Technological Forecasting & Social Change 79 (2012) 1032–1048

Contents lists available at SciVerse ScienceDirect

Technological Forecasting & Social Change

Networks and network resources in technological innovation systems: Towards a conceptual framework for system building

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ARTICLE INFO

Article history:
Received 1 February 2011
Received in revised form 26 September 2011
Accepted 28 September 2011
Available online 7 February 2012

Keywords:
System building
Innovation networks
Network resources
Technological innovation system
Clean technology

ABSTRACT

Previous research has shown that formal networks can play a crucial role in the formation of technological innovation systems (TIS). Firms and other actors collaborate in formal networks not only to generate new knowledge but also to strategically create and shape supportive system resources such as technology specific R&D programs. This paper takes a closer look at the resources, which are developed and deployed by networks to facilitate the building up of a TIS. Networks rely not only on the organizational resources of their members but also on new resources developed at the network level including network governance structures, trust among network members, a common understanding of the strategic goals or a good reputation of the network. Our analysis shows that the capacity of networks to fulfill different tasks of system building especially depends on the network resources they are able to establish. With the differentiation of organizational, network and system resources we introduce a conceptual framework, which makes three important contributions. It highlights the strategic nature of (innovation) system building; it allows us comparing the contribution of different actors and formal networks in this regard; and it improves our understanding of how firm and system level processes are intertwined.

1. Introduction

New technologies often have a hard time to develop and diffuse, especially if they are fundamentally different from established technological structures in a field. In early stages of development, performance of a new technology might be low, market prospects unclear and contexts of use still ill-defined. At the same time, competing established technologies are well supported and stabilized by the wider socio-technical regimes with which they have evolved [1]. In the case of environmental innovations that generate positive externalities, e.g. as they generate less emissions than established technologies, the challenges are even more pronounced [2]. For the development and diffusion of such 'clean' technologies and a potential transition towards more sustainable modes of production and consumption, supportive structures which legitimize and stabilize the emerging technology have to be developed — be it in regulatory terms cf. [3,4] or in the broader sense of an infrastructure for innovation [5].

A crucial point is that technology-specific support structures can neither be taken for granted nor treated as being external to the process of technology development [6]. Instead, they are created and shaped by firms and other actors with a stake in the novel technology (e.g. [7,8]). Innovating actors, in other words, often commit themselves to system building as they set up or adapt broader institutional structures that support the emerging business field [9–12].

The process of system building and the development of new technological fields can be studied with the help of the literature on technological innovation systems [13,14]. The innovation systems approach highlights the role of institutional structures and

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0040-1625/$ – see front matter © 2012 Elsevier Inc. All rights reserved.
doi:10.1016/j.techfore.2012.01.003

the importance of actors for the emergence of technological innovations. A key interest is to identify system failures in the emergence of new technologies and to derive recommendations for technology-specific policies [15,16].

For single actors, system building is often very difficult to achieve, which is why they cooperate with others in this respect [17]. Informal networks or personal linkages [18] are as important here as formal networks of innovating firms. While in the innovation literature, inter-organizational networks have received quite some attention as they facilitate interactive learning and knowledge generation [19] the role of networks in supporting collective action and system building has been less in focus [20]. We believe that a systematic analysis of formal networks, i.e. visible organizational structures where firms and other actors come together to achieve common aims, is important to better understand processes of innovation system building.

In Musiolik and Markard [11] it was shown that formal networks played a crucial role in the emerging technological field of stationary fuel cells as they developed technical standards, specific R&D programs or educational programs, for example. These structures, which were set up as a result of a broad range of activities at the level of different networks, were conceptualized as system resources, which positively contributed to some key innovation system functions (ibid). Some of these networks have been able to exert influence widely, whereas others have only had an effect on one or two system resources. In this paper we follow up on the latter by asking why networks differ in their abilities to influence system resources and which kinds of formal networks might be important for the build-up process of an emerging TIS? In particular, we want to look into processes at the network level to understand how they develop and combine different kinds of resources, which are key for the emerging competences of networks and their ability to create and shape supportive structures at the innovation system level.

To this end we combine concepts from the literature on strategic management [21–23] with the innovation systems literature. The literature on the resource based view (RBV) offers valuable insights into a resource-oriented perspective on innovation system building [24,25]. Following the ideas of the RBV, resources at the organizational level are developed and deployed for strategy making, and set limits to what a firm can do [26–28]. Strategically relevant resources, however, may not only just be located at the firm level but also beyond, i.e., in inter-firm networks [22,29,30] or even at the level of innovation systems or industries [11,31]. For emerging technologies this broader resource space [31] is important as system building can be regarded as a resource driven process. In an environment characterized by a high level of uncertainty and ambiguity [32], key actors may start from the resources they have available and continuously extend these resources while interacting with other organizations [33]. This strategy – forging networks of actors and setting up a cycle that increases the resources available – reduces ambiguity, uncertainty as the technological field is co-created [23].

In our empirical study we focus on a selection of five major formal in the emergent field of stationary fuel cells in Germany. Prior analyses have identified this field as highly dynamic [34–36] and demonstrated the importance of system building in this case [11]. In addition to that, agents of different technological applications (portable, stationary and mobile fuel cells) are currently competing for public support [11,37]. Trust, joint knowledge, power and reputation might be resources drawn on at the network level to develop the field. In the study interviews have been carried out to capture in detail the resource endowment of members, the establishment of resources at the network level and finally their deployment towards system build-up.

The remainder of the paper is structured as follows. Section 2 starts with a brief review of the TIS- and the RBV literature and also specifies our analytical framework. In Section 3, we describe some features of the networks selected and the context they are operating in. Sections 4 and 5 present the results of the empirical analysis: here we report on the different resources used in the selected innovation networks, using two examples to show how these resources have been deployed to influence system resources. We also take initial steps towards generalizing our results, and delineate different types of resources and the role that the different networks play in TIS development. Section 6 concludes.

2. Theoretical background

In the following section, we briefly introduce the technological innovation system concept and the resource concept in the RBV literature, and also specify our analytical framework that links resources at different levels in TIS in our quest to analyze the processes of system building.

2.1. Technological innovation systems and the role of formal networks for system building

The technological innovation system (TIS) perspective highlights the dynamic interplay of actors and broader institutional structures in technological fields (cf. [38–40]). 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 and/or a new product" [34]. Key structural elements of technological innovation systems are actors and institutions. Actors include different kinds of firms, universities and research institutes, financiers, consultants, associations, private consumers and public facilities with different competencies, resources and strategies. Institutions not only facilitate but also constrain the decisions and activities of actors and include technical norms, standards, regulations, values, collective expectations, cognitive frames, culture etc.

The innovation systems approach was developed to highlight the institutional and collective aspects of innovation. In their quest to explain a certain course of technology development, most TIS studies concentrate on the system level as the core unit of analysis. A key interest is to identify system failures in the emergence of new technologies and to derive recommendations for technology-specific policies [15,41,42]. System failures, for example, originate from the role of networks. Weak networks can lead to an insufficient use of complementary resources among actors and thus hamper innovation, while over-strong networks may result in a blindness towards external developments, which also affects innovation system performance negatively [43].

In the following we will argue that, in order to better understand and improve system performance, we have to look into the processes through which technological innovation systems are intentionally created. Actor strategies directed at system building have attracted the attention of TIS scholars just recently [34,11,10]. From inquiries in management studies and other disciplines we know that organizations strategically shape the technological field they are operating in: they control the emergence of new technical standards [7], introduce and legitimate new practices [44], establish new values and business models [45] or influence collective expectations [46,47]. Again these supportive structures provide positive externalities for a collective and can be framed as system resources [11]. However, if we know why and how specific system resources came about, we will better be able to inform strategies to increase system performance.

A second point we make is that formal networks are likely to play a key role in such processes of system building because they enable actors to coordinate their strategies and organize collective action [11,48,49]. Traditionally, the TIS literature has conceptualized networks as informal structures, which facilitate the exchange of information, knowledge and other resources between innovating actors [38]. In contrast to that approach, we use the notion of *formal networks* to highlight that networks can also represent a source of agency in TIS, especially when these networks have the goal to change TIS structures. We define a formal network as an organizational structure with clearly identifiable members where firms and other organizations come together to achieve common aims or to solve specific tasks. From a RBV perspective formal networks can also be conceptualized as bundles of resources which are made available by the network members or which emerge in the network. These resources depend, among other things, on the composition of organizations that form the network [48]. On the basis of this concept we can assume that the system building capacity of a (formal) network is determined by the resources that are available for such kinds of tasks.

The notion of resources already plays a role in the TIS literature. Resources are typically referred to as inputs such as financial or human capital which are needed for the development of a particular technology [15,41]. How resources are developed or strategically deployed has not received much attention. Instead, it is implicitly assumed that the necessary resources exist 'somewhere out there' with the major challenge being that they must be made available for the new technology, e.g. through public R&D support or educational programs [41].[1] In the following, we add a new, more dynamic perspective on resources as assets which are strategically developed, used and transformed by actors in the innovation system. They not only facilitate technology development but also determine the range of strategic activities that innovating actors and formal networks can pursue in a given situation. In this new perspective, resources such as common culture, trust, shared goals or reputation also appear as important factors for the successful development of a new technology, next to financial and human resources.

2.2. Resource based reasoning: basic concepts

The resource based view (RBV) is a key approach in the management literature to explain the competitive advantage of firms [21,50–54]. Its two major underlying assumptions are that firms control different resources and that these differences may persist over time because some resources are difficult to transfer or even immobile (e.g. [21,26,50]). Resources are strategically developed and accumulated within the boundaries of firms. They enable a firm to develop a strategy and to accomplish its aims [26,28]. Below we use resource based reasoning, although our primary interest is in resource development and re-configuration processes in innovation systems, not in the competitive advantage of firms.

The concept of resources has been defined in different ways and the RBV has faced quite some criticism for its all-encompassing resource definition [55,53,56]. For the following we use the definition below:

> Organizational resources are tangible and intangible assets that are owned or controlled by an organization. They are of strategic value and enable an organization to conceive of and implement strategies that improve its efficiency and effectiveness.

Tangible resources are often visible and can be quantified [21,57]. They include financial assets and all kinds of equipment such as plants, machines etc. Intangible resources are deeply rooted in a firm's history and encompass (accumulated) immaterial assets such as patents, know-how, firm culture or the reputation of a firm. Intangible resources can be distinguished further [58,59]: human resources subsume all the skills, knowledge and the motivation of a firm's employees; they are inseparable from its bearer. Structural resources (e.g. firm culture, routines or norms and guidelines) characterize the intra-firm context the employees work in. Relational resources, finally, refer to the extra-firm context and include the potentials derived from the relationship to customers, suppliers and other organizations. They include customer or supplier loyalty as well as the reputation of a firm or brand [60].[2]

While resources at the firm level are central in the RBV literature, the resource concept has also been applied to higher levels of aggregation including inter-firm networks [22,62,63] and industries [64]. The underlying idea is that strategically relevant assets can also be produced beyond firm boundaries. In alliances or networks, firms not only get access to resources of their partners [62]

[1] Resource mobilization is referred to as one of the key functions that determine the performance of a TIS (e.g. [15]).

[2] Recently also the importance of power as a relational resource was pronounced [61]. Power was here defined as social practice of building networks and enrolling other actors in joint projects.

but also to resources that emerge through the interplay of cooperating actors [22].[3] At the industry level, collective resources emerge additionally through the interaction of multiple actors and their effects become apparent in industrial districts and clusters [66,67]. The concept of industry resources is comparable with the idea of system resources in technological innovation systems [11]. Both provide benefits and can be used by a broad range of actors in a field, typically without any restriction of access.

To conclude, resources at different levels have been conceptualized in the literature. Organizational resources are strategically accumulated or produced within firms. Network resources, such as trust among network members or a common vision, are developed within formal networks. Industry or system resources, finally, are collective assets which are often deliberately created to support industry or technology development.

2.3. System building and the role of resources

System building is the deliberate creation or modification of broader institutional or organizational structures (system resources) in a technological innovation system carried out by innovating actors. It includes the creation or re-configuration of value chains [68,11] as well as the creation of a supportive environment for an emerging technology in a more general way [9,6]. System building may be the result of largely autonomous key actors [9,10], but more often it is a collective approach, in which organizations coordinate themselves in bilateral or multilateral interaction [68,11,49,6].

For system building activities the deployment of resources is crucial. Following the ideas of Sarasvathy and colleagues [23,33,69,70] market creation (system building) is a means driven process: in the case of radical innovations, innovating actors start from the means (resources) they control and continuously extend these means while engaging with other stakeholders in networks [33]. Innovating actors, therefore identify, develop and use resources at the organizational, network and system level to steer and control the development of a new TIS. Again, crucial are the available resources (at these different levels) which determine the system building activities of innovating actors. By analyzing the engagement of innovating actors in formal networks, we can focus on the interplay of resources at different levels (organization, network and innovation system), which in turn provide a better understanding of the system building process and the different roles of networks.

2.4. Analytical framework and method

In the following empirical analysis we focus on formal networks, although we acknowledge that autonomous activities of single actors might also contribute to system building. Fig. 1 presents the analytical framework in which resources at the organizational (in red), network (in blue) and system level (in green) are distinguished. Innovating actors make some of their organizational resources (e.g. knowledge) available to others as they cooperate in formal networks. These networks are used, among other things, to create and shape system resources (e.g. a specific support program for fuel cells). As the actors collaborate in networks, they also establish network resources (e.g. mutual trust, reputation), which may be crucial for the effectiveness of the network in terms of system building. A network can use its reputation, for example to make policy makers adapt regulations so that they support the diffusion of the new technology.

To apply the analytical framework and to study the different roles of formal networks in system building we selected the TIS of stationary fuel cells in Germany for a multiple case study [71,72]. In the broader field of stationary fuel cells, around 50 formal networks could be identified [11]. Each of these networks has a clearly identifiable set of members (typically firms) and some kind of common goal or mission. Many networks also have a formal network management and structures that regulate 'network functioning', e.g. how members interact. A pre-study was conducted to identify key networks with a clearly traceable role in innovation system building. On this basis, five networks were selected for an in-depth study.

Our main data source is 30 interviews with key informants (e.g. active network members and professionals in intermediary organizations or associations). Interviewees were asked what the networks had achieved in the field, with a particular focus on how networks were able to accomplish the various tasks at the system level. We also traced which network members contributed to the networks, and whether specific structures and competences developed over time at the network level. All interviews were fully transcribed and compiled in a database together with other documents (e.g. newsletters, information from websites, newspaper articles).

In the subsequent analysis the analytical framework was used to identify resources which were instrumental for system building activities. Resources that remained under the control of an organization (e.g. firm reputation, firm experts), but which were important to fulfill the identified system building tasks [11], were classified as organizational resources. Resources that emerged at the network level and became inseparable from the network (e.g. reputation of the network, network mission, trust among network members) were classified as network resources. As we asked various members of the networks and incorporated their different perspectives we were able to triangulate our data and to assign common labels to text units that referred to similar resources [73,74]. After we identified the resource portfolios of the networks, we compared the networks according to their system building capacities, and delineated different types of networks.

[3] In the literature networks are conceived as both: formal alliances and also as informal networks, the social context a firm is embedded in. As a result resources at the network level are not only delineated in the form of inter-firm complementarities [27] but also as 'network resources' [29] a type of a resource which results from the informal advantages firms obtain from their (informal) social ties (cf. [65] and the literature on social network analysis).

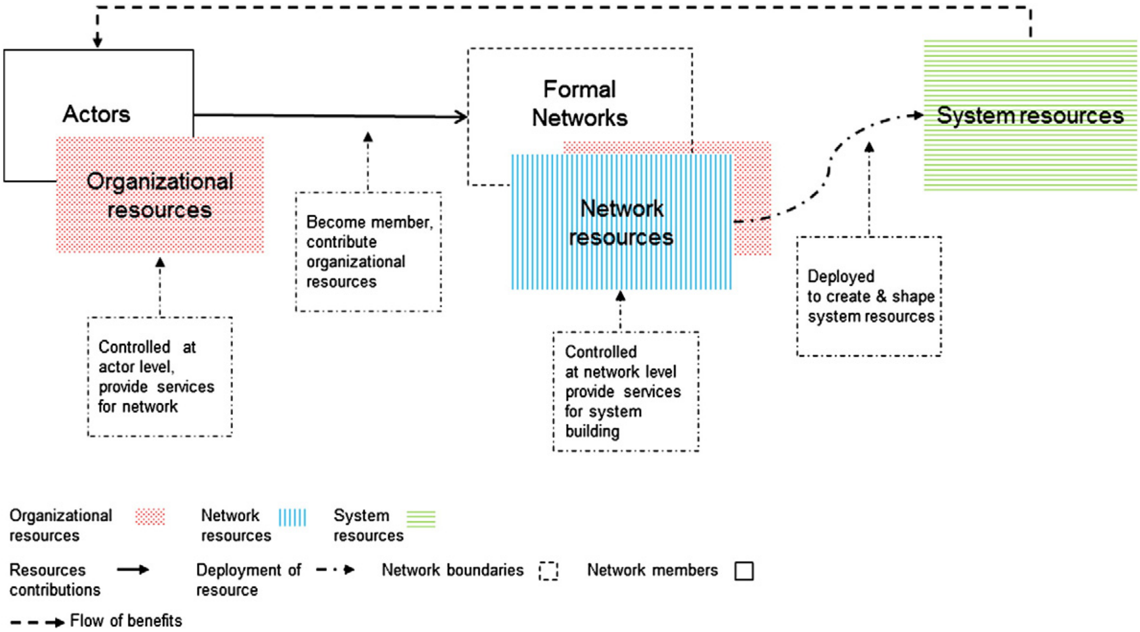

Fig. 1. Analytical framework.

3. Key networks and created and shaped system resources

Stationary fuel cells are small-scale devices for single or two-family homes which generate heat and electricity from natural gas and are based on cogeneration, i.e. the combined generation of heat and power (CHP). In Germany several hundred of stationary fuel cells are currently installed in field tests, while the technology still faces many technological and organizational challenges. Fuel cell manufacturers, for example, are currently struggling to meet the performance standards of conventional boiler heaters in addition to reaching an acceptable price of stationary fuel cells. Despite these obstacles a supportive technological innovation system has been established with many different actors, networks and specific institutions [35,75,36,34]. Formal networks played a key role in system building and the creation of system resources [11].

3.1. Key networks in the TIS on stationary fuel cells

Major TIS build-up activities were triggered through a fuel cell hype in 2001 [76]. Both politicians and firms became confused during the hype and subsequent disappointment cycle. The ambiguity of this situation was accompanied by the uncoordinated emergence of networks, and a diffuse articulation of different needs and expectations. Coordination and structuring of the field, as well as the institutionalization of key networks, became an important step: networks were consolidated and the VDMA fuel cell working group became the leading network of technology developers (suppliers and manufacturers), while key actors of the stationary and mobile application were already organized in their pursuit of public support and attention (e.g. IBZ fuel cell initiative, networks of the automotive industry). The Fuel Cell and Hydrogen Network NRW, in addition to the VDI technical committee and Callux, were less important here, except for complementary system building tasks. Table 1 briefly introduces the networks that were part of our study, all of which play a key role in the innovation system.

The networks selected played different roles in system building, accomplishing tasks in varying degrees of cooperation with each other. Two of the networks not only shaped and created different system resources, but also became embedded in a new governance structure of a national support program. That is why we briefly report on how networks worked together building up a National Innovation Program for Fuel cell technology and Hydrogen (NIP). We then go on to introduce other system resources which they had created and shaped in a less cooperative way.

3.2. Created and shaped system resources

Networks in the field of fuel cells usually compete for public awareness and support. In the Fuel Cell Alliance Germany, however, they cooperated to set-up a National Innovation program of hydrogen and fuel cells (NIP) and a roadmap, the National Development Plan (NEP) as important system resources [11,37].[4] In order to implement the NIP, and to prevent inefficiencies due to the competition between different applications and networks, an intermediary organization, the National Organization for

[4] The lobbying activities of this advocacy coalition [77] were useful to bundle lobbying activities and to speak with one voice to politicians.

Table 1
Features of the formal networks selected.

VDMA fuel cell working group	*Key network* of technology developers (stationary/portable application), emerged in an ongoing institutionalization process, driven and supported by the VDMA association. Long-term orientation: supporting the creation of fuel cell industry in Germany.
IBZ fuel cell initiative	*Strategic alliance* of key energy service providers, manufacturer (stationary application), established on the initiative of energy service providers, driven by joint interests of members. Long-term orientation: supporting the introduction of stationary fuel cells onto the market.
Fuel Cell and Hydrogen Network NRW	*Regional network* of technology developers, energy service providers (all applications), founded and driven by public authorities in North Rhine Westphalia (NRW). Long-term orientation: positioning NRW as a hub for fuel cell technology.
Callux	*Project network* and joint field test of some IBZ members (stationary application), established on the initiative of a leading energy service provider. Short-term to mid-term orientation: providing an initial market, preparing fuel cell market and improve end product.
VDI fuel cell technical committee	*Technical committee* under the roof of the VDI association, driven by energy service providers, manufacturer with interests in market preparation for micro CHP technologies (stationary application). Short-term to mid-term orientation: establishing certain guidelines for market preparation.

Source: interviews and network homepages.

Hydrogen and Fuel cells (NOW GmbH), as well as the NOW advisory board were additionally created as elements of a new (field wide) governance structure (system resource).

In the NIP research, development and demonstration of fuel cells are closely interlinked and supported by public authorities. The aims and activities of the program are structured in the NEP, which also represents the basis for the Federal Government's allocation of funding. A further system resource, the NOW intermediary organization, was created for the implementation of the NIP and the selection of the founded R&D- and demonstration projects. Callux, finally, a joint field test of IBZ members, is the key stationary fuel cells demonstration project supported by the NIP program.

Elements of the NIP and the formal networks are interlinked and work jointly together to develop the field of fuel cells. While the NOW intermediary organization implements the NIP support program, it is controlled by the Federal Government, and steered by the NOW advisory board. Here main representatives of the networks (e.g. IBZ and VDMA), and also of the regional networks and the automotive industry (mobile application of fuel cells), discuss how the NEP common long-term plan is optimized, and solve conflicts in the management of the NIP etc. The NOW advisory board is, therefore, an important communication and coordination channel in the field. Information and requests are channeled between the network members, the NOW GmbH and the Federal Government, while the key networks exert agency and influence the direction of NIP implementation.

In addition to the NIP activities the selected networks also performed system building tasks alone. As the VDMA organizes the fuel cell technology developers, system building was also realized in the field of value chain coordination, i.e. standards and component adaptation (e.g. valves and pumps), and supplier qualification. The IBZ has influenced system resources in co-operation with the VDMA fuel cell working group (e.g. NIP, NEP and NOW GmbH). However, important specific system resources, such as (positive) collective expectations and the awareness of stationary fuel cells, have been additionally shaped. While the IBZ network was very successful in lobbying for support within the NIP program [11] a joint field test project (Callux) was additionally implemented. The Fuel Cell and Hydrogen Network NRW, as the biggest regional network, is steering an influential regional support program and is also contributing to the qualification of suppliers. Finally, guidelines have been established through the VDI technical committee. They make the achieved state of knowledge in a new field explicit, and are often supplemented with artifacts (e.g. tools such as simulation software). Artifacts and the combined knowledge contribute to the assignment of roles for the downstream service providers.

4. Resource portfolios and their deployment

In the following we take a closer look at how the networks were able to create and shape the aforementioned system resources. What were the supportive structures and the resources they drew upon to achieve their goals?

4.1. Resource portfolios of the networks selected

For each network, Table 2 lists those resources that were used for system building, according to what was reported in the interviews. The analysis shows that in each case a broad range of different resources was used. In the table we differentiate between organizational and network resources and assign the various resources to some overarching categories from the literature (i.e. tangible, human, structural and relational resources, cf. Section 2.2).

Tangible resources such as financial capital included fees paid by the firms that are members of the network, as well as finances from public authorities or support programs. These organizational resources were used to employ a service provider for the production of a joint software tool in the case of the VDI technical committee, or to employ a network manager in the VDMA example. In addition to that, other tangible resources such as standard components were provided by members but also jointly created at the network level in the case of the IBZ Info-CDs for communication purposes.

Human resources included all the individuals, representatives of the different member firms, and experts with partly different skills, competences and knowledge in each of the networks. In addition to that joint knowledge was also established thought the

Table 2
Resource portfolios of the networks selected.

	VDMA fuel cell working group	IBZ fuel cell initiative	Fuel Cell and Hydrogen Network NRW	Callux	VDI fuel cell technical committee
Tangible resources	• Fees of members • Specifications, data of systems and components • Artifacts e.g. joint connector technique (Preliminary standards)	• Fees of members • *Joint artifacts PR and communication* e.g. *homepage, hotline, Info-CD, joint booths at trade fairs*	• Financial support of local authorities • *Joint artifacts* e.g. *homepage and data base of competence and products of fuel cell firms*	• Financial support of members and subsidies NIP • Artifacts e.g. Callux box (Preliminary standards) • Field test pilot plans and pilot costumers	• Financial support members • Data for reference load profiles • *Joint artifacts* e.g. *simulation software*
Human resources	• Skilled experts working groups and their knowledge, information • *Joint knowledge requirements and cost drivers of fuel cell systems*	• Skilled experts PR and technique and their knowledge, information • *Joint knowledge product development and application*	• Skilled experts working groups and their knowledge, information	• Skilled PR and technology experts and their knowledge, information • *Joint applied knowledge from field tests*	• Skilled experts standardization and guidelines • *Joint knowledge* e.g. *reference load profiles*
Structural resources	• Governance structure: steering committee and emerging working groups • *Network culture and procedure to exchange specifications* • *Common understanding of goals at system level* • Support of VDMA network manager	• *Governance structure: Steering committee and working groups, network culture to divide tasks, common understanding of goals at system level* • *Trust and stabilization of members*	• Governance structure: yearly meeting of members, working groups • Support of NRW network management	• Callux governance structure to conduct field tests and to realize joint support measures • Coordination and support ZSW institute	• VDI governance structure: procedure to establish and publish guidelines • VDI network management support • *Common understanding of goals market preparation*
Relational resources	• Reputation of VDMA association • *Reputation of VDMA fuel cell working group as professional organized interest group* • Relationships of VDMA network manager to politicians • *Power as accepted and legitimized network of suppliers (critical mass of industry firms)* • *Fuel Cell Alliance Germany (advocacy coalition)* • *3 seats in NOW advisory board*	• *Reputation as competence center for stationary fuel cells* • *Power as key network in stationary field (alliance of key actors)* • Power and influence of members • German Energy Agency (DENA) relationships to politicians • *Fuel Cell Alliance Germany (advocacy coalition)* • *Callux joint field test network* • *2 seats in NOW advisory board*	• Relationships to politicians of network management • *Reputation and visibility as the biggest fuel cell and hydrogen network*		• Reputation and legitimization of VDI association

A further distinction depicted in this table is between organizational resources (regular) and *network resources* (italics, underlined), cf. Section 5.1 for the details.
Source: interviews.

collaboration of these heterogeneous experts within the networks: the interaction of suppliers and manufacturers in the VDMA working group had uncovered a joint understanding of cost drivers and the need of standardization of fuel cells, while in the IBZ case, knowledge in joint product development (e.g. fuel cell systems in virtual power plants) was revealed [12].

Structural resources were important to make the networks capable of work. All networks were based on governance structures such as specific rules and cultures (e.g. concerning membership, knowledge exchange) and modes of interaction (meetings, sub-committees etc.). Here, organizational resources were used and network resources were established. In some networks, governance structures were developed and adapted over time and accomplished with trust and a joint understanding of goals, while in the case of Callux and VDI, sets of already established rules could be used or copied. The VDI, for instance, provided an established procedure which defines how a technical committee has to be set-up and proceed in order to publish a commonly accepted VDI guideline.

Relational resources included assets such as power and reputation. The reputation of associations (e.g. VDI and VDMA) and also of the new established networks has been described as a beneficial resource: the VDMA network operates with the VDMA association's reputation (e.g. as a credible and professional lobbying organization), and the technical committee can take along the VDI reputation and publish its joint work as a VDI guideline. Some networks, however, did not primarily rely on the reputation of their members. The IBZ fuel cell initiative, for example, developed and used its own reputation (network resource) as the competence center of stationary fuel cells. Power, as a resource of the network, originates from different sources. The constitution of the network members and their relationships to politicians were important organizational resources for the networks. Access to influential networks (e.g. Fuel Cell Alliance Germany) and seats in the influential governance structure of the National Innovation Program (NIP) Hydrogen and Fuel Cell Technology (e.g. NOW advisory board) have been mentioned here, for example to be useful in the implementation process of the NIP. These network resources were established while the network evolved.

The comparison of the five networks shows that they are well comparable in terms of financial and human resources. All networks operate on the basis of contributions by their members (firms and associations). There are also some similarities with regard to reputation that is transferred from member firms and the associations, which is involved in two cases. However, there are also differences among the networks. Some resources are very specific: trust, reputation and power are examples. This specificity is related to the fact that these resources were developed over some time — partly based on some of the other resources previously mentioned. Trust, for instance, has been developed while as certain members regularly met and achieved joint goals, accomplished by the governance structure of the networks.

The analysis of the portfolios also shows that the IBZ and the VDMA networks develop much more network resources than the other networks. Most of them are related to the structural and relational category. The other networks do not develop many resources here but mostly rely on financial and human resources. The general pattern which evolves in the comparison is that for some networks, the organizational resources that are provided by the members play the key role whereas for other networks, the development and use of network resources are crucial. IBZ and VDMA are examples of the latter type. These networks can manage a variety of tasks while they are deploying and combining resources at the network level. VDI and Callux, as examples of the former, draw on resources at the organizational level to fulfill particular tasks at the system level.

It seems that the kinds of resources used and created in the networks make a difference, which is why, in the following, we take a closer look at two selected types.

4.2. Deployment of resources in the VDI and the IBZ cases

In this section, we take a closer look at how the different resources delineated in Table 2 were combined, altered and deployed in order to shape supportive structures at the system level. In addition, we differentiate the interplay of the different levels, i.e. how established system resources or contributed organizational resources have had an influence on the network. Due to space limitations, we can only report the results of two of the five networks. The VDI case was chosen because it represents a short-term to mid-term orientation network with a clear focus on one type of task: the development of technical guidelines. The IBZ case, in contrast, is a formal network with a mid- to long-term perspective to fulfill a series of system building activities that also change over time. In Table 2, we have already observed that the latter network encompasses a broader range of resources to draw upon.

4.2.1. The case of the VDI technical committee

The main task of the VDI technical committee is the establishment of guidelines and technical norms for small scale cogeneration plants. Guidelines are important for market preparation of new technologies i.e. when service providers (e.g. fitters, architects) as well as fuel cell operators have to cope with high uncertainty, low level of transparency and information asymmetries. They make the achieved knowledge in the field explicit, define quality standards and also different kinds of operational procedures. As a result, the guidelines clarify the tasks which different actors (e.g. technology developers, fitters, fuel cell operators) have to pursue, and they also help to qualify downstream service providers.

In order to develop guidelines and to achieve the secondary goals, the VDI technical committee drew on financial resources (provided by the member firms) and on a series of experts, both from industrial players and research institutes. A crucial subtask of the network was to integrate and formalize the distributed knowledge of the various experts. This ‘joint knowledge’ was a key ‘ingredient’ for the formulation of the guidelines. It can be interpreted as a resource that was not readily available but developed over time through the interaction of the individuals. Similarly, it was reported that a common understanding of the goals (and limits) of each guideline had to be established. There were also partly conflicting interests that had to be resolved.

Of key importance for these processes of goal formulation and conflict resolution were the governance structures provided by the VDI association. These structures represent an organizational resource the association has built up over time. It is temporally shared with the different technical committees the association supports. Furthermore, during the guideline development process it became clear that software for the simulation of load profiles would be very helpful for applying a guideline in practice. For this end, data on reference load profiles were needed that could only be provided by electric utility companies. Finally, interviewees highlighted that the reputation of the VDI association was also essential to legitimate the guidelines.

Fig. 2 depicts how the different resources were connected for the development of the guidelines (system level, in green). On the left, the different types of network members are listed. The arrows show which organizational resources the members have provided (in red). These direct resource inputs are then combined with those resources that developed over time within the network (blue color, in the middle of the box). The network boundary indicates on which resources the network can draw while influencing system resources.

The diagram underlines that the VDI association played a particular role in the network as it provided pre-defined governance structures, a field-wide reputation as well as support for network management. In other words, the VDI provided its reputation and legitimation together with its experience in setting up guidelines, while the other members of the committee contributed to the content of the guidelines. Firms interested in market preparation, therefore, depended on the resources of the VDI association to develop guidelines. The case also shows that some organizational resources were altered to develop new resources at the network level (joint knowledge, common goals), while others such as VDI reputation are directly deployed towards the system level and the production and legitimating of guidelines. The establishment of guidelines at the system level had no effect on the resources at the network. In the IBZ case, however, established system resources also strengthened relational resources (e.g. power and reputation) of the network. We come back to this point in the next case.

4.2.2. *The case of the IBZ fuel cell initiative*

In contrast to the VDI technical committee, the IBZ fuel cell initiative has established and influenced a broad range of system resources. For example, the network shaped the awareness of stationary fuel cell technology, contributed to the qualification of service providers and also lobbied in favor of the National Innovation Program (NIP) Hydrogen and Fuel Cell Technology. Due to the complexity of the IBZ example, we only discuss the manipulation of three system resources in the following: awareness,

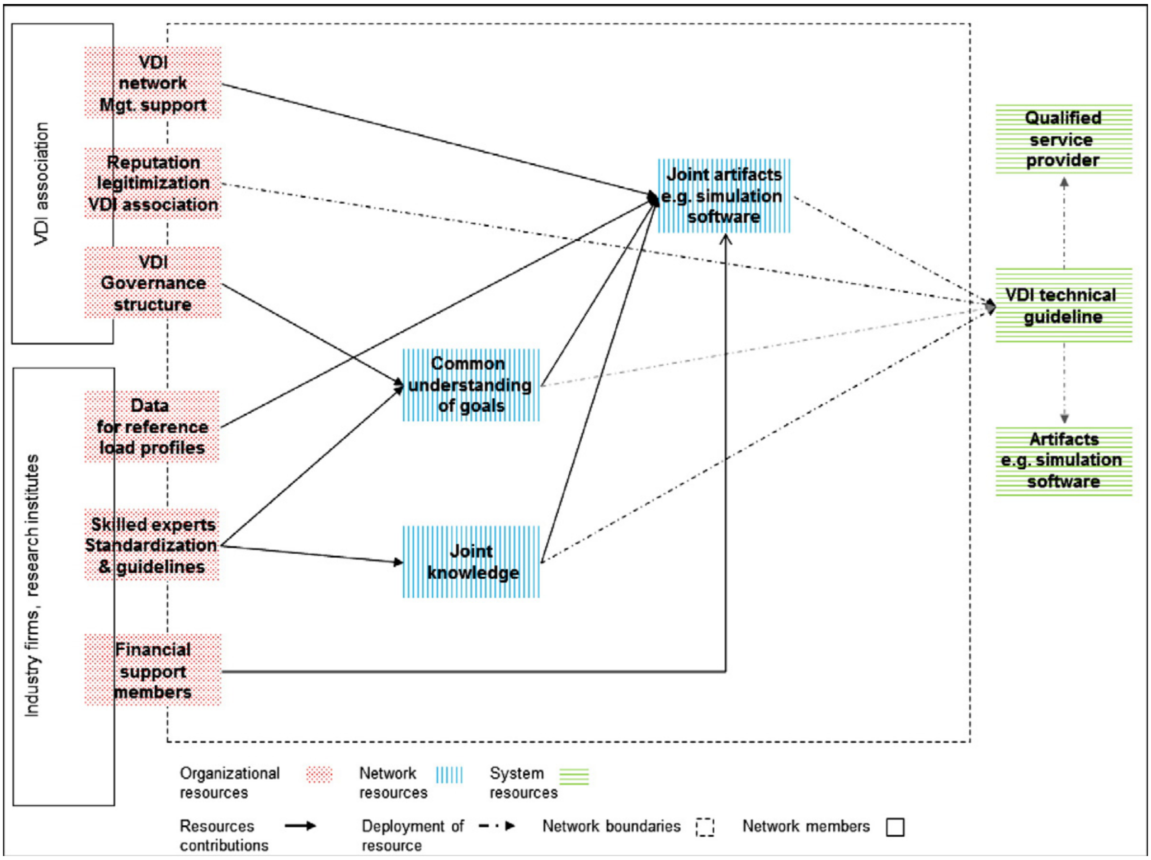

Fig. 2. System building in the case of the VDI technical committee.

collective expectations on stationary fuel cells and the NIP support program. Again, the idea is to show how the network depended on different kinds of resources to accomplish its tasks.

One reason to found the IBZ was that a hype on fuel cell technology occurred around 2001 [76]. It became increasingly clear that the promises which many firms had given to position themselves for the expected competitive race could not be fulfilled. Through the IBZ fuel cells initiative, therefore, some leading firms decided to coordinate their PR and communication efforts and to present a more realistic picture of fuel cell technology in the public (i.e. to manage collective expectations). While these firms had technological expertise as well as financial resources at their disposal, the more crucial resources needed to achieve this goal were a common understanding and internal rules of how to agree on possibly conflictive issues (governance structures). These resources were created through the foundation of a steering committee, in addition to the close interaction of network members. In addition to that, more 'practical' resources such as the IBZ web page, a newsletter-letter, info-CDs, an information hotline, joint booths at trade fairs and IBZ press releases were developed. These joint artifacts for PR and communication were directly deployed to influence the awareness, image and collective expectations on stationary fuel cells. However, in order to be more effective, the IBZ fuel cells initiative also worked on building up a reputation. This went hand in hand with the communication efforts and also depended on the expertise and joint knowledge of the network. Today, the IBZ has a renowned standing as the competence center for stationary fuel cells in Germany. This reputation is a valuable resource that can be deployed for a broad range of purposes. Finally, it was reported that trust among the IBZ members increased over time, resulting in a case of escalated commitment [78]: a key member could convince the less committed IBZ firms to start the joint field test Callux to increase visibility, and additionally influence public awareness. As a consequence, the network became more and more stable and was able to take over new and even more complex tasks. One of these new tasks was lobbying in favor of the NIP support program.

For the manipulation of the NIP support program, the IBZ could deploy its power and influence as key network in the field of stationary fuel cells. This resource at the network level is based on the power contributed by IBZ members, but was further accomplished through the accumulated reputation as a competence center of stationary fuel cells. Joint knowledge and expertise, in addition to the access to the Fuel Cell Alliance Germany, supported the network to exert its influence in the establishment process of NIP, NEP, and NOW (cf. Section 3). Interestingly, the establishment of the NIP support program and the subsequent new governance structures (e.g. NOW advisory board) also increased the quality of the relational resources of the IBZ. The power and

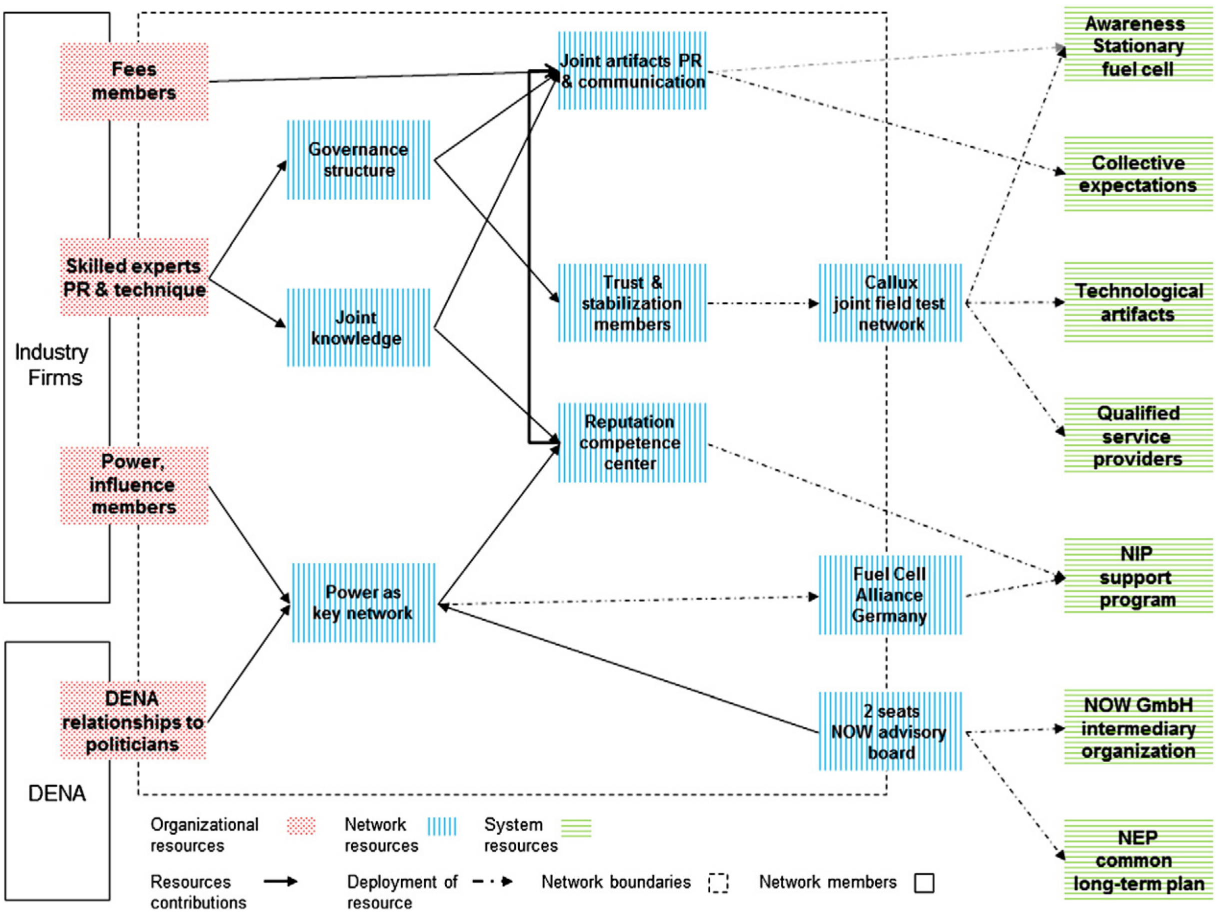

Fig. 3. System building in the IBZ case.

reputation of the network were strengthened through the establishment of system resources. Through the NOW advisory board IBZ network can exert power and influence both the NIP implementation and the NEP adaption (c.f. Section 3).

Fig. 3 depicts the different kinds of resources the IBZ relies on. Financial resources, skilled experts, and power and relationships to politicians are provided by the member firms and an association. These inputs are transformed into network resources (blue boxes), which then are used towards the creation and shaping of system resources (green boxes, right side). The IBZ combines and deploys organizational resources to create a range of new ones, which are used for multiple purposes. Of particular importance here are common goals, trust among network members and the reputation of the network. Notably, the interviewees not only reported the relevance of these network specific resources but also mentioned that they are deliberately strengthened (e.g. reputation is enhanced through targeted communication and 'networking' activities).

Due to the key role of network resources, the IBZ did not to a great extent depend on the resources of specific members. The inputs, in other words, were not very specific but the resources that were developed on the basis of these inputs are very unique, influential and inseparably linked to the network. Relational resources such as power and reputation in particular seemed to play a key role in system building and the creation and change of supportive institutions. However, it took time to develop these specific network resources, which is why the IBZ was rather weak at the beginning and only became influential over time.

The comparison of IBZ and VDI shows the IBZ has many more network resources at its disposal. A network which draws on network resources may combine a variety of them to influence a broad range of system resources, whereas a network which draws on organizational resources is constrained in its resource combination and deployment at the system level. In addition to this, in the IBZ case the quality of some network resources was increased through the establishment of complementary system resources (e.g. NIP governance structure), while in the case of the VDI network these effects were not studied. Both networks can also be differentiated according to how they obtained these resources. In the IBZ case network members were strategically accumulating and creating resources at the network level, while in the case of the VDI the technical committee had to couple with an established organization to get access to essential resources.[5] For the latter network, the associations still decide on which purpose the resources are deployed. That is also true for the IBZ, but as the network draws mainly on network resources, the IBZ can control the deployment of this type of resource.

Resources at the organizational and network level have different properties. In the next section we summarize and specify the identified resources, and discuss how the identified network types differ in their ability to create and shape a TIS.

5. Differentiation of resources and networks in system building

Our results have shown that the five networks used different kinds of resources to achieve their goals. In this section, we compare the characteristics of organizational- and network resources and discuss how they affect the system building capacity of formal networks.

5.1. Comparison of organizational resource and network resources

Formal networks develop and use resources to achieve their strategic goals, in a similar way to firms and other organizations. In our study we identified two kinds of resource deployed by the networks. Firstly, all networks relied on organizational resources provided by their members. These were either transferred into the network as in the case of financial resources, or they remained 'attached' and under the control of the members while they were used within the network. Examples for the latter include the reputation, the political contacts of members or the experts employed by members. We will refer to these resources as *organizational resources of network members*. Secondly, the networks also relied on resources that were developed over time within the network. Examples of network resources encompass trust among members, network culture, a common understanding of goals, a specific mode of network governance and the reputation of a network. We refer to them as *network resources* with the following definition:

> Network resources are assets of a formal network that are of strategic value for network members. They are generated through the interplay of actors and their organizational resources in the network.

Table 2 lists the firm and network resources that were used for system building by the five networks in our study. Organizational resources of network members and network resources have different properties. We compare where they are created, when they become available for the network, how they are controlled and which advantages can be expected with regard to system building (cf. Table 3).

Organizational resources of network members become available at the network level if a firm, for example, joins the network and decides to grant others access to some of its resources. The member still owns and controls these resources, and it might also decide to withdraw them again. With regard to system building, organizational resources have the advantage that they come with the members, i.e. they are typically available as soon as a member joins. A disadvantage is that in order to achieve particular system building tasks, specific members (and their resources) may be needed, which creates a certain dependency and limitation in

[5] Therefore the description of the IBZ case has the character of a time observation of the actual system building capacity of the network, whereas the course of action to produce guidelines in the VDI case is rather stable.

Table 3
Properties of organizational resources of networks and network resources.

	Organizational resources of network members	Network resources
Creation	Created at the firm level; creation is typically independent of the processes at the network level	Created within the network, e.g. through the interaction of network members
Availability	Often directly available when an organization joins the network (e.g. when the network is established)	Might take time to develop, availability delayed
Control	Controlled by members, resource access may be withdrawn (e.g. through exit)	Not under the control of single members, access cannot be withdrawn, network can further maintain and modify the resource
Advantages and disadvantages with regard to system building	Resource can be directly deployed to a specific task; system building capacity might be constrained	Resource can be tailored and maintained in favor of multiple system building tasks; system building capacity have to be developed

Source: own depiction.

system building. Take for example the VDI association with its resources for the development of technical norms (Fig. 2). If it had not participated, the set-up of common guidelines would probably have been much more difficult.

Network resources are generated and accumulated over time through the interplay of network members. As a consequence they are not readily available when the network is set up. The creation of network resources may be a deliberate act (e.g. establishment and adaptation of the governance structure in the IBZ), but they may also emerge in a less planned way (e.g. trust among members, reputation of the network), which means that their nature and benefits are not necessarily clear in the beginning. Network resources are controlled by 'the network', i.e. they can be deployed, developed further or changed where the network members see fit. Ideally they can be continuously adapted to the needs of the network. Some network resources such as its reputation may also be of more general use, i.e. they can be deployed for a broad range of tasks.

The identified resource types are instrumental to detect the importance of different networks in system building i.e. what kinds of tasks the networks can achieve. In the following we discuss different types of networks, depending on which types of resources they typically develop and deploy.

5.2. Discussion of the importance of different networks for system building

Our empirical analysis has also shown that different networks play different roles in the formation of an innovation system, and they depend on different kinds of resources to achieve their goals. Some networks rely mainly on the resources of their members, while others develop a broad range of network resources. The IBZ, for example, combines a variety of network resources to influence major system resources such as the National Innovation Program. The VDI committee, in contrast, relies primarily on organizational resources and uses just a few network resources to develop guidelines. This task is rather specific, and was reported to be less complex than setting up and managing the aforementioned innovation program.

In Table 4 we conceptually compare two different types of networks: those drawing primarily on organizational resources and those that deploy a broad range of network resources.

Networks can be based on established organizations and use primarily the resources already available in these organizations. The underlying strategy is to identify complementary resources of different actors, to combine these resources (through the membership of the actors that control them) in a network and to apply them directly towards the network goals. This is how a member of the VDI technical committee described it:

> "In order to better organize their interests [in market preparation], they [industry firms] joined forces in the technical committee of fuel cells for domestic homes, and started to explore the possibilities offered by the VDI association for the market preparation of stationary fuel cells. If you look at the field of activity [..] the VDI is strong in the creation of guidelines which are not obligatory, but so secure in terms of technology that they are convertible for all applications. The set-up of technologically high quality guidelines is what the VDI does particularly well."

Such networks might remain constrained in what they can achieve at the system level. The challenge is that they strongly depend on the resources provided by their members. Organizational resources available at the network level cannot be freely combined, leveraged and deployed. As a result, such networks may only be able to create and shape some specific system resources, while there may be other tasks at the system level they cannot fulfill.[6]

Networks, which extensively draw on network resources, have advantages in the case of complex system building tasks. Their underlying strategy is based on the development and accumulation of network resources. They are less constrained as they can combine and deploy different network resources for different tasks. Some influential members might even see new valuable

[6] To give an example, in the case of VDI technical committee, market entry barriers in the area of apartment houses came onto the agenda: as tenants in apartment houses could choose their energy supplier in a liberalized market, landlords would not install decentralized CHP technologies. However, as soon as it became clear that this was a political topic (related to the billing of energy costs), the members of the technical committee realized that they could not work towards solutions within the structures of the VDI network.

Table 4
Comparison of two different types of networks.

	Networks drawing primarily on organizational resources	Networks drawing extensively on network resources
Key resource type	Organizational resources of members	Network resources
Underlying strategy	Identification and combination of complementary resources of network members for specific tasks	Development and accumulation of network resources to extent system building capacity
Resource combination and deployment	Constrained, resources under control of network members	Rather flexible and adaptable, key resources under the control of the network
Influence at system level	Single task oriented: networks influence rather specific and towards not very complex system resources	Multi tasks oriented: networks influence rather systemic towards complex system resources
Relevance for members	Limited ability to adapt to future needs of members, often do not represent key network in TIS	Adaptable to future needs of members, network may play a key role in TIS formation

Source: own depiction.

resource combinations, and steer the networks towards new system building goals. In other words, these networks may evolve (in a co-evolutionary manner) in relation to the tasks or problems which appear as the technology matures, or as one member of the IBZ has stated:

> "We did not start out in 2001 with the aim to achieve A, B, C and D in certain way. The requirements of the IBZ have changed and have developed […]. I think the cool thing about IBZ is that the network has to continuously to renew itself, to continuously reinvent itself. And I believe that the secret of success of a good network is its continuous renewal, and that's why we can actually say: that is the point where IBZ is currently standing."

These kinds of networks are multi-task oriented and may be able to create a broad range of system resources, as well as addressing very complex and challenging tasks at the system level.[7]

Finally, both types of networks can be differentiated in their relevance for their members. The latter type has a long-term perspective, develops and combines various resources, and can adapt to the future needs of members and emerging tasks in the TIS build-up. In addition, the quality of the resources at its disposal (e.g. reputation and power) may even increase as the system and its structural elements evolve. That is why they also play a key role for their members. Single task networks in contrast, are more constrained in their adaption to the future needs of the members. The quality of their main organizational resources is rather unaffected by structural TIS build-up.

6. Summary and outlook

In this paper, we have been studying *why networks differ in their abilities to influence system resources* and *which kinds of formal networks might be important for the build-up process of an emerging TIS*. Formal networks rely on different bundles of resources, which explain why the networks can take over different tasks in terms of system building. On the one hand, networks use and combine the organizational resources of their members: financial resources, expertise, firm reputation etc. On the other hand, new intangible resources emerge at the network level including specific governance structures, a common understanding of the strategic goals, trust among network members or the reputation of the network. While both types of resources were necessary for system building, our analysis showed that network resources are not readily available when a network is set up but need time to develop. Once established, they can become quite important for achieving the network goals. Moreover, they can often be applied to a broad variety of tasks. Through the development of network resources a formal network may become more influential and powerful over time, even if the organizational resources provided by the network members do not change a lot.

On the basis of these differences in resources, we suggested to distinguish two types of formal networks: those that rely primarily on the organizational resources of network members, and those that build extensively on network resources.[8] In the fuel cell TIS, the former were used for specific system building tasks, which were easily comprehensible and of a defined scope, and the latter were applied in situations where system building was more complex and the tasks were less foreseeable and manageable. The flexibility of the second type of networks and their ability to address multiple tasks were crucial for successful system building in this case. The IBZ fuel cell initiative, for example, was reported as being crucial in the competition of different fuel cell applications and for the formation of the TIS for stationary fuel cells in Germany. Without the network, influential system resources such as the National Innovation Program might not have been modified in favor of stationary fuel cells.

As a consequence, networks that draw extensively on network resources may also turn out to play an essential role in other emerging technological fields, especially when compared with networks which are primarily based on organizational resources.

[7] If these networks also have a long term perspective, there might be some learning effects in system building, and they may develop specific capabilities to fulfill TIS build-up tasks more effectively.

[8] We must acknowledge that the delineated networks are ideal types in a continuum of different formal networks in TIS.

In addition, networks with a long-term perspective may also accumulate important relational resources (e.g. power, reputation), which again make them less dependent on the contributions of their members.

6.1. Contributions to TIS concept

This study has developed a differentiated perspective on the role of resources in technological innovation systems. While earlier studies have already pointed to the importance of resource mobilization for successful technology development [15,41], the resource concept remained very general and the underlying processes did not receive much attention. Our framework makes at least three improvements here: firstly, it directs our attention to processes of resource creation and transformation. Resources that are crucial for the technology at hand are often specific and not readily available, which is why they have to be developed over time. The strategies of different actors and formal networks play an important role in this regard [34,79 this issue]. Secondly, our framework points to the strategic value of resources for the actors in an innovation system. This is in line with the original ideas of resource-based reasoning in the strategic management literature [21,26]. Our particular focus was on the strategic value of resources for system building, but the resource concept could have also been applied to other processes in innovation systems, e.g. to the competition between different technological variants for public funding. A crucial benefit for TIS studies is that the resource concept can be used to explain the strategies of organizations in technological innovation systems [24]. Thirdly, we distinguished resources at different levels of aggregation, i.e. resources at the organizational level, network resources at the level of formal networks, and system resources at the TIS level. This differentiation was particularly helpful to explain the transformation of resources. In the IBZ network, for example, expertise, financial resources and personal contacts of member firms were the basis on which the reputation, political influence and trust of the network grew, which finally enabled the development of system resources such as the Callux field test platform and the NIP support program.

Another major contribution is related to how we conceptualize networks in technological innovation systems. So far, they have been primarily regarded as (informal) structures that facilitate knowledge exchange [38,80] or expand the resource base of individual firms [81,29]. Our framework extends this view, as it points to the role of (formal) networks as organizational structures: formal networks can be conceptualized as a source of agency, as entities which control and accumulate different kinds of resources as well as pursuing specific strategies, e.g. in terms of system building.

We believe that these new perspectives are of general value for innovation studies. In this paper we have applied them specifically to the issue of innovation system building, resulting in a threefold contribution: Firstly, our approach highlights the strategic nature of system building with a deliberate deployment of resources at different levels. This complements the view that system formation is largely an emergent process without much coordinated action. In general, system building has received rather little attention in the TIS literature until now. Our analysis shows that system building was initiated with actors identifying deficits in the technological field (e.g. ill-defined interfaces between components of a product, missing skilled fitters) and joining forces in formal networks to develop structures that help to improve the situation (e.g. technical norms, educational programs). In these networks, they used different sets of existing organizational resources but they also developed new resources and competences at the network level. These network resources often take time to build up, which means that the range of tasks a network can fulfill increases as network resources are accumulated and established.[9] In situations where different innovative technologies compete for public support, some network resources can be expected to be central for system building.

Secondly, the resource concept helps to analyze the role of different actors and networks for system building. While TIS scholars have regularly pointed to the pivotal role of prime movers [81], there was little conceptual explanation for what differentiates a key actor or system builder from a more peripheral actor. Resource-based reasoning highlights that organizations possess different resources and that some of these resources may be unique and difficult to substitute [21,26]. While we were studying processes at the network level, it became obvious that specific resource contributions by the network members were essential to accomplish the aims of the network. These members represent a difficult-to-substitute key actor for a specific system building task: without their procedural competences and resources, the development of certain system resources would be difficult (e.g. the VDI case). Formal networks can be differentiated in a similar way with regard to their importance for the TIS. Networks have different sets of resources, i.e. organizational resources and network resources, which they can deploy for system building. An analysis of the resource and competence base of different networks can therefore be key in the assessment of their system building capacity. It has to be noted, though, that this resource portfolio will change over time (and thus the role of the network).

Thirdly, we have directed attention to the interplay of firm, network and system level processes thus contributing to the broader research agenda on micro-level dynamics in broader socio-technical transformations [24,25,79]. Take the interplay of resources at different levels: as attractive system resources are developed, new actors enter the innovation system, which possibly makes new and complementary organizational resources available. While studying networks, we not only got a better understanding of how resources are established, combined and finally deployed for system building, but also of the interplay between these levels. In a similar vein, we saw that a newly created system resource, the governance structure of the NIP, had a positive feed-back on the reputation of the IBZ network. Through these feed-backs, cumulative effects may be triggered which are crucial for the dynamics we observe in many technological fields [82].

[9] These findings correspond with a model developed in the RBV literature [26]. In the model, a stock of accumulated assets determines what a firm can actually do, while a flow of assets leads to a higher level of strategic opportunities. This flow of assets is rather planned and steered. This might also holds true for key innovation networks in TIS, in which key members of the networks strategically steer the development of resources and capacities in system building.

6.2. Limitations and future research

The present study clearly has its limitations with regard to the generalization of its results. We have analyzed a specific TIS in a defined national setting with a selected set of formal networks. While it seems to be plausible that some of the aforementioned observations and conceptualizations can be transferred to other cases, this remains to be tested in further studies with a similar research design. For example, German industries are known for the typically strong role played by formal networks and associations [83]. In other countries, we might identify network structures that differ from those presented before. Still, we believe that similar approaches to coordinate different kinds of actors can be found.

Today, we are just beginning to understand the particularities of the strategic moves of firms and system building ([11,84 this issue]). The use of resource based reasoning, and the integration of the resource concept in TIS, thus opens up possibilities for conceptually incorporating strategic decision-making at the firm level into the development process of a TIS. So far, we have concentrated on co-operative strategies directed at system building. However, we can additionally expect groups of firms and networks to compete in the development of system resources, especially if these resources provide very different benefits for different constituencies [12]. Further research may follow up on these issues, thus providing additional insights into the maneuvers and strategies of firms and other actors in emerging technological fields.

Future studies may also shed light on the obstacles of collective action in the presence of ambiguity. Ill-functioning networks can be analyzed, for example, with regard to what hampers the development of critical resources at the network level. Network formation may be hindered because potential network members are afraid of 'giving away' valuable organizational resources. Alternatively, there might even be too much network formation. In the case of fuel cells, politicians as well as firms became confused during the hype in 2001 and the subsequent disappointment [76,84]. The hype was accompanied by an uncoordinated emergence of networks, and a manifold articulation of needs and expectations. Both the coordination and structuring of the network activities and the development of an overall governance structure (at the system level) became very important, and could, finally, be achieved through the coordinated activities of leading actors in the field. Therefore, a better understanding of the underlying social processes and of leadership in networks is also needed. Future studies may follow up on this issue as they analyze how system builders [9] steer and guide the development of TIS. Findings from the entrepreneurship literature might be a promising starting point in this regard [33,70,85].[10]

These examples for future research will not only increase our understanding of system building, i.e. the interplay of strategic action and technology development at the innovation system level but it will also contribute to the even broader research agenda on socio-technical transitions towards more sustainable modes of production and consumption [87].

Acknowledgment

The authors would like to thank the Competence Center Environment and Sustainability of the ETH Domain (CCES) for funding. In addition this paper also profited from constructive inputs at the Academy of Management Annual Meeting 2011 in San Antonio. Finally, we would especially like to thank the special issue editors and three anonymous reviewers for helpful comments on earlier drafts and Mike Simpson and Tara Helbling for proofreading.

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[10] According to this perspective another level of analysis has also been taken into account: the intra-firm context and the internal resources and networks of a firm's business unit. Especially system builders or champions [86] within big firms have to draw on internal resources of their business units to secure their activities in technology entrepreneurship. It was already evident in our interviews that achievements at the TIS level (e.g. creation of NIP support program) also had an impact on 'the standing' of fuel cell business units of the manufacturers studied. Activities within firms, formal networks and at the level of the TIS are thus interlinked.

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