronounces the interplay of actors/key processes (cumulative causation, interactive emergence), the literature on large technical systems highlights individual system builders. Third, the review illustrates that a deeper understanding of agency and strategic action is needed. That is why we also review approaches towards system building at the micro-level.

2.2. Micro-level approaches to system building

The main idea of the literature on institutional entrepreneurship (IE) is to analyze the role of actors and strategy in institutional change and to reintroduce agency in institutional analysis (DiMaggio, 1988). Its focus is under which conditions actors become institutional entrepreneurs and how the process of institutional entrepreneurship unfolds (Leca et al., 2008). Institutional entrepreneurs often have to attain positions which enable them to bring together complementary stakeholders, to convince highly embedded key actors, or to orchestrate collective action (Maguire et al., 2004). Therefore, institutional entrepreneurship is a complex political and social process in which entrepreneurs have to mobilize individual resources such as social skills, to integrate resources of complementary actors or to develop and deploy (new) resources such as legitimation and social capital in broader networks (Fligstein, 1997). System building is understood as micro-level activities in the creation of new institutions or the transformation of existing ones with various systemic impacts. However, influential entrepreneurs can hardly change institutions alone, that is why they typically mobilize allies and develop different types of networks (Fligstein, 1997; Rao, 1998). As a result the IE literature acknowledges both: collective institutional entrepreneurship through formal networks as well the central role of single individuals. What unites the field, is the emphasis on intentional strategies and the development and deployment of different types of resources to change critical institutions which

then facilitate innovation (Dorado, 2005).⁶

A specific stream within the broad entrepreneurship and innovation management literature focuses on system building when discussing radical innovation and the process of market creation (Dew et al., 2008; Sarasvathy and Dew, 2005; Wiltbank et al., 2006).⁷ Entrepreneurs or so called innovation champions are individuals who informally emerge (in an organization) and make a decisive contribution to the innovation by actively and enthusiastically promoting its progress through different critical stages (Howell and Higgins, 1990). These system builders fulfill an important role. Innovation activities at different levels are often orchestrated as different system builders work together in the development of a broader innovation network (Klerkx and Aarts, 2013). Often some overarching organizations so called innovation intermediaries are deployed or developed to coordinate the innovation community and to organize collective action (Howells, 2006; Lynn et al., 1996). System builders work here in multidisciplinary settings whereby reducing ambiguity, finding common ground for collaboration, and inventing broader organizational and institutional solutions in the face of obstacles, resource constraints, and legacy system are vital (Hajek et al., 2011).⁸

Sarasvathy and colleagues developed a better understanding of such kinds of entrepreneurial processes. When faced with ambiguity and high uncertainty, entrepreneurs start from the resources they have at their disposal and continuously extend these resources while they interact with other stakeholder in networks (Sarasvathy, 2001; Sarasvathy, 2008; Sarasvathy and Dew, 2005).⁹ The creation and co-ordination of new business opportunities starts if actors pre-commit to a new technological path, persuade others to follow, and set in motion a chain of joint commitments.¹⁰ Subsequently entrepreneurial system building strategies must have a crucial impact on the actor involvement or the embedding processes of distributed actors in different types of networks to increase the resources available (ibid.). Agency is distributed among a network of actors but is also evident in the interventions of system builders steering and coordinating the embedding and co-creation process. In fact, market creation (system building) is a means-driven process. It does not as much depend on the problems at the system level but more on the availability and development of resources for entrepreneurial system building.

To summarize, the micro-level perspective adds further features of strategic system building. First, powerful entrepreneurs can be central for the creation and shaping of TIS structures as they might control all resources necessary. Less influential actors, however, can hardly create system resources on their own. Consequently, system building is often a collective process. Different types of organizations or formal networks are deployed or developed to coordinate strategies and organize collective action. These organizations are often labeled as intermediaries, which coordinate different actors, provide new resources and facilitate collective action and system building (Howells, 2006; Musiolik et al., 2012).¹¹ Second, resources and their availability or distribution have an

⁶ In this regard, the literature contributes to the understanding of entrepreneurial system building, although a well-established system concept is not applied.

⁷ Accordingly this literature not only analyzes ‘who is the entrepreneur’ but is increasingly interested in the entrepreneurial process of market creation.

⁸ Therefore, system building skills in communication and agenda construction, in norm setting, value framing, and other forms of leadership within social processes are important individual competences of system builders.

⁹ As the future cannot be predicted, a specific line of action for problem-solving and decision making which reduce uncertainty and ambiguity as a new business field or market is co-created is key.

¹⁰ According to Sarasvathy, a pre-commitment is a self-imposed, non-negotiable constraint which stacks the deck in favor of or against specific choices. In radical innovations initial relationships between heterogeneous actors have to evolve in the absence of established routines, trust and clear specifications of future profits. Sarasvathy points to the fact that the problem of opportunism and free riding is irrelevant in the absence of visible market opportunities, and that the concepts of docility and intelligent altruism explain the emergence of collective action in technology entrepreneurship.

¹¹ In this paper we do not further draw on the literature of innovation intermediaries

⁵ The outcomes of strategic actions cannot be attributed to any single entrepreneur. Therefore interactive emergence stands in contrast to the traditional view on strategy and the “design school”.

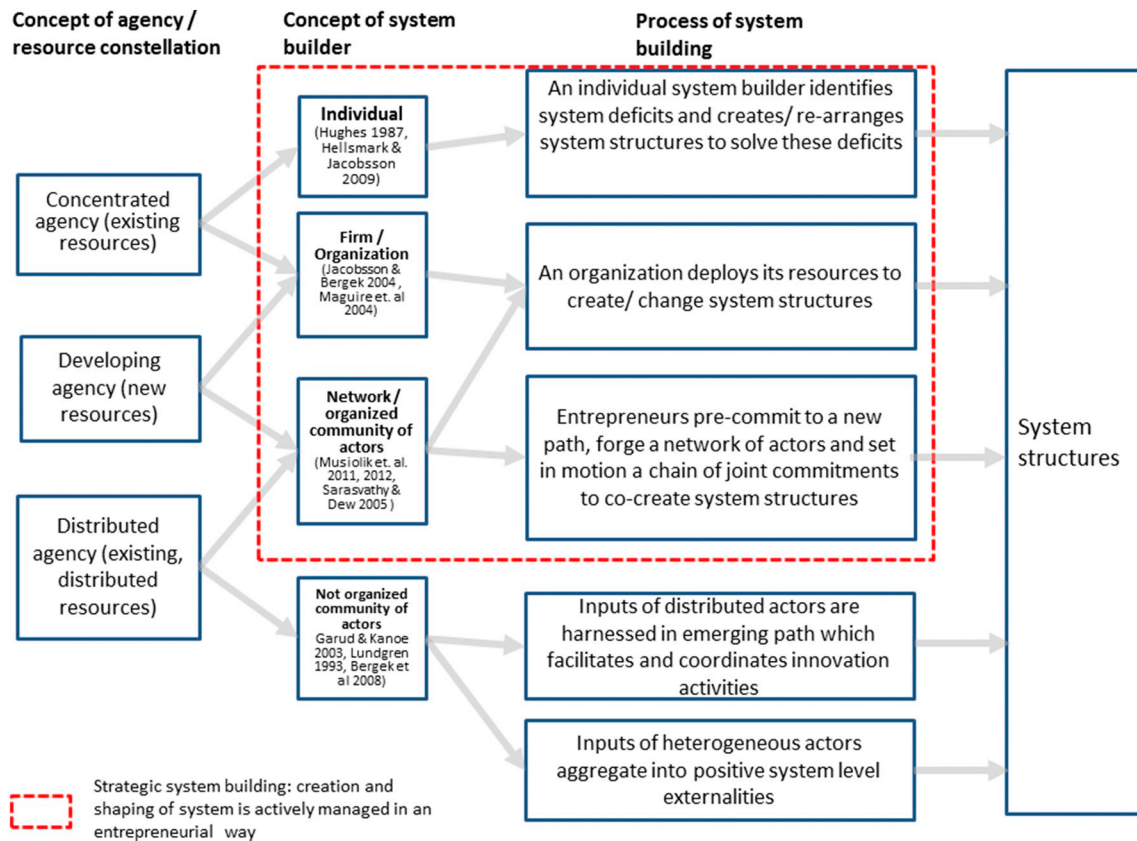


Fig. 1. Delineation of strategic system building.

impact on strategy, e.g. on the range of strategic actions a system builder can pursue and on the actors he needs to collaborate with.

Fig. 1 summarizes the findings of the literature review and distinguishes the ‘space’ of (strategic) system building from emergent processes of system formation. Explicitly or implicitly, the approaches draw on different concepts of agency, types of system builders and refer to different processes of system formation. Arrows indicate on which basis a certain understanding of system building (or formation) can be explained. The figure suggests that we can expect situations in which all necessary resources for system building exist and are under the control of powerful individuals or available within the boundaries of an organization (concentrated agency). However, resources for system building such as reputation and lobbying power might also be missing and have to be developed beforehand (Musiolik et al., 2012). To this end, new organizations can be created, which – over time – may turn into influential system builders (developing agency). Finally, existing resources could also be distributed between actors (distributed agency). System building may then again be coordinated through networks or a ‘community of actors’ or it may occur in an uncoordinated way (not organized community of actors).

3. Analytical framework

To analyze the process and conditions of strategic system building, we take a perspective in which resources are central: They are the

(footnote continued)

(Kivimaa, 2014), but we acknowledge the difference between existing professional organizations such as industry associations etc. which facilitate innovation while providing innovation services and newly established interest groups or formal networks were individuals from the emergent field jointly work together to solve common problems and organize collective actions. These networks are less professionalized, however might also become important associations in the future.

targets of strategic activities and, at the same time, they influence what strategic options are available in a given situation. We draw on an analytical framework of resources at the organizational-, network- and system level (Musiolik and Markard, 2012). This framework links the concept of a key system builder (Hughes, 1979) and the entrepreneurial process of resource-driven system building (Sarasvathy and Dew, 2005) with the idea that strategically created meso-level structures interact as components of a broader technological innovation system (TIS) (Hekkert et al., 2007; Suurs and Hekkert, 2009).

System builders identify systemic problems (e.g. deficits in TIS functions) and initiate activities towards their solution. We understand system building as a means-driven process in which system builders start from the resources they control and continuously extend these while engaging with other stakeholders. It depends – as do other strategic actions – on different resources and the conditions under which they can be deployed (resource constellations). We expect that different resource constellations enable different ways of system building and that we can identify typical strategies or modes of system building. Below we define and distinguish resources with regard to who has access to them.¹²

- Organizational resources (OR) are tangible and intangible assets of strategic value (here: for system building) which only one organization can access¹³ (e.g. firm reputation, patents, brands).
- Network resources (NR) are tangible and intangible assets of strategic value (here: for system building) to which network members have access (club-resources) (e.g. influence of a network in political lobbying).
- System resources (SR) are tangible and intangible assets of strategic

¹² A different criterion would be who has developed them or who controls them, which is not necessarily the same as access.

¹³ Unless the organization decides to share them (e.g. in the case of co-branding).

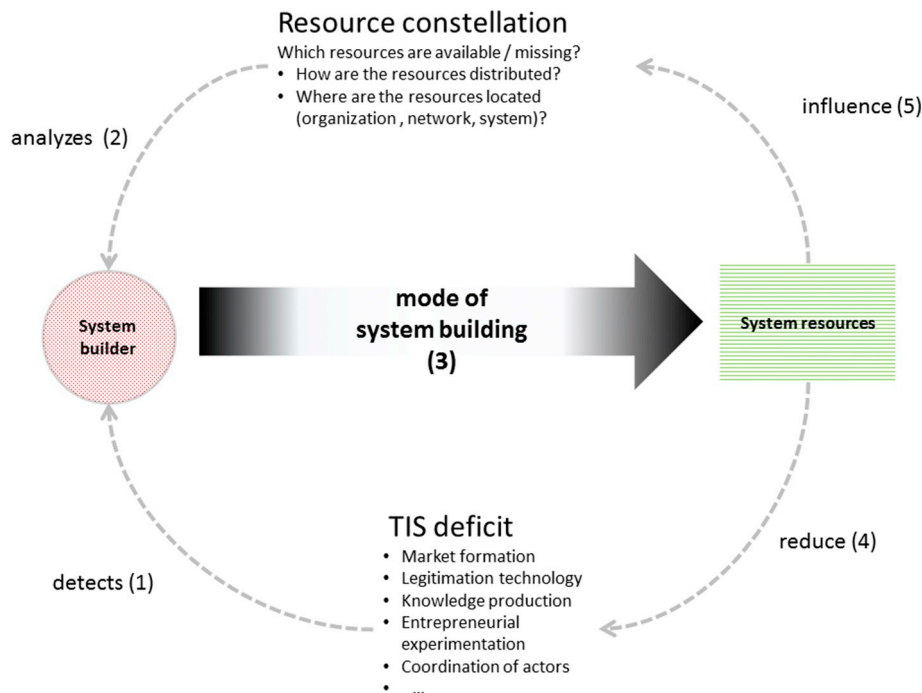


Fig. 2. Entrepreneurial actions and conditions for strategic system building.

value to which actors in the TIS have access (e.g. technology specific support program, technology legitimacy). They are non-excludable, i.e. every actor involved in the development of the technology can use them. They can be used for different purposes, including but not limited to further system building.

Organizational, network and system resources are often created at (and controlled by) the respective level but there are exceptions.¹⁴

In addition, we distinguish different resource constellations. From the review in Section 2 we already know that resources that are needed for system building might be controlled by single organizations (concentrated agency), or distributed among different actors (distributed agency). Furthermore, they might already exist or they have to be developed first (developing agency). We expect that strategies of system builders are influenced by these different resource constellations.

Fig. 2 depicts our analytical framework. System builders detect functional TIS-deficits such as problems in the formation of markets (1), develop strategies (and resource requirements) to address these and analyze (2) the resource constellation in the broader TIS (black dotted arrows). Based on this, they launch system building activities or modes (3) alone or in collaboration with other actors (resource driven system building, thick black arrow). Once new system resources have been created (or changed) this has not only an impact on further innovation activities of TIS actors but also changes prior resource constellations (5). At the same time, changes in system resources will affect system performance and – ideally – reduce earlier deficits (4).

4. Method

The TIS on stationary fuel cells in Germany represents a particularly fruitful case to study the activities of system builders. We selected this technological field for three reasons. First, while the TIS is still in the formation phase, important technology specific structures such as a support program or standards have already been established in recent

years. Secondly, fuel cell technology is not only a radical innovation but also a complex technology, which requires a whole industry to be built up for a well-functioning innovation system. Thirdly, we could draw on the data of previous studies (Markard and Truffer, 2008a; Musiolik and Markard, 2011; Ruef and Markard, 2010), which helped us to identify system builders and to better understand the problems they are confronted with.

Because research on strategic system building is rather new, we used a case study approach (Eisenhardt, 1989; Yin, 1994). A case was defined by the exceptional phenomena that an individual or an organization strategically creates and shapes supportive meso-level structures (system resource), although a broad range of further actors also benefits from these activities. A pre-study and case selection was followed by the subsequent data generation and analysis. In the pre-study, we conducted literature studies, desktop research and interviews in the field. As we were interested in innovation activities of actors which had led to creation and shaping of system resources, we chose key persons such as managers of innovation networks or associations for interviews. These persons were able to point us to the major problems (functional problems or TIS deficits cf. Section 2) and to give us further information about system builders and organizations involved in system building (snowball method). At the end of this first analytical step, we had identified ten cases of system building in which one or more actors had recognized one or more deficits and had strategically worked towards the creation and shaping of system structures to address the deficit(s). Some of the cases were very similar in terms of resources constellations and addressed TIS deficits (e.g. two cases of supplier integration). Subsequently, we carefully chose seven cases for an in-depth study.

The case selection was followed by additional interviews with key system builders to generate a more specific case data base. For the preparation of each interview, we examined websites, annual reports, newsletters and newspapers articles. Semi-structured expert interviews were then conducted. In the interviews we discussed major TIS deficits (e.g. missing suppliers) and how they were tackled. Every interview included questions about the innovation activities, the involvement with other actors, the reason for the initiatives and the perceived benefits of creating and shaping components at the system level. In total, 16 interviews were carried out with key system builders (1.5 h on

¹⁴ A technology standard, for example, may be developed and controlled by one actor even though it is used by many organizations at the TIS level in the sense of a system resource.

average), and another 32 interviews (same empirical fields but other informants) could be used as additional sources of information (triangulation). For each of these cases, we collected data from our interview protocols, which we complemented by firm reports, press release and other publicly available documents. Interviews were fully transcribed and consolidated with the other documents in a database.

In the data analysis, we could draw on several hundreds of pages of interview data and other documents, which were analyzed with the help of a coding software (MaxQDA). According to Miles and Huberman (Miles and Huberman, 1984), we developed an assignment rule and analyzed the generated text documents according to the system building activities and the type of resources the system builder had used (organizational, network, system resources). Based on the identified activities, we were finally able to identify similar cases and to describe typical modes of system building within the derived dimension (resource constellations).

5. Results

In this section we present seven empirical case studies of system building and analyze the resources and modes which have been deployed, and then differentiate emergent system formation and strategic system building.

5.1. Observed system building cases

A short history of the TIS of stationary fuel cells including different networks working towards system building has already been introduced in Musiolik and Markard (2011). Below, we depict the selected cases and describe the main activities towards system building and their results, i.e. system resources which have been created and shaped. The cases are structured according to the TIS deficits that had to be solved.

5.1.1. Weak knowledge base

The creation and diffusion of basic scientific knowledge is key for TIS formation and the value appropriation by private firms (Van De Ven, 1993b). In the BMWA¹⁵ case, a federal ministry played a key role in strengthening the knowledge base in the area of fuel cells in Germany. Triggered by the energy crisis and environmental concerns, the BMWA started to intensify support of basic research of hydrogen and fuel cell technologies. In 2000, the federal ministry launched a special program for residential fuel cell heating devices, the “Zukunfts-Investitions-Programm (ZIP)”. More than half of its funds (about 60 Mio. Euro for three years) were allocated to stationary applications. As a result, a specific support program for stationary fuel cells was created and basic scientific fuel cell knowledge increased. The program triggered additional investment from universities and industry partners. Through newly established R&D-consortia initial partnerships within the fuel cell value chain were initiated and complex components such as the membrane electrode assembly (MEA) were jointly developed and made available. The step from basic research to applied R&D and field tests was further complemented by the foundation of fuel cell specific research institutes.

5.1.2. Procurement market immature

In the TIS for stationary fuel cells, core components were costly as well as produced in low quality and numbers. Established suppliers from other industries possessed suitable components and valuable manufacturing capabilities but little understanding of specific requirements of the fuel cell technology. The adaption of standard components and the qualification and integration of component suppliers was therefore an issue. Two fuel cell manufacturers (CFCL and Baxi-

innotech) addressed this deficit in different ways.

In the CFCL case, a leading manufacturer managed its supply chain in a pro-active way. CFCL acquired specific technological knowledge to produce and optimize a highly efficient fuel cell. However, on the step from small scale to mass production the firm realized that central ceramic components were needed at a lower price and in a better quality. The company therefore developed a strategy to employ the manufacturing capabilities of established suppliers. CFCL chose partners from the German ceramic industry, non-exclusive collaboration agreements were established, and specifications, technological knowledge and licenses deliberately transferred to the suppliers. While CFCL was supervising the development of the ceramic components, the suppliers could sell the components also to other manufacturers. Based on the higher demand, it was expected that the component price would decrease while its quality would continuously increase on the way to mass production. In sum, a deliberate knowledge transfer and strategic cooperation lead to the qualification and integration of suppliers, new parts of emergent value chain and the co-creation of cheap standardized components.

Baxi Innotech was following a different approach towards supplier qualification and integration. It was reported that the CEO of Baxi was a leading actor in a network of an industry association (the VDMA fuel cell working group) and thus shaped the strategic direction of joint activities. The company motivated partner suppliers to enter the network, communicated its technological specification, and thus contributed to the generation of a joint understanding of fuel cell requirements among the network members. Additionally, Baxi and other network members initiated and oversaw a support program to finance and supervise small-scale R&D projects such as the adjustment of standard fuel cell components (e.g. pumps, valves). By exchanging requirements between system manufacturers and suppliers in the network and by the subsequent execution of R&D projects, an orchestrated adaption of stationary fuel cells and components was initiated. Due to these activities, Baxi and other manufactures trained and integrated suppliers, contributed to the establishment of an efficient network of joint technology development and influenced the adaption of standardized components. Interestingly, Baxi also used the network to introduce preliminary standards (e.g. a Japanese connector technique) and to initiate the subsequent adaption of components and to decrease to overall prize of stationary fuel cells.

5.1.3. Sales market immature

The successful market launch of stationary fuel cells highly depends on the interested end costumers, and clear actor roles of energy service providers, fitters and other downstream service providers. It was reported that field-testing activities were highly interrelated to other subsequent market preparation activities. In order to develop new business models energy service providers such as EWE were active in regional field testing (EWE case) and in networks (EWE Callux case) to steer market formation at a national level.

EWE as a leading energy service provider installed and tested several hundred fuel cell pilot plants since 1998. Through the field tests, EWE provided finance, pilot costumers, and distribution channels to fuel cell manufacturers. A business platform between EWE and a local association of fitters was also founded (Table 1).

Through this cooperation, EWE introduced contracting schemes¹⁶ into a regional market. It was reported that the involved actor groups, i.e. EWE, fitters, manufacturer and end customer, accumulated experience with contracting and the installation and maintenance of stationary fuel cells, thus routinizing their interaction as service processes became established. EWE steered and initiated the whole

¹⁵ BMWA Bundesministerium für Wirtschaft und Arbeit (Federal Ministry of Economic Affairs and Employment).

¹⁶ Contracting is an essential element of the business strategy of EWE. In contracting schemes the end customers does not own the fuel cell plant but close a contract with the energy service provider for delivering heat and energy.

Table 1
Cases in which system builders created and shaped system resources.

	a. BMWA	b. CFCL	c. VDMA	d. EWE	e. Callux	f. Fuel cell alliance	g. NOW
Focal TIS deficit	Weak knowledge base	Procurement market immature	Procurement market immature	Sales market immature	Sales market immature	Weak coordination of TIS actor community	Weak coordination of TIS actor community
Key system builder	Federal Ministry of Economic Affairs and Employment	CFCL fuel cell manufacturer	Baxi Imotech fuel cell manufacturer	EWE energy service provider	EWE energy service provider	System builder of VDMA working group, IBZ network, ZSW research institute, Fuel cell Europe association	Manager of NOW organization
Activities towards deficit reduction	Developed strategy to support basic research due to energy crises & environmental concerns Allocated 60 million of funding Shifted towards applied R&D D. field tests in ZIP program due to industry and business development concerns Founded fuel cell research infrastructure in federal states	Recognized the need for integrating the manufacturing capabilities of suppliers Strategically chose suppliers for non-exclusive collaboration contracts Transferred knowledge, specification, licenses, means of production to suppliers Supervised and supported the production of cheaper ceramic components with higher quality	CEO became head of steering committee of the VDMA working group, shaped the strategic direction of activities Motivated suppliers to become members Exchanged its fuel cells specifications, contributed to generation of joint understanding of fuel cell requirements Influenced creation of KGP specific support program, supervised projects in KGP program Introduced and diffused Japanese connection technique	Started field testing, provided finance, selected pilot costumers Founded a cooperation with local fitters, introduced local fitters, architects, maintenance of fuel cells Founded information and training center Conducted info campaigns	Promoted foundation of joint field test project joint installation of 800 pilot plants at a national level Conducting joint activities in marketing and communication Work on a vocational training program and guidelines for fitters Initiated to work on joint technical solutions, e.g. components for smart grid solutions (Callux box)	Met to activate and organize the field in 2005 Wrote a strategy paper, founded the Fuel Cell Alliance Germany Convinced relevant ministries to bundle activities, to found a strategy group Crafted draft of a fuel cell road map (NEP), developed NIP program structure, idea of NOW project organization Used NEP and window of opportunity after elections in 2005 to anchor NIP program	Supervised selection of NIP projects, lighthous projects, management of R&D and supply chains Mediated interests between different parties, initiated the modification of regulations, funding guidelines Promoted cross-sectional tasks: joint work in standardization committees, fuel cell campaigns, and international exchange
Created and shaped system resources	R&D support program Strengthened scientific knowledge base Initial partnerships and parts of fuel cell value chain Integrated fuel cell components	Integrated, qualified suppliers as new actors with crucial competences Standardized components for stationary fuel cells New part of value chain	KGP support program Establishment of an network of technology developers Qualified suppliers Adapted standard components (standard connection technique)	Trained service providers, established service processes Local nursing market for manufacturers Increased awareness of stationary fuel cells	Callux project network Joint technological solutions, desulfurization cartridge, Callux box Vocational training program for fitters Trained service providers, established service processes, bridging market at national level	Organized fuel cell community, new network structure (NOW advisory board) NEP a joint national fuel cell roadmap NIP a public private partnership between industry, science, government and NOW	Governance structure to manage field development, avoid competitive issues and create synergies and guidance Strong networks of actors for different applications (e.g. Callux) Caretaker, coordinated position in international standardization committees

process. As a result, both fitters and a wider public were prepared, and the interests of future customers were raised. In this way a so called nursing market (Ericsson and Maitland, 1989) was provided which also supports the manufacturer while sales and profits were still low.

Due to the complexity of the fuel cell technology, EWE realized that local initiatives are not sufficient to introduce stationary fuel cells into an (immature) market. In the EWE Callux case, the energy service provider persuaded other actors to submit a joint project proposal for a joint field test project in the context of the newly realized NIP-support program (cf. case f). After the proposal was accepted, a project network structure was established in order to coordinate joint measurement and to realize synergies in market formation and in subsequent installation of 800 pilot plants at a national level (lighthouse project). EWE had a key role in this network. Due to different joint activities, trust and an efficient (organizational) network structure emerged. EWE used these structures to initiate the work on further joint technological and organizational solutions, e.g. a standard component (Callux Box) for a remote control and smart grid solution for stationary fuel cells as well as a module for the vocational training of fitters. Through Callux and the joint installation of several hundreds of fuel cells, elements of a bridging market (Andersson and Jacobsson, 2000) were established, and suppliers and fuel cell manufactures further financially supported on the way to the mass market.

5.1.4. Weak coordination of TIS actor community

In many cases, the formation of a TIS lasts for years and may evolve in a rather uncoordinated way (Jacobsson and Bergek, 2004). A strategy for structuring and coordinating the formation of a TIS, i.e. exerting governance and realizing synergies, becomes quite important if different TIS compete. As central system builders were afraid of losing ground in comparison to the developments in Japan, a massive co-ordinated initiative in Germany was realized.

In the “Fuel Cell Alliance case” system builders from the established networks of stationary fuel cells (IBZ, VDMA) linked up with key players from mobile and portable applications of fuel cells and founded a “Fuel Cell Alliance Germany”. Through this strategic initiative, a field that was before characterized by multiple fuel cell initiatives became structured and organized. Key system builders such as EWE took the initiative to compile a fuel cell strategy paper and to organize meetings with politicians. Triggered by this coordination process, the federal ministries also bundled their interests and a joint strategy group was established. Here, industry and ministries worked closely together on a collective strategy to further develop the field. Various ideas and aims became structured and led to the establishment of a joint fuel cell roadmap (the National Fuel Cell Development Plan NEP). After the federal election in 2005, this strategy group identified a window of opportunity to link up with the new government and to submit the idea of a national fuel cell support program. The NIP support program became anchored in the new government's coalition agreement, a public-private partnership between industry, science and federal government was realized, and an organization (NOW GmbH) was created to implement it.

The “NOW case” is related to the previous case. At the time of the foundation of the NIP-Program it became clear that the governance and coordination of actors was still an issue. In order to avoid competitive issues among fuel cell firms and to realize synergies during the program's implementation, the new intermediary was established. It was managed by key persons from the field of stationary fuel cells with specific knowledge, contacts and reputation. They were in charge of steering the direction and speed of the NIP Program. They supervised the foundation and selection of field test network (such as Callux) and tried to optimize their composition, i.e. manage emergent R&D and supply chains. In addition to that, NOW managers were active in the mediation of different interests, in facilitating the communication between industry and ministries, and in the advancement of the fuel cell roadmap NEP and critical regulations and funding schemes. Finally, the

program organization also promoted cross-sectional tasks and conducted information campaigns about NIP projects and the fuel cell technology, while supporting international knowledge exchange and the presence of the German industry in international standardization boards. These activities had various effects: Firstly, synergies between projects and strong networks of actors within the different applications could be identified and developed. Secondly, as a dedicated organization NOW could increase the (international) awareness and assertiveness of German fuel cell sector. This became visible through the employment of a joint caretaker and a coordinated German position in international standardization boards. Thirdly, a governance structure to manage NOW was established.¹⁷

The comparison of the different cases shows that system builders initiate activities to solve common TIS deficits and to fulfill system building. It seems that these challenges, or TIS deficits, are typical for new technologies. However, what is more important here is that different system builders chose different approaches to solve these common problems. The general pattern which emerges from the description is that in some examples, a single organization or pair of actors and in other cases intermediary organization was involved in initiating and executing system building. In the next section, we elaborate on these findings and delineate different system building modes.

5.2. Analyzing the cases conceptually

In this section, we conceptually analyze the selected case studies according to the analytical framework introduced in Section 3. First, the resources used are discussed, and then key modes of system building are delineated.

Table 2 depicts each of the cases in conceptual terms. The system builder, the involved complementary actors, and deployed resources are illustrated (organizational, network and system resources). Arrows indicate the direct influence of the system builder and dotted arrows indicate indirect influence. Similar cases are consolidated.

In the BMWA case, a federal ministry had used its financial resources in addition to its legal power for a direct and “top-down” creation of a support program. This program represented a valuable system resource for other actors in the field as it initiated and facilitated further research activities and partnerships and finally strengthened the knowledge-base of fuel cells in Germany. Public authorities led the way and facilitated the activities of science and private firms. The involved ministry did not need to collaborate with other actors in terms of systems building because all necessary resources were concentrated within the organization.

This holds not true for the CFCL and the EWE cases. These two cases are comparable because system building depended on different and rather distributed organizational resources.

CFCL and EWE each had visions about their future business roles and each developed strategies to involve complementary actors and to integrate the resources necessary. Both system building processes were based on the foundation of strong alliances in which organizational resources such as contacts to pilot costumers, finance, knowledge or licenses were transferred (arrow from the system builder to the actor).¹⁸ While in the CFCL case the resources for system building were just distributed between CFCL and a supplier (Table 2, Figure b), the situation in the EWE case was even more complex as two alliances (with

¹⁷ Meanwhile the NOW advisory board, a further network, was established to represent the fuel cell system builders and aforementioned networks. As a result, not only were these new system structures established, but the fuel cell community was also organized and could operate on the interlinked overarching networks (e.g. VDMA, IBZ, NOW advisory board). Interestingly, the key system builders of the formal networks also played a key role in the newly created NOW advisory board and could further influence the progress the TIS.

¹⁸ While the partner firms get trained and qualified, they also invest in the development of own resources and capabilities and become further committed into the TIS of stationary fuel cells (escalating commitment).

Table 2
Conceptual description of the cases.

Cases	a. BMWA	b. CFCL	d. EWE	c. VDMA	e. IBZ	f. Fuel cell alliance	g. NOW
Description of strategic intervention	Launching a support program to initiate R&D consortia as parts of initial fuel cell value chain	b. Integration of supplier with complementary resources to co-create standard components d. Integration of local fitters to co-create nursing market and prepare end-customers		c. Organizing and coordinating broader integration process of suppliers through interventions in network e. Coordinating joint activities in market formation to achieve synergies, risks sharing, higher visibility through joint activities in network		Organizing key entrepreneurs and coordinating consensus on a roadmap to convince public authorities for a coordinated intervention (support program)	Deploy a network to launch an organization which then professionalize coordination & provides system building services
Mode of system building	Use of concentrated OR for top-down creation of SR Single mode	Distributed resources & transfer of OR to activate an alliance for co-creation of SR Partner mode		Development & deployment of intermediate NR for direct creation of SR Intermediary mode		Development & deployment of intermediate NR/SR for creation of SR Intermediary mode	Creation of an organization with specific OR which then directly creates and shapes SR Single mode

SB=system builder A= complementary actor

Organizational resources OR Network resources NR System resources SR direct influence indirect influence Intermediary boundaries

the fitters and the manufacturers) had to be established (Table 2, Figure d). What unites the cases is that the partner actors used the transferred existing organizational resources to create system resources such as new cheap standard components or an initial “nursing” market for stationary fuel cells.

The VDMA and the Callux cases are comparable in the role of the focal system builder and the resources used. In these cases, system building depended on the developed of new intermediary organization and to availability of (new) resources in addition to skills of the system builder(s), e.g. in agenda setting and organizing collective action. While the representatives of Baxi and EWE were steering activities of the VDMA and Callux networks, they could influence the aggregation of the organizational resources of the network members (e.g. financial resources) in addition to the development of new network resources such as joint technological knowledge about fuel cell systems or trust between the members. These new resources are inseparable from the network but in both cases deployed to shape system resources, i.e. qualified supplier, adapted standard components and a bridging market. In sum by developing intermediaries and new resources all necessary resources were available for a direct creation of the system resources.

In the EWE Fuel Cell Alliance case, EWE, as a leading system builder in the field of stationary fuel cells, had to cooperate with other system builders from other fields in order to secure political support in the competition for funding. System building depended here on the creation of new resources. In order to convince state actors to set up a fuel cell support program, EWE and other system builders had to develop

network resources such as political influence, reputation and joint knowledge. In addition, it was necessary to create a system resource: a common long-term plan (fuel cell roadmap NEP). With the help of these resources they convinced state actors to commit financial resources and to establish a joint fuel cell support-program (NIP-Program). This program represents a key system resources as the alliance was able to ensure that one third of the support program's funds were invested in stationary fuel cells.

Finally, in the NOW case system builders launched a new organization and assigned specific resources and tasks to the NOW GmbH. This case is comparable to the BMWA case, as the newly created organization fulfills its role as a “caretaker” and uses its assigned and acquired organizational resources such as finance and political influence to provide system building services, i.e. the broader management of the TIS on stationary fuel cells. While the employed NOW managers drew on their personal contacts, reputation and knowledge, they could additionally use the finance and unique position of the organization to optimize the NIP and further framework conditions such as international standardization in favor of the fuel cell technology in Germany. In the NOW case, only the assigned and acquired organizational resources of the NOW are crucial for system building.

5.3. Three modes of strategic system building

Modes of strategic system building can be distinguished in terms of initial resource constellations (concentrated or distributed) and

whether the required resources already exist or not (cf. Section 3).

In the BMWa and the NOW case, the system builders only depended on existing organizational resources, i.e. they were able to form system resource without the support of other actors and resources.¹⁹ The detection of TIS problems and subsequent actions towards a solution could be realized by a single organization. There was no need for actor integration or coordination. This mode can be deployed in situations in which the resources for system building already exist and are under the control of a system builder. We refer to this form of strategic system building as “single mode”.

In the other cases, system building activities either depended on distributed organizational resources or on the development of new resources. In the CFCL- and EWE cases, key system builders did not have all necessary resources at their disposal. However, they could identify complementary resources for system building within their broader network of collaborators. As these actors were initially not familiar with fuel cell technology (non TIS actors), an embedding process and the development of a strong alliance was needed beforehand. Entrepreneurial initiatives were clearly referable to CFCL and EWE, however, the formation of system resources was the result of a co-creation process. This is why we label system building in these cases as “partner mode”. This mode can be applied in situations, in which the resources for system building exist but are controlled by different actors.

In the remaining cases (CALLUX, VDMA and Fuel cell Alliance), system building was even more complex. Based on the detected TIS deficit, system builders realized that the necessary resources did not exist at all. Therefore, activities in coordination and development of new intermediary organizations were of importance. Again, as system builders were leading the formation of such organizations, they could directly influence network activities and develop new resources such as trust, joint knowledge or network reputation. These resources could then be deployed for creating system resources. We refer to this type of system building as “intermediary mode”.

Table 3 summarizes the three modes of system building, which we identified in our analysis. In addition, it became apparent that system builders are confronted with typical resource constellations: i) the necessary resources might be concentrated and under full control of one actor, ii) distributed between some actors, or iii) missing at all. These different constellations require different actions in terms of resources deployment and strategic interventions (cf. Fig. 3).

5.4. Comparing strategic and emergent system formation

There is not one but many ways, in which system resources form and change (cf. Section 2). In very basic terms we can distinguish emergent system formation and strategic system building (Table 4). Our case study directed attention to the latter but this does not mean that the former is not important or less relevant.

In every socio-technical system (and innovation system), actors are embedded in and at the same time co-create broader networks and institutional structures that enable and guide their actions. The underlying process of system formation can be described as interactive emergence and by the aggregation of different resources and activities as well as by the interplay of different processes. Multiple organizational decisions of different actors accumulate, thereby creating and changing system structures such as technology legitimacy or collective expectations. These system elements, in turn, guide further action and might also stimulate the entry of new actors, which then again use them to orient their actions.

¹⁹ However, a distinction between the two cases can also be drawn. While in the BMWa case public authorities directly created a support program, the launch of the NOW intermediary organization depended on a complex institutionalization process and the assignment of a specific role and resources in the NIP support program.

What we have observed in the TIS of stationary fuel cells is a different way. Over time, actors became organized in various alliances and intermediary organizations. System structures were strategically created and changed in order to solve TIS deficits and coordinate subsequent action (strategic system building). System builders deployed different strategies, depending on which resources they had at their disposal.

In comparison, both ways of system formation differ in their level of explicit coordination and their ability to take targeted strategic actions. In our case study, we found that intermediary organizations made a big difference when it comes to strategic system building. Among others, they come with a capacity to take strategic collective action at the system level, which might be a crucial asset for a TIS to develop and mature further. At the same time, there is also a risk that through such an intense and explicit level of coordination, alternative views and approaches might be hindered or even suppressed. We assume that rather uncoordinated innovation communities lack well-developed intermediary organizations as infrastructures for entrepreneurial interventions. As a consequence we expect limitations in their abilities to develop a collective strategy (e.g. a joint roadmap) and to achieve strategic decisions (e.g. standards). This is certainly something to explore further in future research.

To conclude, system resources form in different ways and they can co-exist, whether they were developed strategically or emerged. In early TIS formation, actors might often not be coordinated in formal networks or through other types of intermediary organizations and system formation may be rather emergent than strategic. The same might also apply to later phases of TIS development. For example, a lack of urgency or trust as well as conflicting views might well hamper joint strategic action. Nonetheless, there might also be coordinated system building as in our fuel cell case. It will certainly be interesting to explore further, how different ways of system formation unfold in different stages of TIS development and what fosters or hinders different approaches.

6. Discussion and conclusions

In this paper, we followed up on earlier work on the issue of system building. Strategic system building is central for the creation of innovation systems, even though system structures also emerge without traceable strategic intent. Scholars have described various accounts of entrepreneurial interventions. So there are obviously different options for system building. Drawing from earlier ideas on the importance of resources, we have argued that different modes of system building depend on the availability and the distribution of resources required for system building: The single mode in which a system builder creates system structures in an independent way can be applied if the necessary (input) resources are already available and controlled by the system builder. The partner mode, in which a system builder partners with 2–3 other actors in order to co-create a system resource can be used if the resources are available but distributed across different actors. A third mode, the intermediary mode, is applied if the required (input) resources are not available yet and, again, require the collaboration of different actors. In this mode, a system builder coordinates activities in a network of collaborators to develop new, intermediate organizational structures, which then can be used to create a system structures.

With our study we make three contributions to the TIS literature. Our findings improve the understanding of i) the emergence of technology innovation systems, ii) the strengths of a resource perspective, and iii) the entrepreneurial process and the role of system builders. First, we highlight the complexity and some of the challenges of system building. Only under specific circumstances can a system builder act more or less independently. The picture of a heroic, Edison-type system builder who puts all the necessary components in place is certainly appealing but seems rather unlikely for many of complex technological and organizational relationships in contemporary technological

Table 3
Three modes of strategic system building.

	Single mode	Partner mode	Intermediary mode
Concept of system builder	Single organization	Alliance of partners	Broader network of actors
Resources (constellation)	Concentrated organizational resources	Distributed organizational resources	Development of new resources
Description of mode	A resourceful and powerful actor detects a deficit and directly creates and shapes a system resource to stimulate the development of a new technology. System resource build-up is not particularly demanding or overly complex.	An actor who cannot create a system resource on its own involves other actors with complementary resources. System resource build-up is not particularly demanding or complex.	Many actors form a network. A system builder initiates and coordinates joint system resource creation in the network. System resource build-up is demanding.
Example	State actor(s) (or foundations or associations) set up R&D program.	Manufacturer and supplier develop a standardized component which can also be used by other firms.	Common development of industry standard(s).

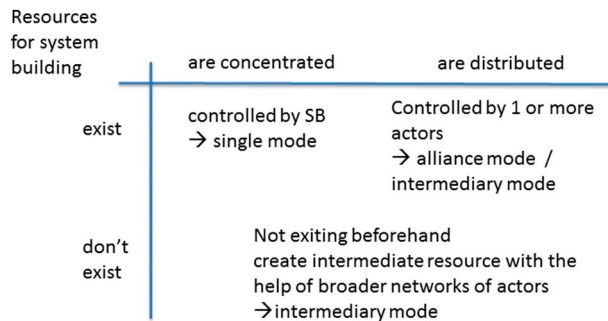


Fig. 3. Resource constellations and impact on mode(s).

innovation systems. Large corporations or the state may well be able to operate in a single actor mode but this seems to be the exception rather than the rule (Kukk et al., 2015). At the same time, collaborative system building (mode 2 and 3) has its own challenges because it is more time consuming and requires a careful balancing of interests. As a consequence, today's system builders have to develop particular skills to forge alliances, broader networks and build trust among partners (Hajek et al., 2011).

Second, system building is a step-wise process with closed loops, in which the outcomes of prior system building activities define the conditions for subsequent system building. Especially our “intermediary mode” cases showed how system building tasks (can) get more and more complex and demanding, given that prior system building –

including the creation of network resources – was successful. Take for e.g. the complex institutionalization process of the NEP development plan. The development of a joint roadmap depended on an overarching coordination process of the wider TIS actor community including intermediary organizations and resources such as joint knowledge and trust. This points to positive feedbacks and cumulative effects, once system builders have managed to create well-functioning alliances or networks that involve a broad range of actors and are able to mobilize a variety of resources. At the same time though, this also opens up questions about path-creation and potential lock-in, if some networks become overly influential for a TIS (Carlsson and Jacobsson, 1997).

Third, this research has improved our understanding of the entrepreneurial process and the role of system builders in radical innovation. We have seen different types and roles of actors engaging in system building, including a ministry, a manufacturer, a service organization and a key user (e.g. EWE). Mostly they were not working in an isolated way but cooperating with others, thereby providing guidance, motivation and coordination. System building, in other words, has a strong component of creating involvement and joint goals and the embedding of actors, in addition to the required technological and organizational skills. This is again related to the cumulative nature of system building: system builders started with the organizational resources they had available and increased the set of available resources, while they were interacting with other actors. Over time, system builders in different system building endeavors may even join forces and unleash even broader, coordinated system building activities. This entrepreneurial process reduces uncertainty and ambiguity as the

Table 4
Differentiation of emergent system formation and strategic system building.

	Emergent system formation (Not organized TIS actor community)	Strategic system building (Organized TIS actor community)
Description	Actors are coordinated via (informal) institutions such as collective expectations; Disperse organizational decisions and activities aggregate to system level effects	Actors are coordinated through intermediary organizations in an explicit and strategic way; Organizational decisions and activities are orchestrated by interlinked system builders
Agency/resource constellation	Uncoordinated distributed agency; emergent collective behavior of actors	Coordinated agency; system building is actively managed in an entrepreneurial way
Process of system building	Aggregation of different resources and activities lead to formation/change of system structures (emergent system formation)	System resources are deliberately created and shaped through strategic interventions; different modes of system building
Typical system level resources	Formation/change of: <input type="checkbox"/> Common knowledge <input type="checkbox"/> Technology legitimacy <input type="checkbox"/> Collective expectations <input type="checkbox"/> Specific labor markets	Creation and shaping of: <input type="checkbox"/> New intermediaries <input type="checkbox"/> Value chains/networks <input type="checkbox"/> Joint educational programs <input type="checkbox"/> Technology standards <input type="checkbox"/> Technology roadmaps <input type="checkbox"/> Public support programs
Ability to take strategic action at system level	Limited abilities to develop a collective strategy (e.g. strategic decisions on collective actions)	Ability to develop a collective strategy (based on the available resource/level of coordination)
Empirical example	Image processing technology in Sweden (Lundgren (1993, 1995)	Stationary fuel cells in Germany (Musiolik and Markard, 2011, 2012)

market and the TIS is co-created. Accordingly, the research also contributed to a better understanding of the different resources system builders can deploy and how the entrepreneurial process might unfold at higher levels of aggregation (Saravathy and Dew, 2005).

Our study has several limitations. We have analyzed a specific empirical field in a defined national setting with a selected set of cases on system building. Based on specific resource configurations, we have identified three modes of system building. However, further research might reveal that these types can be expanded or differentiated further, e.g. with regard to the types of system resources created. Moreover, while it seems to be plausible that some of the aforementioned observations and conceptualizations can be transferred to other fields and national settings, this remains to be tested in further studies. For example, German industries are known for the typically strong role played by intermediaries such as industry associations (Vasudeva, 2009). That system builders became active in intermediate organizational structures might be typical for the German context. In addition, we might think of cultural contexts (e.g. in Korea or Japan) in which the creation and shaping of new industries is coordinated between the state and large companies. System building here typically follows a top-down approach and is not so much a coordinated process steered by entrepreneurs. Still, we believe that similar approaches to coordinate different kinds of actors can be found.

Another limitation is that we did not observe major conflicts. So our study has a risk to paint TIS formation, alliance formation and system building in a too bright light. The innovation literature has reported numerous cases, in which different actors, or actor groups, have struggled over e.g. technology standards, industry roadmaps or technology legitimacy (Lyytinen and Fomin, 2002; Markard and Erlinghagen, 2017; Suarez, 2004; West, 2003). As a consequence, there is certainly an opportunity to analyze fields and issues with a higher degree of contestation and to compare competition and cooperation when it comes to the formation of system resources.

Today, we are just beginning to understand the role of system builders and the process of system building (Hellsmark and Jacobsson, 2009; Kukkk et al., 2015; Musiolik et al., 2012). The resource perspective seems to be promising for analyzing strategic system building. Future studies may shed light on the interaction of different system building activities (both complementary as well as conflicting) or the interplay of modes and TIS dynamics. A particularly fruitful direction for further research might be system building and path-creation. System builders can have a crucial impact on the structure and the dynamics of an innovation system and the subsequent path of technology development. They might be able to manipulate distinct paths of technology development, i.e. favoring specific socio-technical variants while excluding others. Identifying system builders and analyzing their strategies and resources can be essential to better understand the emergence of technological paths and also better design support programs and policy advices.

Finally, the availability and interplay of different modes in TIS formation might be another interesting field of study. The modes identified might evolve over time from the least complex single mode to the more demanding intermediary mode. Again, it might take time until crucial actors are organized, new resources are established, and a formal network becomes capable of work. In certain TIS phases, the achieved modes might be insufficient to develop the technological field any further. At this stage, system builders might be able to bring the emerging path to higher levels of coordination and development. In addition we observed the professionalization of the organizational structure (networks). Such processes of maturation in system building seem to offer valuable insights as well.

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