Research Policy 45 (2016) 330–344

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Institutional dynamics and technology legitimacy – A framework and a case study on biogas technology

Jochen Markard[a,*], Steffen Wirth[b], Bernhard Truffer[c,d]

[a] Swiss Federal Institute of Technology Zurich, Department of Management, Technology and Economics, Chair of Sustainability and Technology, Weinbergstrasse 56/58, 8092 Zurich, Switzerland
[b] IFZ – Inter-University Research Centre for Technology, Work and Culture, Schloegelgasse 2, 8010 Graz, Austria
[c] Eawag – Swiss Federal Institute of Aquatic Science and Technology, Ueberlandstrasse 133, 8600 Duebendorf, Switzerland
[d] Chair of Geography of Transitions in Urban Infrastructures, Faculty of Geosciences, University of Utrecht, Heidelberglaan 2, NL-3584 CS Utrecht, Netherlands

ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 31 July 2015
Accepted 16 October 2015
Available online 7 November 2015

Keywords:
Technology legitimacy
Technological innovation system
Institutional change
Biogas
Agriculture
Energy sector

ABSTRACT

Legitimacy is central for both novel and established technologies to mobilize the resources necessary for growth and survival. A loss of legitimacy, in turn, can have detrimental effects for an industry. In this paper, we study the rise and fall of technology legitimacy of agricultural biogas in Germany over a period of more than 20 years (1990–2012). The field witnessed impressive growth and professionalization for many years and has become one of the key technologies in Germany's energy transition. In recent years, however, it has been confronted with major criticism, which finally resulted in a substantial cut-back of public and political support. The aim of our study is twofold. In empirical terms, we will explain the technology's loss of legitimacy despite its compliance with original policy objectives: growth and maturation. In theoretical terms, we work toward a more general framework to understand technology legitimacy and to explain the institutional dynamics of technological innovation systems.

1. Introduction

Whether a technology thrives and flourishes depends, among others, on how well it is aligned with the norms, values and beliefs in its wider context. A technology that is well understood, compatible with established practices, socially accepted and perhaps even endorsed by regulation, possesses a high degree of legitimacy, which is essential for resource mobilization and successful development (Bergek et al., 2008a, 2008b; Hekkert et al., 2007; Rao, 2002). Conversely, if there are conflicts and institutional misalignment, technology development may be hampered (Breukers and Wolsink, 2007; Geels and Verhees, 2011; Wirth et al., 2013).

In this paper we study the development of a novel technology with a focus on institutional structures. We analyze which technology-specific institutional structures emerge, how they interact with context structures and how both, technology-specific and contextual institutions change over time. Our focus is on the alignment (or misalignment) of the focal technology with elements in its wider context, which we refer to as *technology legitimacy*. Analyzing institutional alignment and misalignment will help us to explain technology dynamics, including exponential growth and major drawbacks.

Legitimacy is of critical importance for the development and prospering of firms, technologies and industries (Aldrich and Fiol, 1994; Bergek et al., 2008b; Zimmerman and Zeitz, 2002). Legitimacy has been conceptualized as the perceived consonance of an entity with its institutional environment, i.e. a socially constructed set of norms, values, beliefs and practices in its context (Scott, 2008; Suchman, 1995). The concept has been widely used in organizational institutionalism explaining, among others, that organizations conform to their institutional environment so that they can mobilize critical resources (DiMaggio and Powell, 1983; Meyer and Rowan, 1977). While legitimacy of organizations has received much attention in the literature (Deephouse and Suchman, 2008), comparably few scholars have looked into legitimacy at the level of an industry or technological field (Aldrich and Fiol, 1994; Bergek et al., 2008b; Geels and Verhees, 2011; Rao, 2002).

Legitimacy is important for both novel and established technologies as it is a prerequisite to mobilize financial, human and

* Corresponding author.
E-mail address: jmarkard@ethz.ch (J. Markard).

http://dx.doi.org/10.1016/j.respol.2015.10.009
0048-7333/

material resources as well as regulatory support (Bergek et al., 2008a; Hekkert et al., 2007). Legitimacy is created in a collective, social process involving organizations such as technology developers, experts, associations or interest groups (Bergek et al., 2008b; Johnson et al., 2006; Rao, 2004). Creation of legitimacy is particularly vital for novel technologies, especially if they are radically different from existing ones (Aldrich and Fiol, 1994; Bergek et al., 2008b; Harris-Lovett et al., 2015). As a consequence, it is implicitly assumed that once a new technology is well known and supported by a critical mass of actors (e.g. Bergek et al., 2008b), once its liability of newness is overcome, legitimacy is less of an issue.

However, also established technologies may go through phases of low legitimacy and crisis. In the case of nuclear power, for example, legitimacy has seen ups and downs as a result of changing societal values and framing struggles between technology proponents and anti-nuclear activists (Garud et al., 2010; Geels and Verhees, 2011). Such legitimacy dynamics, i.e. changes in the alignment of a focal technology and its wider institutional context, is what we are interested in. Especially the loss of legitimacy is an issue that deserves further attention because of its potentially detrimental effects for an entire technological field or industry (Jonsson et al., 2009; Lawrence et al., 1997; Ruef and Markard, 2010).

In our empirical analysis, we will show that a novel technology that has grown successfully and left its infant years behind might still run into legitimacy troubles. Interestingly, the loss of legitimacy might even be a consequence of strong growth, e.g. due to an increased competition for customers or resources, or because the expansion reveals institutional misalignments in the context. In theoretical terms, we draw on the technological innovation systems concept (e.g. Bergek et al., 2008a, 2015; Markard and Truffer, 2008) and insights from institutional theory (e.g. Deephouse and Suchman, 2008; Scott, 2008). Analytically, we focus on (alignment and misalignment of) institutional structures of the focal technology and the context.

As an empirical case, we have chosen agricultural biogas, a novel technology that has emerged at the interface of two different sectors, agriculture and energy supply. Biogas depends on resources from both sectors, which means that it is confronted with different 'institutional demands'. Biogas can be used for the generation of electricity and heat, as vehicle fuel or as a substitute for natural gas. It is an alternative to fossil and nuclear energy sources, which is why the technology has received widespread public policy support over the past decades. Our study concentrates on the developments in Germany, which is a frontrunner in the promotion of renewable energies. As of 2013, Germany was the world's leading country in agricultural biogas with around 7,700 plants generating 25 TWh of electricity (equal to 4.7% of the country's electricity consumption). In Germany, biogas has grown rapidly but became recently confronted with increasing criticism. The technology has been criticized for competing with food production, causing corn monocultures, rising lease prices for arable land and odor and traffic nuisance at the local scale. Moreover, subsidies for renewable energy have received negative press because of the high costs involved. As a consequence, the German government has meanwhile cut back formerly favorable regulatory support for biogas, thus causing a severe breakdown in the market for biogas plants and leaving the technology with rather uncertain prospects.

Biogas in Germany can be viewed an example of a novel technological field that saw technological improvement, professionalization and strong growth, followed by a loss of legitimacy it still has to recover from. But how did this happen? Why did the former hope for crisis-ridden agriculture eventually create new problems in the very same sector? And what are the underlying institutional processes in the ups and downs of technology legitimacy?

To answer these questions, the paper proceeds as follows. In Section 2, we briefly review the literature on legitimacy and develop a framework to study legitimacy dynamics in technological innovation systems. Section 3 describes our methods and data sources. Section 4 presents the results. In Section 5 we discuss our findings in the light of our framework. Section 6 concludes.

2. Theoretical framework

In the literature, legitimacy has been ascribed to different entities and different processes associated with the creation of legitimacy have been highlighted. This is what we discuss next before introducing our framework.

Legitimacy is a central concept in institutional theory, which highlights that it is important to conform with established institutional structures (Deephouse and Suchman, 2008; DiMaggio and Powell, 1983; Scott, 2008). Legitimacy has been conceptualized as the perceived consonance of an entity with a socially constructed set of norms, values, beliefs and practices in its context (Scott, 2008; Suchman, 1995). Legitimacy can be ascribed to different kinds of entities, including individuals, organizations, business models, industries, technologies etc. (Aldrich and Fiol, 1994). Legitimacy can be a key factor for the success of organizations (or other entities) because it is a precondition for gaining access to critical resources (Aldrich and Fiol, 1994; Deephouse and Suchman, 2008; Zimmerman and Zeitz, 2002).

Legitimacy is often studied in relation to novelties, i.e. new ventures, technologies or industries as they face a particular need to mobilize resources or regulatory support, for legitimacy is key (Aldrich and Fiol, 1994; Zimmerman and Zeitz, 2002). However, also established entities depend on resources and continuous support by their environment, for which they require legitimacy (Pfeffer and Salancik, 1978). For established entities, legitimacy is often only a salient issue, if it is dwindling and they are confronted with criticism. Our case will show the detrimental consequences of a loss of legitimacy.

Scholars have distinguished different types of legitimacy, including cognitive, normative and regulatory legitimacy (Aldrich and Fiol, 1994; Scott, 2008; Suchman, 1995). Cognitive legitimacy refers to the degree to which an entity is known, understood and taken for granted. Normative legitimacy is about conformity with societal values and widely shared beliefs, while regulatory (or sociopolitical) legitimacy is associated with the compliance to formal rules, laws and regulations.

Legitimacy is neither given nor purely emergent. Instead, it is created in a collective, social process that remains subject to contingencies (Johnson et al., 2006). In his study on the early American car industry, Rao (2002) shows how various public and private actors, including social movements, have contributed to the formation of industry legitimacy. Johnson et al. (2006) distinguish four stages in the legitimation of new social objects: innovation, i.e. creation of the new object; local validation, i.e. local actors construe the new object as consonant with an existing cultural framework of beliefs; diffusion, i.e. the new object is applied to new contexts and general validation, the object becomes part of society's shared culture.

Many studies have concentrated on the role of actors and strategic action in the creation of legitimacy at the industry[1] or technology level, highlighting processes such as lobbying, coalition building, negotiation, compromise seeking, framing or categorization (Aldrich and Fiol, 1994; Garud et al., 2010; Geels and Verhees, 2011; Harris-Lovett et al., 2015; Rao, 2004). At the same time,

[1] Here we also refer to studies on industry legitimacy to mobilize the respective insights. Industry and technology legitimacy are on a similar level of aggregation and we expect similar characteristics, e.g. in terms of legitimacy dynamics.

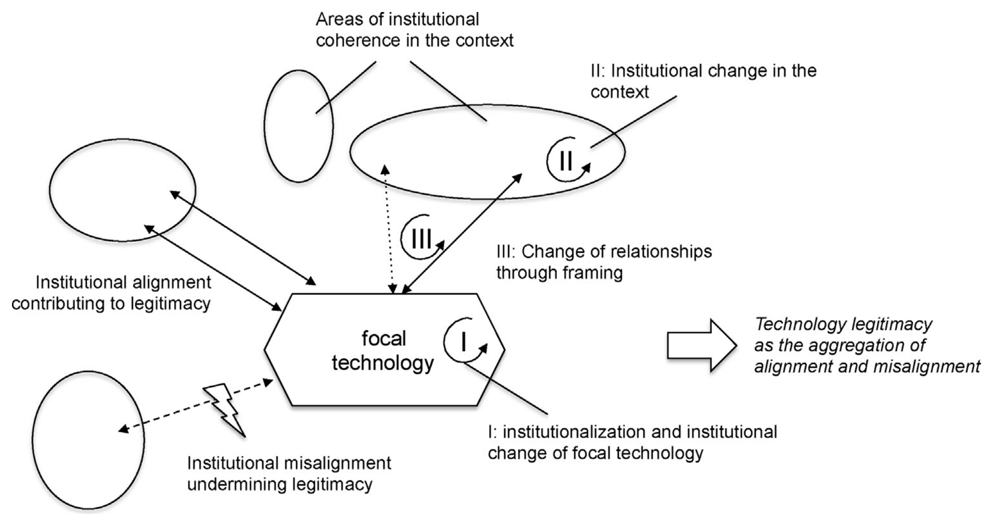

Fig. 1. Focal technology and its relationships with context structures.

scholars also point to more abstract processes, e.g. as (industry) convergence around a dominant design, or creating linkages with established educational curricula (Aldrich and Fiol, 1994), contributing to legitimacy creation. In the literature on technological innovation systems, technology legitimacy is seen both as an outcome of collective action[2] and as a result of systemic feedback effects in the sense of virtuous circles. Moreover, it is mentioned (but not shown) that legitimacy can also be affected by changing problem agendas at the societal level (Bergek et al., 2008b). In fact, this is what we will demonstrate in our paper.

In the following, we concentrate on the institutional change processes associated with legitimacy. We distinguish formation and change (i) of technology-specific institutions, (ii) of institutions in the wider context and (iii) of the relationships between them. We assume that different kinds of actors drive and influence these processes.[3] However, in our framework we background strategic action and institutional work. Instead we focus on its outcome in the form of institutional changes and the consequences for changes in legitimacy.

2.1. Framework at a glance

Our framework consists of five building blocks, which we will introduce in further detail below: a technological innovation system associated with the focal technology, its context, alignment and misalignment of institutional structures, technology legitimacy and legitimacy dynamics. We propose to study technology legitimacy by taking a closer look at the relationships between technology-specific institutional structures, which are part of a focal technological innovation system (TIS), and institutions in the context.

In Fig. 1 these relationships are depicted as arrows, which either represent institutional alignment (regular arrows) or misalignment (dashed arrows with flash). The context can be understood as an infinite repertoire of institutional structures (not depicted here but in Fig. 4 further below). The context contains areas with a certain degree of coherence (ellipses), such as sectors, legal systems or socio-technical regimes. Technology development depends on the provision of resources from the context, which is why the structures and 'demands' of the context matter. The focal technology (hexagon) is related to the institutions in the context at various points and legitimacy depends on how well technology-specific and context institutions are aligned. Technology legitimacy is created either through adaptation of the technology (process I, circular arrow), institutional change of context structures (process II) or framing (process III).

2.2. Technological innovation system

A technological innovation system (TIS) has been defined as a set of interrelated actors and institutional structures in a specific technological domain that contribute to the development of a focal technology (Bergek et al., 2008a). The TIS concept covers both emerging and mature technologies. 'Technological domain' can refer to a particular area of technological knowledge and competence (e.g. microelectronics, thin-film coating), a specific product or service (e.g. mobile phone, solar cell, load management) or even to a larger societal function such as energy supply, food production or health care (cf. Carlsson et al., 2002). Technologies are interrelated and nested (Sandén and Hillman, 2011) and it is very much at the discretion of the analyst at what level of aggregation (horizontal and vertical) he defines the focal TIS (Markard et al., 2015).

The technological innovation system is assumed to hold, or develop, a certain degree of institutional coherence in the sense that there is a shared understanding among the actors in field about the purpose of the technology, key design principles and technology characteristics. This is very similar to the common understanding of purposes, rules and relationships in organizational fields (Wooten and Hoffman, 2008) or strategic action fields (Fligstein and McAdam, 2011).

Institutional structures in the TIS include cognitive elements as in the case of technological expectations and visions (Swanson and Ramiller, 1997; van Lente and Rip, 1998), normative elements such as performance criteria (Kaplan and Murray, 2010; Rao, 1994) and regulatory elements, e.g. formal standards (Funk and Methe, 2001; Garud et al., 2002). Further examples include established practices, business models or commonly acknowledged actor roles.

Actors include individuals and collective actors (technology developers, research institutes, associations, social movement

[2] "Legitimacy is not given, (. . .) but rather formed through conscious actions by various organizations and individuals in a socio-political process of legitimation, which incorporates cognitive, normative as well as regulative aspects." (Bergek et al., 2008b, p. 581).

[3] Note that we think of actors as agents embedded in institutional structures that constrain but also enable (individual and collective) action, including activities that lead to changes in these very structures (e.g. Garud et al., 2007).

groups, experts, consultants, users etc.) that actively contribute to the development of the focal technology.

2.3. Context

The technological innovation system is situated in a broader environment or context (Bergek et al., 2015; Markard et al., 2015). We suggest thinking of the context as an infinite repertoire that comprises institutional structures, actors and actor networks. The main difference is that the elements of the innovation system are specific for the focal technology, while those of the context are not.

Similar to the TIS, the context is assumed to comprise areas of higher order structure. Examples include other technological innovation systems, regional or national innovation systems, legal and political systems etc. (Bergek et al., 2015). Also existing sectors such as energy supply, transportation, health care or agriculture are context structures that exhibit some degree of institutional coherence as they are characterized with a host of regulations, organizational practices, user expectations, beliefs etc. Socio-technical regimes are very similar in this regard. They have been described as large sets of semi-coherent institutional and technological structures that affect (and often hinder) emerging technologies due to a rigid institutionalization of their core structures (Fuenfschilling and Truffer, 2014; Geels, 2002).

Which of the context elements matter for a focal technology has to be determined empirically. We expect that technological or spatial proximity plays a role (cf. Fligstein and McAdam, 2011) but it is beyond the scope of this paper to elaborate on this. What is relevant with regard to legitimacy is that context structures such as larger societal problems or political goals can be mobilized by TIS actors to motivate (and legitimate) the focal technology.

2.4. Institutional alignment and misalignment

Institutions such as societal values, technical design rules, business models or consumer expectations – whether in the context or in the focal innovation system – may be aligned, misaligned or not connected at all. Institutions are aligned if they enable, incentivize or constrain similar actions in a specific situation. An example is a technological design practice that is taken up in the formulation of a technology standard, or the purpose of a technology conforming to policy goals and regulations.

Institutional structures are misaligned, or conflicting, if actors that follow one institution will come in conflict with another. Business practices, for example, may be in conflict with moral values or even formal regulations, or a novel technology does not conform to the norms and performance criteria of an established technology (and the larger socio-technical regime the latter is embedded in). Misalignment weakens the effect institutions have on the decisions of actors, while alignment corresponds to a strengthening of institutional forces.

Given the variety of existing and competing technologies, sector structures, political systems and regulatory contexts as well as regional variation of culture and social values, the context of a TIS can be viewed as a large patchwork, or landscape, of institutional structures, some of which are coherent and aligned with each other, while others are in conflict and still others have no connection.[4] Technology proponents as well as opponents can use some (and not necessarily the same) of these structures to position (frame) the technology in different ways.

[4] Note that these relationships may change over time (cf. Section 2.6).

2.5. Technology legitimacy

The focal technology may be aligned with some institutions of the context, while being misaligned with others, cf. Fig. 1. Still other parts of the context may not matter at all because there is little or no connection (although they may be 'activated' at some point in time). The car, for example, is aligned with societal values such as freedom, autonomy and self-determination while it is in conflict with climate protection, resource-independence or the idea of 'green cities'.

We define *technology legitimacy* as a commonly perceived alignment (or misalignment) of a focal technology with institutional structures in its context. We characterize and specify technology with the use of three dimensions, which we also refer to as technology-specific institutions: its purpose (cognitive dimension), informal design rules (normative dimension) as well as formal technology standards and the materialization of technology (regulatory dimension), cf. Table 1.

In our definition of technology legitimacy, we concentrate on the 'technological core' of the TIS, i.e. we do not look into the legitimacy of the (entire) TIS.[5] In particular, we differentiate technology legitimacy from the legitimacy of TIS actors and concentrate on the former. Although we expect interesting interactions between the two, e.g. well-established actors transferring legitimacy to a novel technology or new ventures benefiting from the promises of a specific technology, we will not explore it any further in this paper.

Given that a technology has many facets and is connected in different ways with its context, there may be institutional alignment, corresponding to a high degree of legitimacy as well as misalignment (low degree of legitimacy) at the same time. In other words, a technology is not legitimate (or illegitimate) per se but legitimacy is rather an aggregation of more and less legitimate aspects. Against this background, we regard technology legitimacy as an *overall or integral perception* of how well a specific technology is aligned to the context, or not.

Also note that institutional alignment and misalignment may occur within a TIS. While we assume a general degree of alignment (e.g. a common understanding of the purpose of the technology and its performance criteria), there may well be misalignment or even institutional conflict within the TIS. Competing technological variants, or standards, supported by different constituencies may be an example (Cusumano et al., 1992; Markard et al., 2009). As a consequence, some parts of a TIS may be aligned with a particular context element, while others are not. Community owned wind parks, for example, are in line with larger societal values such as participation and regional autonomy, while investor owned wind parks are not (Breukers and Wolsink, 2007).

Finally, our definition also highlights that technology legitimacy is a matter of perspective and interest, which means that different stakeholders, or audiences, may have differing views on the legitimacy of a technology. A *common perception* of technology legitimacy emerges where groups of actors hold and express similar perceptions.

2.6. Legitimacy dynamics

Technologies and technological innovation systems change over time. They emerge at some point, build up structure, grow and stabilize, they may go through phases of contention and reconfiguration, and eventually, they may also decline or break apart. We also expect context structures to change over time, with some

[5] Note that the TIS literature (cf. Section 2.2) is not very explicit in this regard but rather seems to have the entire TIS in view, when discussing 'legitimation'.

Table 1
Institutional dimensions to specify the focal technology.

Type of institution	Content	Diagnostic questions	Specifics
Cognitive	Understanding and purpose of technology	What is biogas? What is its purpose, what problem can it solve?	
Normative	Major design principles	What is a 'good' biogas plant? What are unwritten rules or guiding principles for building and operating biogas plants?	
Regulatory	Socio-technical materialization	How do biogas plants look like? What are typical technology characteristics? How are they operated?	Plant size, main substrate, construction, ownership and operation

being more stable than others. Context dynamics will largely be independent of developments in the focal TIS, although there might be situations in which the TIS has an impact on changes in the context (as in the case we will present below).

As a consequence of these changes, technology legitimacy may change as well. In our framework, we distinguish three major processes that contribute to changes in technology legitimacy. The first is the *formation and change of the focal technology and other institutional structures in the technological innovation system*. As the TIS emerges and grows, it becomes institutionalized, i.e. it builds up cognitive, normative and regulatory institutional structures.[6] In early years, technology-specific institutions are often adapted to existing institutions in the context in order to create legitimacy (Bergek et al., 2008b). As the technology matures and changes over time, this may have consequences for legitimacy. In general, legitimacy increases when technology-specific institutions emerge that are aligned with some context structures and not in conflict with others.

A second key process is the *formation and change of institutional structures in the context.* Context changes may both increase or decrease the legitimacy of the focal technology. For example environmental issues such as air pollution or climate change have seen ups and downs in societal discourses (Schmidt et al., 2013). In times in which climate change is key issue, we can expect that the legitimacy of low-carbon technologies increases, while the legitimacy of carbon-intense technologies decreases. As a consequence of context changes, established industries may be confronted with specific problems, which question existing technologies. The car industry, for example, was confronted – at different times – with concerns about safety and air pollution (Penna and Geels, 2012), which undermined the legitimacy of then existing cars and lead to technology changes.

The third key process refers to the *formation and change of institutional relationships between the focal innovation system and the context*. These relationships, and whether there is institutional alignment or not, change as a consequence of the first two processes. However, relationships may also change as a consequence of framing (e.g. Benford and Snow, 2000). Framing is essentially a cognitive process about the selection and connection of context structures: some are highlighted as being important for the focal technology while others are ignored. Through framing, a technology is positioned (or re-positioned) in its context. For a novel technology it is an a priori open issue how it is positioned in relation to existing institutional structures, e.g. whether it is presented as an environmentally friendly, job-creating, competitiveness enhancing etc. Also established technologies can be re-interpreted (and thus re-legitimized). Nuclear energy, for example, after losing legitimacy due to anti-nuclear protests, was re-positioned as a sustainable, climate-friendly technology when CO_2-emissions became an important issue on the sociopolitical agenda (Garud et al.,2010).

3. Research design and methods

Our research consisted of three parts, an introductory basic analysis, an in-depth study of institutional dynamics and a media analysis. The basic analysis of the TIS and the context was inspired by the schemes proposed by Bergek et al. (2008a), Markard et al. (2009) and Bergek et al. (2015). Its primary goals were to determine the boundaries of the TIS, to develop a sufficient understanding of what happened and to identify major context structures for further examination. To this end, we conducted a comprehensive study of reports, statistics, studies (including papers in scientific journals) and articles in professional journals on biogas in Germany. Another central data source were the monitoring reports of the German Biomass Research Centre (DBFZ) on the effects of the German feed-in tariff (EEG) on biogas development (e.g. DBFZ, 2014). The basic analysis was concluded by two half-day meetings with two biogas experts, in which we cross-checked our first interpretations and conclusions.

As a result of this first part, we decided to do a longitudinal analysis – from 1990 when the first biogas plants appeared in Germany to 2012. In terms of spatial boundaries, we started with one region, Baden-Wuerttemberg – the cradle of biogas in Germany, but soon expanded our scope to the national level as we saw that the legitimacy loss of biogas was very much a nation-wide phenomenon. Furthermore, we decided to study agriculture and energy supply as two important sectors in the context and to concentrate on 'major problems' in these sectors as important cognitive institutions the novel technology could relate to. In addition, we identified the EEG as a central regulatory context institutions associated with the energy sector. At the technology level, we operationalized the three dimensions as depicted in Table 1.

The second part of our study was an in-depth analysis of changes in the aforementioned institutional structures both in the TIS and in the context. This was, among others, guided by the diagnostic questions listed in Table 1. For this main part of the analysis, we mobilized different data sources: unpublished data on 800 biogas plants (to which we gained access through the German Biogas Research Center, legislative documents of the Renewable Energies Act (EEG) and a series of 15 expert interviews. The latter were very important as they served to identify the informal institutional structures and 'soft factors', e.g. what was taken for granted when setting up biogas plants. Interview partners were official biogas advisors, engineers and planners, biogas professionals, and representatives of agricultural authorities, conservation organizations and the German Biogas Association. Most of them had a 15–20-year expertise in the field. Some of them have been 'at the heart' of biogas development in Germany, i.e. they had first-hand experience of how the technology emerged and matured. Interviews were conducted between October 2011 and November 2012, they were semi-structured and lasted from 60 to 150 min. All of them were recorded and transcribed afterwards.

[6] In early stages of TIS formation we expect cognitive institutions such as ideas, concepts and expectations to play a dominant role, while in later stages these are more and more complemented by normative and formal regulatory institutions (e.g. technical norms, dominant designs).

Box 1: Method details of media analysis

For the analysis of attention to biogas and energy crops and the criticism expressed in different media, we analyzed contents from 2000 to 2012, which covers the criticism and 6 years before. We chose two outlets, which can be assumed to represent different audiences. The first one is the magazine of the German biogas association (Biogas Journal); it the most important organ in the community of biogas professionals in Germany. It was founded in 2000 and today has a circulation of 10,000 bimonthly copies. Over the observation period it has grown from one issue in the first year, to two (2001–2005), four (2006–2010) and six issues (since 2011). In the Biogas Journal we analyzed the 49 editorials of all its issues to get a good overview of all 'hot topics'. Results of this content analysis are incorporated in the text of chapter 4.

The second source is Sueddeutsche Zeitung, the highest-circulation, independent quality newspaper in Germany with nation-wide coverage. In Sueddeutsche Zeitung, we searched for articles with "biogas" and "nachwachsende Rohstoffe" (energy crops) as keywords to cover the controversy about energy crops and to keep the overall number of articles (205) manageable. For a detailed analysis we extracted those 86 articles that were of sufficient length (e.g. no short notes or event announcements) and had a focus on biogas, i.e. no articles about renewable energies in general. In Sueddeutsche, evaluative statements were identified in each article and categorized according to major lines of argumentation derived from the text. The articles were also analyzed quantitatively, measuring issue attention and overall tone of the article (positive vs. negative; inspired by Stiehler et al., 2012).

Afterwards we summarized our main findings in a table and developed a detailed description of the developments in the form of a narrative. This was split into three phases. The start of the second phase was chosen so that it marks the major shift in socio-technical design of biogas plants (dominant use of energy crops), while the start of the third phase marks the beginning of public criticism. Next, we discussed the outcome of our research in 'feedback sessions' with two biogas experts, one of whom we already interviewed before and one who we approached for the first time. We refined our findings as a result of this feedback.

In the third part of our analysis, we targeted technology legitimacy or, more precisely, the loss of legitimacy.[7] We used two methods. First, we conducted a systematic review of six earlier studies on the acceptance of biogas (cf. Table 3). These were based on interviews, surveys and media discourse analyses. From this we already gained a profound understanding of major criticism related to biogas (and biofuels) and when it occurred. Second, we conducted an analysis of press articles on agricultural biogas from 1992 to 2012. These were analyzed both qualitatively and quantitatively. For the media analysis we chose two sources, a daily newspaper (Sueddeutsche Zeitung) to cover the public discourse and the magazine of the German biogas association to cover the discourse of biogas professionals (see Box 1 for further details). This allowed us to integrate perceptions from two different audiences.

4. Results

This section starts with a brief overview including technological and regulatory developments and critique biogas was (and still is) confronted with. After that, technology development, changes in the context and legitimacy dynamics will be described in detail for the three periods. Each of these three sub-sections is organized as follows: context developments and major problems, understanding of biogas technology, design rules, materialization and summary, cf. Table 2.

4.1. Technology development, media attention and loss of legitimacy

The first generation of agricultural biogas plants in Germany had an average plant size of around 70 kW and was operated with liquid manure and dung as the main substrates (Schulz, 1996). Biogas plants were built as an integral part of the organic waste cycle in dairy and livestock farming. Toward the end of the 1990s, the novel TIS started to grow rapidly and received additional regulatory support by the renewable energies law (EEG) of 2000. Alternative streams of biomass inputs were explored including the use of dedicated 'energy crops'.

Since around 2002, corn silage has been used as a substrate for biogas plants in addition to manure. In 2004, the feed-in tariff of the EEG was revised now containing strong incentives for the use of energy crops. The next two years witnessed a veritable biogas boom in which the number of plants almost doubled from around 2,000 to 3,500, cf. Fig. 2. Meanwhile, a new generation of biogas plants had emerged. They were much larger in size (300 kW on average) and professionally built by supra-regional firms.

In subsequent years, plants continued to grow both in absolute numbers and average size. The 2009 revision of the EEG maintained strong incentives for the use of energy crops. For new plants, corn became the dominant substrate for biogas production and technology providers were offering turnkey plants with standard sizes of 300 and 500 kW. A second boom phase occurred from 2009 to 2011. In 2012, EEG support was reduced significantly. At the end of 2012, 7500 biogas plants were installed in Germany with an electricity generation capacity of more than 3 GW.

Before 2000, biogas gained only very little attention in the wider public (Jensen et al., 2012). From 2000 to 2004, press coverage of biogas and energy crops in Sueddeutsche Zeitung was at a moderate level.[8] With the first boom in 2005 and 2006 this picture changed. More frequent articles explained the use of energy crops for biogas production, highlighting issues such as job creation, generating additional income for farmers, the contribution to the transition of the energy sector or climate protection. Attention peaked in 2007, followed by a major decline and a second wave with a smaller peak in 2011.

Criticism first emerged among farmers and biogas professionals around 2005 (interview with biogas advisor). In 2006, the Biogas Journal prominently addressed the critique for the first time. Since then it has remained a recurrent theme. In the public discourse, criticism appeared somewhat later around 2007. In Sueddeutsche Zeitung, negative press articles had a first small peak in 2007, followed by a second wave that peaked in 2011. In 2007 the majority of articles were still positive, while in 2011 almost every second article had a predominantly negative tone (cf. Fig. 3).

The critique in both the professional and the public domain was largely similar. It included competition of food vs. energy, corn monoculture, negative effects like odor, noise and transport nuisances (Kabasci et al., 2012; Sperling, 2012; Zschache et al., 2010). Also the environmental impacts of biogas plants in terms of bio-

[7] In fact, conflict, criticism and loss of legitimacy is often easier to detect in press articles than institutional alignment because the latter is not, or just indirectly, reported, e.g. when the focal technology is mentioned in association with larger societal problems, to which it represents a solution.

[8] Note that Fig. 4 only depicts 86 articles dedicated to biogas *and* energy crops. The number of articles in which biogas and energy crops are *mentioned* was 205 and the number of articles, which mention biogas in different contexts was more than 2400.

Table 2
Change of context and biogas technology in Germany over time.

	Phase I (1990–2001)	Phase II (2002–2006)	Phase III (2007–2012)
Context institutions			
Developments and problems in the agricultural sector	Closure of farms, replacement of guaranteed prices for agricultural products, overfertilization	Closure of farms, low food prices, fallow land	Closure of farms, high food prices (at two times), rising lease prices
Developments and problems in the electricity sector	Market liberalization, expansion of renewable energies	Liberalization, phase-out of nuclear (since 2002), expansion of renewable energies	Climate change, Fukushima and renewed phase-out decision, energy transition, EEG costs
Regulations of feed-in tariff (EEG)	General feed-in tariff implemented in 1991: no differentiation of technology, EEG 2000: differentiated tariffs	EEG 2004: bonus for energy crops and pre-defined size categories	EEG 2009: bonuses for energy crops and manure, EEG 2012: significant tariff reduction for energy from biogas
Technology-specific institutions			
Understanding and purpose of technology	Biogas is a technology for sustainable agriculture; main purpose: waste recycling	Biogas is an agro-energy technology: it generates income for farmers and it is an element in the energy transition; shared vision: farmer becomes energy producer	Biogas is an energy technology and an investment; it is a corner stone of the energy transition and an alternative to conventional farming
Design rules	Farm size and farm business taken as given; biogas technology handles residues		Size categories of EEG taken as given; biogas technology produces energy
	Biogas plants must fit the farm; technology must be integrated into farm routines; digestate must be of good quality	Biogas should fit the farm; technology must generate additional income for farmers, esp. in times of low food prices	Biogas must generate a good return; plants must be optimized in terms of energy-output; farm routines should be adapted to technology needs
Socio-technical materialization			
Average size of new plants	70 kW	420 kW	520 kW
Main substrate (input)	Manure plus organic waste	Manure plus corn silage	Corn plus manure
Construction	Self-construction by farmers and/or construction work by local engineers	Construction work by local engineers and supra-regionally operating construction firms	Turn-key plants (standard sizes, e.g. 300 and 500 kW) by supra-regionally and internationally operating construction firms
Main operators	Dairy farmers	Dairy farmers, animal husbandry farmers	Dairy farmers, animal husbandry farmers (partly combined with arable farming), energy utilities
Technology diffusion			
Number of plants (first and last year of period)	50–1300	1600–3500	3800–7500
Regional diffusion	Baden-Wuerttemberg (Southeast), Bavaria (West and Southeast), Lower Saxony	Baden-Wuerttemberg, Bavaria, Lower Saxony, Eastern Germany	Entire country
Legitimacy of biogas technology in professional community and public	High (in professional community)	Medium (in professional community) High (in broader public)	Medium-Low (in professional community) Medium (in broader public)

diversity, water, and methane emissions were questioned (Schuh, 2011). Interestingly, there was even a special term emerging in the discourse: "Vermaisung" ('maizification') became a buzzword capturing much of the criticism related to biogas technology (Linhart and Dhungel, 2013).

This brief overview shows that the technology witnessed a massive and successful diffusion, furthered by regulatory support. Diffusion was accompanied by two waves of attention in the public press. Negative press came along with the 2nd biogas boom and was very prominent. We take this as an indicator for a major loss of technology legitimacy.

4.2. Early TIS formation (1990–2001)

During this period, the agricultural sector had to deal with three major problems. One was the closure of large numbers of farms ("Höfesterben") and the corresponding concentration of production.[9] Moreover, a major shift in the common agricultural policy of the European Union took effect from 1993 onwards. Guaranteed prices for agricultural products were first lowered and later replaced by direct payments to farmers. These payments also included set-aside premiums for agricultural land. As a consequence, economic pressure on farmers increased. The third challenge was an ever-intensified use of chemical fertilizers that resulted in overfertilization. The negative environmental effects of this were getting ever more attention (Köberle, 1994).

In the energy sector, the prevailing issue during that time was market liberalization. The 1996 directive of the European Commission mandated a stepwise introduction of competition in electricity supply. European energy policy also demanded an increase in

[9] This is a development that began back in the 1960s and 1970s and still goes on today. It is not limited to Germany but a general phenomenon in agriculture, triggered by mechanization (novel & bigger machines) and an increased use of chemicals, among others.

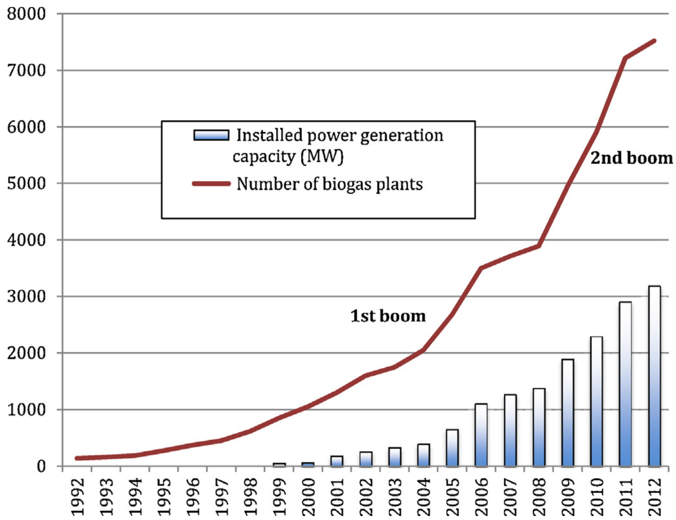

Fig. 2. Diffusion of agricultural biogas plants in Germany, Source: http://www.de.statista.com.

renewable energy generation (target setting) to be achieved by national regulations. Germany was one of the pioneering countries to introduce a feed-in tariff for renewable electricity in 1991. With the implementation of the renewable electricity law (EEG) in 2000, technology-specific tariffs were introduced with the intention to better address the needs of different technologies.

During the first phase, biogas was understood as a technology to improve organic waste recycling in agriculture. It was regarded as a technology for sustainable agriculture and as an important element of a circular economy. Primary goals for the development and use of biogas plants at that time were improved fertilization, soil enrichment (humus, water retention capacity), better management of manure (odor nuisance) and groundwater protection (Graf, 1996; Schulz, 1996). Energy production and generating additional income for farmers were further goals but of secondary importance (Köberle, 1994).

Existing (context) structures in agriculture were taken for granted, which means that farm size, its main business (e.g. dairy farming, cattle breeding) or the amount and nature of organic waste were regarded as frame-conditions for setting up biogas. Pioneers saw 'no reason for doing it differently'. Biogas plants were adapted to each farm and designed to fit well into the established daily routines of farming.

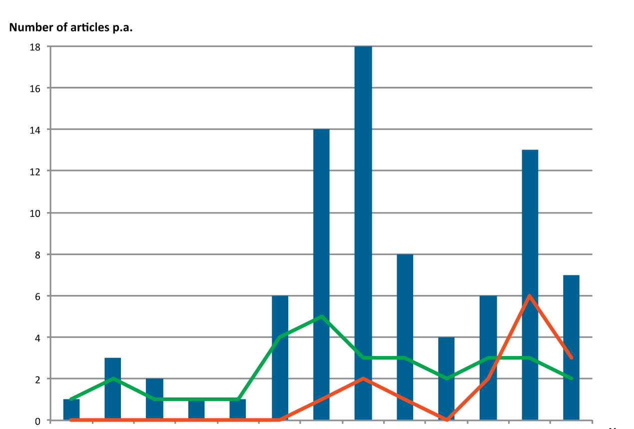

Fig. 3. Number and tone of topical press articles covering biogas and energy crops (positive: green, negative: red, otherwise neutral or ambivalent). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Source: Sueddeutsche Zeitung.

Early biogas plants were rather small in size and used manure as the main substrate. Some also co-digested organic waste from non-farming sources (e.g. from restaurants or butcheries). Biogas plants generated small amounts of energy used for heating farm buildings. Plants were self-constructed by farmers or by local engineers that integrated 'normal' technical components, which were available in other markets in a modular way (Köberle, 1994). Many working hours were done without payment.

Biogas pioneers were mostly dairy farmers and there were close ties to the growing niche of organic farming, where good agricultural practice was strongly connected to the use of natural fertilizers (Köberle, 1994).[10] Technology developers were individuals with a background in agriculture and engineering that met regularly, exchanged knowledge and coordinated activities in the so-called Bundschuh-Biogas-Group, a close network of practitioners in Southern Germany. Group members shared common values such as peasant autonomy and the virtue of organic farming. These early supporters also founded the German Biogas Association (GBA) at the agricultural school for organic farming in Baden-Wuerttemberg in 1992.

In the early years, technology legitimacy grew within the emerging community of biogas professionals. A shared understanding of biogas emerged and improved functionality and reliability also contributed to the technology being perceived as viable. Formal support through the EEG (especially from 2000 on) contributed to the creation of legitimacy.

To sum up, biogas emerged as a novel technology within the agricultural sector. It was regarded as a technology for sustainable waste recycling, linking up with and addressing the broader issue of overfertilization. In this first phase, biogas plants were well integrated into existing farm structures and adapted to farming practices. We also see various networks emerging with close ties to agriculture and organic farming and the German Biogas Association as a dedicated intermediary TIS actor. In these early years, regulatory support for renewable electricity stimulated the development but had little effect on the socio-technical materialization of biogas plants.

4.3. First boom: energy crops and professionalization (2002–2006)

From 2002 to 2006, economic pressure on farming remained high, as food prices were low or strongly fluctuating. Structural change continued with farmers giving up their business and farm sizes increasing. In addition, increasing shares of fallow agricultural land seemed to call for an alternative use.

In the energy sector, market liberalization continued and in 2002, the German government decided to phase out nuclear power, which generated about one third of the country's electricity at that time. This decision came along with strong political support for expanding the use of renewable energies, expressed among others in the EEG from 2004. With regard to biogas, the novel regulation included an attractive bonus for the use of energy crops, guaranteed feed-in payments for a period of 20 years and further bonuses for heat use and innovative technology. Finally, predefined size categories were introduced, i.e. feed-in payments were differentiated depending on the size of biogas plants.[11]

In the second phase, energy production became very important for the understanding of biogas. Biogas was increasingly regarded as an energy technology. For example in 2002 the Ger-

[10] In the late nineties, still about 25% of the biogas plants were operated on organic farms.

[11] Plants with an installed capacity up to 500 kW received 9.9 €ct/kWh plus a bonus of 6 €ct/kWh.

man Biogas Association estimated that 10% of Germany's power supply could be provided by biogas, given that two thirds of the manure from animal husbandry and an additional 20% of Germany's farmland were used for the production of energy crops (Jensen et al., 2012). At around the same time, the slogan "Vom Landwirt zum Energiewirt" ('Farmer turns into energy producer') emerged. It suggested not only that energy production becomes important in agriculture but also that farmers take up a new and entirely different role. Moreover, biogas was seen as a solution to the precarious income situation in the agricultural sector. Finally, together with wind and solar energy, biogas was regarded as an important part of the transition of the energy sector toward renewable energies.

The normative design principles of biogas plants changed as well. While integration into existing farm structures and routines was still relevant, generation of additional income for farmers became more and more important.

The socio-technical design of new and – to some extent – also existing biogas plants changed fundamentally. Biogas plants considerably grew in size, with the average of new plants being six times bigger than in the first phase. The installed electricity generation capacity increased by a factor of six. More importantly though, corn silage became a major input for biogas production, in addition to manure. Producing energy crops seemed to fit well with the fact that there was much fallow land in agriculture. Organic waste from outside the agricultural sector was not used any more.

With the strong growth of the TIS the underlying actor base expanded and its structure changed. Animal husbandry farmers showed increasing interest in biogas with plants that were typically much larger than for dairy farms. Planning, construction and financing of biogas plants became more and more professionalized and self-constructed plants grew rare. Dedicated biogas manufacturers emerged and expanded rapidly with the boom. In 2006, the German Biogas Association (GBA) reported 420 biogas firms as members, a year later even 470 firms (Schnell, 2006, 2007). The following statement of a GBA representative illustrates professionalization within the TIS: "The current demand for information on biogas plants shows that the former field of eco-freaks has finally become a serious business in agriculture." (da Costa Gomez, 2004).

The GBA played an influential role in the revision of the EEG as the following statement of the association's vice president illustrates: "Virtually all our demands and suggestions will be implemented in the future regulations of the EEG . . . none of these [achievements] would have been realized without the Biogas Association, without the continuous work in the executive committee and the office . . . Biogas is the winner of the novel EEG. And who invests in biogas will be a winner as well." (Ott, 2004).

A key development in this second phase is the rapidly growing use of energy crops for biogas production, especially maize.[12] The use of energy crops was initially supported by many stakeholders. In Baden-Wuerttemberg, for example, the association of farmers association and a local nature conservation organization conjointly argued in favor of "energy from the field" (LNV BW et al., 2003). At the national level, the German Biogas Association (GBA), the Bioenergy Association and the German Farmers' Association developed a common position in support of energy crops (Ott, 2003).

Three years later in 2006, however, the GBA advised that the arguments of the biogas skeptics, who criticized maize monoculture, scarcity of raw materials for the food industry, increasing land lease prices or odor nuisance, should be taken seriously (Pellmeyer, 2006). Experts also pointed to the risks of the boom and warned of manufacturers with a lack of experience (Bensmann, 2006). The tendency toward very large plants was also seen critical by some of the biogas professionals (Bensmann, 2007). These warnings should prove to be correct as the criticism became part of the public discourse not much later (cf. Section 4.1).

> "We argued for small, manure-based 75 kW plants and a manageable technology. But, the North and East German states became prevalent and politically pushed big plants, 500 kW at the minimum. Construction firms perceived the big business. That's how things got out of control." *Interview with an official biogas advisor*

In summary, the second phase was characterized by the increasing use of energy crops and a shift in the understanding of biogas from a technology for sustainable agriculture to a technology for renewable energy generation. Biogas was presented as a solution to major problems in both agriculture (low income, fallow land) and energy supply (alternative to nuclear). In fact, biogas was at the core of a novel vision for the role of farmers (becoming energy producers). The EEG of 2004 formalized the novel understanding of the technology and significantly contributed to the first biogas boom. The actor base expanded rapidly, new intermediaries emerged and the technology professionalized. Associations were able to exert influence on policy making.

4.4. Continued growth and criticism (2007–2012)

In the third phase, closure of farms continued at a more moderate pace than before. There were two periods of high food prices (from 2007 to 2008 and in 2011). Moreover, farmers were confronted with rising lease prices for arable land (Emmann and Theuvsen, 2012). In the German energy sector, the energy transition accelerated and there was a massive expansion of wind and solar, among others. Climate change received high media attention, especially around the Copenhagen climate summit in 2009 (Schmidt et al., 2013). In 2011, the German government decided on an accelerated phase-out of nuclear power plants as a consequence of the Fukushima nuclear accident. Since 2012, the EEG has been confronted with criticism because the price electricity consumers have to pay for the support of renewables has increased disproportionally over time (Leprich et al., 2013).

Between 2007 and 2012, formal regulation for biogas changed twice. With the EEG of 2009, the bonus for energy crops increased from 6 to 7 €ct/kWh for plants up to 500 kW. An additional bonus of 4 €ct/kWh (up to 150 kW) or 1 €ct/kWh (above 500 kW) was granted for the use of at least 30% manure. What was meant as a specific incentive for the use of energy crops also made the use of corn (for up to 70% of the input) more profitable. In 2012, basic feed-in payments for biogas were slightly increased but all bonuses were removed and the underlying requirements (minimum heat use, maximum input of energy crops) became mandatory.

The understanding of the technology shifted further. Biogas was now primarily seen as energy technology used to generate power, gas, fuel and heat (Trojecka, 2007). Even more, it was presented as a corner stone for the energy transition with its supply of basic, peak and even balancing energy (Maciejczyk, 2009). Furthermore, biogas was regarded as a business, an investment opportunity to generate attractive returns.

> "[Biogas entrepreneurs] are farmers that want something else, that have the capacity to manage a company with some hundred employees, . . . they are neither satisfied with 100 kW nor with 400 kW if they can earn more with 600 kW." *Interview with a biogas professional*

Consistent with the earlier image of farmers converting into biogas producers, biogas was framed as an alternative to conventional

[12] From 2002 to 2006 cultivation of corn in Germany increased by 15%.

agriculture (Maciejczyk, 2010). It was argued that biogas plants generate a reliable income compared to the highly volatile prices for agricultural products.

> "Those who have invested in recent years already knew that biogas plants are big today. It was impossible to offer them something like 60 kW or so. They were in contact with others, they wanted to copy. They knew this [plants of several 100 kW] is he standard today." *Interview with representative of ministry of agriculture*

Design principles for novel biogas plants changed as well. The size categories of the feed-in tariff became a major orientation for most biogas projects, which means that they were taken as a reference point to which other parameters had to be adapted. Standard plant sizes were chosen and substrate inputs were optimized with regard to electricity generation. Existing structures including size of the farm, primary products or established routines played much less of a role than before. In fact, they were adapted to increasing the energy output. For example, biogas farmers leased additional land to meet the energy demand of the plant or they bought energy crops from other farmers. Quite a few farmers also turned entirely to the production of energy crops.

In the third period, the TIS again expanded massively, even though 2007 and 2008 were bad years for plant manufacturers (cf. Fig. 2). Overall more than 4,000 new plants were built with an average size of 520 kW. In fact, two standard sizes (300 and 500 kW) of biogas plants emerged. For the first time, biogas technology diffused all over the country with hot spots in Lower Saxony, Bavaria and Baden-Wuerttemberg. Corn became the dominant substrate as it guaranteed high energy yields. The total area used for the cultivation of corn increased by 50% to 2.5 Mio ha (equivalent to 15% of the agricultural area in Germany).[13] About one third of it is used for biogas production.

The actor base expanded further. It was estimated that in 2009 the German biogas 'industry' comprised 11,000 jobs (Pellmeyer, 2009b). Manufacturers began to offer biogas plants internationally. Plant operators included dairy and animal husbandry farmers, but also electric utilities (Pellmeyer, 2009a). Both municipal and supra-regional utilities had entered the TIS, investing predominantly in large plants on a megawatt scale. In such projects, farmers played a new role as suppliers of substrate, instead of owners and operators of biogas plants.

The fundamental changes of the technology were widely recognized, provoking different reactions. BGA representatives repeatedly stated that site-adapted biogas plants with a secure substrate supply and an optimal use of heat were a primary objective for the development of the novel technology (Ott, 2007; Pellmeyer, 2008; da Costa Gomez, 2010a,b). They also emphasized that large plants are not necessarily "beautiful" or efficient (Ott, 2007; da Costa Gomez, 2008). These statements are an implicit critique of stand-alone,[14] megawatt scale biogas plants running primarily on energy crops.

A central issue in this third period was how to deal with financial support for energy crops in the revision of the feed-in tariff (EEG). According to the GBA, a bonus for manure offered the chance to again pursue the original idea of a decentralized energy supply with many small and site-adapted biogas plants (Pellmeyer, 2009a). Several stakeholders including conservationists, the German Farmers' Association or delegates of the agricultural committee of the parliament, however, opposed any further bonus increase (Olzem, 2008). Food industry and agricultural cooperatives even wanted to entirely remove the bonus and launched campaigns against biogas (da Costa Gomez, 2008).

In the 2009 revision of the EEG, bonus proponents succeeded. What followed was the second biogas boom, which gave even more support to the critical voices that highlighted the negative repercussions on landscape, biodiversity, food prices or local neighborhoods. This opposition not only precipitated in the daily news (cf. Section 4.1) but also confronted plant operators and construction firms with citizens' initiatives against biogas (Maciejczyk, 2010). Moreover, globally rising food prices contributed to the perception that energy generation was competing with food production (Britz and Delzeit, 2013). In 2011, the bonus for energy crops was subject to massive critique by different actors (da Costa Gomez, 2011; Friedmann, 2011). Finally, in the novel EEG of 2012 all bonuses were abandoned.

The third phase can be summarized as follows: the TIS expanded and matured further with a large actor base, new roles and a more differentiated value chain. Biogas became an industry-like technology with de facto standards and a clear orientation toward energy production. It was presented both as a key element of the energy transition and as a viable alternative to conventional agriculture, i.e. transformative for both of its key reference sectors. Again, the technology received substantial financial support through the EEG. At the same time, impacts on the agricultural sector became more and more obvious and criticism was expressed by many different actors. The EEG of 2012 took up the critique in the form of significantly reduced payments with the intention to slow down the growth of the TIS.

5. Discussion

In this section we interpret our findings in the light of our theoretical framework. In the first phase, biogas plants were built by pioneers in agriculture and little known. It was presented as a technology for sustainable agriculture, with the primary objective of waste recycling and improved fertilization (Fig. 4a, process III). This connection building between a novel technology and salient issues in a nearby context has been referred to as framing (cf. Benford and Snow, 2000; Hargrave and Van de Ven, 2006). As overfertilization was a commonly accepted challenge in agriculture, this early purpose of the technology was soon adopted widely and contributed to the creation of cognitive legitimacy.

Furthermore, the technology was adapted to existing farm structures and agricultural practices (Fig. 4a, process I). Structures of the agricultural context, in other words, were primarily regarded as frame conditions for technology development. Biogas plants were designed to fit smoothly into these existing structures and farming procedures. In conceptual terms, the novel technology was adapted to the sectoral context, or institutionally embedded (e.g. Kemp et al., 1998; Lange, 2009).

Another process that contributed to legitimacy creation was the appreciation of biogas as renewable energy production technology and formal endorsement by the early EEG (Fig. 4a, process II). This can be viewed as an example of regulatory legitimation, in which context structures adapt to the novel technology. The dashed line indicates that the relationship was not strong at that time.

Through all of these processes, biogas technology became aligned in different ways with different institutional context structures. Technology development in this phase was characterized by a strong adaptation to existing context structures, mostly to those of the agricultural sector.

In the second phase, the understanding of biogas changed. The novel technology was increasingly framed as an energy technology and as an additional source of income for farmers. The 'all-rounder

[13] See http://www.maiskomitee.de/web/public/Fakten.aspx/Statistik/Deutschland (accessed 26.03.14).

[14] This refers to biogas plants not integrated into existing farms and their waste streams.

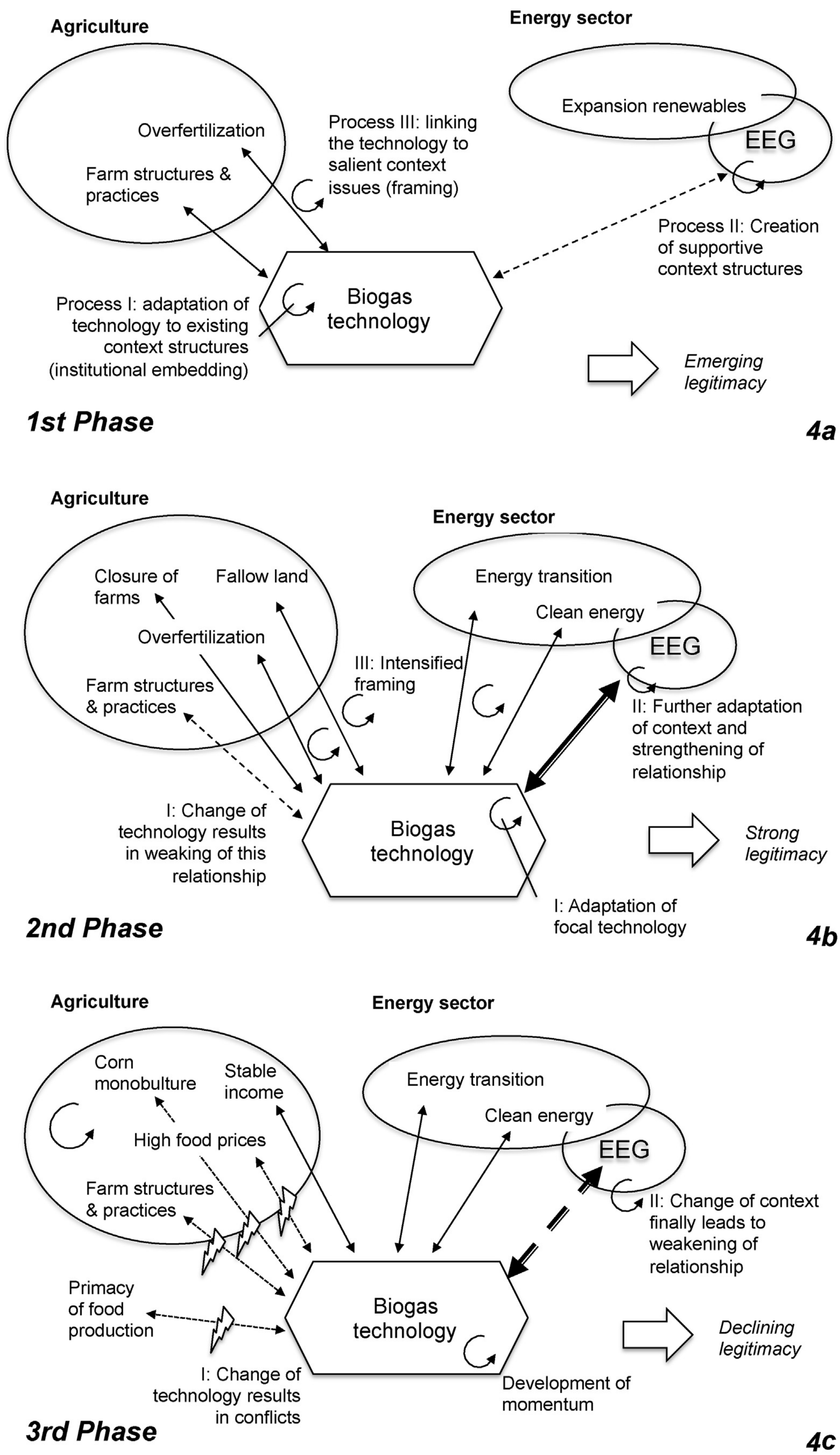

Fig. 4. Institutional alignment and misalignment of biogas over time.

biogas' became a solution for a host of context issues: overfertilization and soil improvement, fallow land, source of clean energy and element of the energy transition. In other words, framing intensified (Fig. 4b, process III) and cognitive legitimacy grew stronger. At the same time, the relationships became more diverse. Moreover, regulatory ties with the EEG intensified (Fig. 4b, bold arrow), both as a result of adaptation of the technology and in the context.[15]

While the energy sector became an ever more influential 'reference point' for the novel technology, the importance of adaptation to existing agricultural structures became less important for biogas plants built in the second phase. This can be interpreted as a partial weakening of institutional alignment (Fig. 4b).

In the third period, biogas was presented as being transformative for both energy supply and agriculture. Conflicts with the context arose because established agricultural structures were not taken as frame conditions but subordinated instead to serve the needs of biogas technology (Fig. 4c, dashed arrows with flashes). In other words, the TIS had developed strong institutional structures that generated momentum (Hughes, 1987; Van de Ven, 2005). At the same time, EEG regulation became the key context reference for the TIS. Moreover, the success and growth of biogas contributed to its legitimacy. This is similar to what is described as formation of critical mass in the literature (e.g. Bergek et al., 2008b).

The subsequent expansion resulted in even more conflicts with established institutions in agriculture. Biogas was now framed as a competitor and threat to conventional farming. Normatively, technology legitimacy was undermined by actors who referred to larger societal values, especially the primacy of food over energy production (cf. Fig. 4c).

6. Conclusion and outlook

Legitimacy is crucial for firms, industries and technologies to emerge, expand and survive. It is the basis for securing resource flows and maintaining support. Technology legitimacy has not received much attention in the scholarly literature so far and our paper addresses a gap in this regard. We propose to conceptualize technology legitimacy as a commonly perceived, aggregated alignment of a focal technology with selected institutional structures in its context.

In this paper we traced the institutional dynamics of biogas technology. We could show how the TIS institutionalized and expanded in the beginning when technology was positioned as a solution to prevailing problems in agriculture. Over time, the relationships with context structures changed: new connections emerged, some grew stronger and others became misaligned. As a consequence, technology legitimacy at first increased, became formalized over time (as the technology was endorsed by regulation) and finally declined when the consequences of widespread energy crop farming became apparent.

We can now answer our initial question of how a seemingly promising technology was confronted with a major loss of legitimacy despite its successful expansion. As the TIS emerged, it became very much aligned with institutional structures of agriculture. Over time, institutional ties with the energy sector became stronger and were formalized. At some point they very much shaped technology development, thereby 'overriding' earlier alignment with agricultural structures and practices. As the technology matured and gained momentum, the institutional 'demands' of the two context sectors proved to be irreconcilable and it was primarily the institutional conflict with agriculture that was responsible for the loss of legitimacy. Our case, in other words, is an example of two essentially different and originally unrelated sectors (energy and agriculture) that – through a novel technology – became intertwined and were then confronted with institutional conflict.

What made this conflict even more difficult to resolve were high growth rates and rapid expansion of the novel technology as well as its critical mass and the increasing lobbying capacity of TIS actors. Abundance of financial resources set in course a dynamic, which very much exceeded the initial expectations. This made policy learning and swift re-regulation more difficult.

While the case presented here is certainly particular in some regards (e.g. strong role of regulation), we expect these mechanisms and the general processes of our framework to apply in other instances as well. Of particular interest for further studies, in our view, are technological fields such as nuclear energy or fossil fuels that are confronted with fundamental legitimacy issues, which may have path-changing consequences (Geels and Verhees, 2011; Penna and Geels, 2012; Turnheim and Geels, 2012).

This case and the framework will be a first step on this road. Further research is warranted to address some of the particularities associated with the study of technology legitimacy, which we will briefly discuss below.

First, different audiences may view specific events and legitimacy issues differently (Buchanan and Dawson, 2007). In our analysis we distinguished two audiences, the professional community and the broader public. We found indications that legitimacy concerns in the professional community were expressed earlier and in a more differentiated way than in the public discourse but we did not explore such differences any further. This seems to be an interesting issue for future research, which also links up with the question whether we can devise a somewhat more objective measure for the fit of a technology and its context. The distinction of radical vs. incremental innovations (cf. Markard and Truffer, 2006) might be related to this.

Another issue is about comparing different contexts (cf. Bergek et al., 2015; Wirth et al., 2013). As a technology matures, it will also expand to different contexts, which may include novel sectors (e.g. internet technology becoming an integral part of banking) as well as novel regions (such as solar or wind power diffusing globally). Technology legitimacy can be expected to vary across sectoral and spatial contexts, which is why comparative analyses (e.g. between different countries) seem to be promising. An alternative research design would be to compare different parts of a technological innovation system in terms of legitimacy. While one application may be viewed as legitimate (e.g. using nuclear for energy generation) another may be not (nuclear weapons).

Third, TIS actors may be included into the analysis of technology legitimacy. Key actors may significantly contribute to industry legitimacy as in the case of self-regulation in the chemical industry (King and Lenox, 2000) or potable water reuse in California (Binz et al., in press) but they may also damage technology legitimacy. The BP oil spill, for example, negatively affected the reputation of the oil industry.[16] In our case, especially investors that built very large, centralized biogas plants were confronted with local opposition and received negative press, which is like to have contributed to the technology's loss of legitimacy.

Another very important issue will be to engage with agency and struggles over legitimacy. While actors, their different interests and strategies showed up in our results, we did not address them in any detail. However, scholars of legitimacy have repeatedly pointed to the strong role of legitimacy creation by different types

[15] The EEG not only strengthened technology legitimacy but also directly mobilized massive financial resources that fueled the rapid expansion of the German biogas TIS.

[16] http://oilprice.com/Energy/Energy-General/Oil-Industry-Reputation-Hit-By-Gulf-Oil-Spill-Survey-Shows.html (accessed 28.03.14).

of actors (Rao, 1994), framing struggles (Garud et al., 2010; Geels and Verhees, 2011) and corporate political action (Sarasini, 2013; Sühlsen and Hisschemöller, 2014). Future research will therefore benefit from exploring the role of actor strategies with regard to technology legitimacy further.

Finally, technology legitimacy may very well be a moving target, especially in the case of socio-technical transitions (Geels and Schot, 2010; Markard et al., 2012), when both focal technology and institutional structures in the context undergo far-reaching changes. In such situations, the context may transform as quickly as the focal technology – as a result of the focal technology emerging and independent of it.

These issues underline that the study of technology legitimacy holds many promising avenues for further research. It is not only interesting from a research point of view but also highly relevant for policy and strategy making, given the consequences legitimacy dynamics have for both novel and mature technologies.

Acknowledgements

This work was funded by the Swiss National Science Foundation (grant number: 100018 130353). Earlier versions of the paper were presented at the 30th EGOS colloquium in Rotterdam in 2014 and at a workshop on Low Carbon Energy Innovation at Eindhoven University in 2013. We thank the organizers and participants of these meetings, the anonymous reviewers as well as Lea Fünfschilling, Melf Hinrich-Ehlers and Keith Sue for their valuable comments.

Appendix A

Table 3
Studies related to the legitimacy of bioenergy in Germany.

Authors and year	Title	Scope	Method	Key findings
Zschache et al. (2010)	Public interpretations in the discourse on bioenergy: a qualitative media analysis	Bioenergy (biofuels, biogas, biomass in general) 2004–2008	Media analysis	Increasing and sincere criticism: bioenergy has become a highly contested issue
Linzbach (2011)	Political discourse on biogas and its reflection in regulatory institutionalization	Biogas and bioenergy 2003–2011	Discourse analysis of transcriptions of debates during plenary sessions	Biogas and bioenergy are a sub-discourse of a broader discourse on climate protection and energy security. Biogas is interpreted as being beneficial for Germany (energy supply, climate protection, economy, agriculture)
Kabasci et al. (2012)	Change of image of biogas technology	Biogas 2009–2011	Survey of residents, operators, and producers; expert interviews; workshops	Critical remarks about odor, noise and transport nuisances and rising lease prices for arable land because of energy crops cultivation
Sperling (2012)	The Angry Countryside – the installation of biogas plants as a contested issue in a German region	Recent development of biogas	Case study of a region with one of the highest biogas plant density	Local residents regard new types of biogas plants (large-scale) in the countryside as a threat
Stiehler et al. (2012)	Side effects of biogas plants perceived by German citizens	Biogas 2004–2011 (focus on 2011)	Media analysis and online survey in Bavaria	Biogas is criticized concerning corn monocultures, loss of biodiversity, soil erosion, and the food vs. plate rivalry.
Linhart and Dhungel (2013)	The public discourse on increased cultivation of corn in Germany	Corn 2007–?	Media analysis (discourse and actors)	Negative statements concerning corn cultivation are predominant, German farmers association is an outsider with its positive assessment

References

Aldrich, H.E., Fiol, C.M., 1994. Fools rush in? The institutional context of industry creation. Acad. Manag. Rev. 19, 645–670.

Benford, R.D., Snow, D.A., 2000. Framing processes and social movements: an overview and assessment. Annu. Rev. Sociol. 26, 611–639.

Bensmann, M., 2006. Tierisch viel Power. Neue energie 01/06, 41–47.

Bensmann, M., 2007. Freie Fahrt für Fermenter. Neue energie 01/07, 52–55.

Bergek, A., Hekkert, M.P., Jacobsson, S., Markard, J., Sanden, B.A., Truffer, B., 2015. Technological innovation systems in contexts: conceptualizing contextual structures and interaction dynamics. Environ. Innov. Soc. Trans. 16, 51–64.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008a. Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. Res. Policy 37, 407–429.

Bergek, A., Jacobsson, S., Sanden, B.A., 2008b. 'Legitimation' and 'development of external economies': two key processes in the formation phase of technological innovation systems. Technol. Anal. Strateg. Manag. 20, 575–592.

Binz, C., Sedlak, D., Kiparsky, M., Truffer, B., 2015. Legitimizing disruptive innovations – how support for potable water reuse was constructed in California. Technol. Forecast. Soc. Change (in press).

Breukers, S., Wolsink, M., 2007. Wind power implementation in changing institutional landscapes: an international comparison. Energy Policy 35, 2737–2750.

Britz, W., Delzeit, R., 2013. The impact of German biogas production on European and global agricultural markets, land use and the environment. Energy Policy 62, 1268–1275.

Buchanan, D., Dawson, P., 2007. Discourse and audience: organizational change as multi-story process. J. Manag. Stud. 44, 669–686.

Carlsson, B., Jacobsson, S., Holmén, M., Rickne, A., 2002. Innovation systems: analytical and methodological issues. Res. Policy 31, 233–245.

Cusumano, M.A., Mylonadis, Y., Rosenbloom, R.S., 1992. Strategic maneuvering and mass-market dynamics: the triumph of VHS over beta. Bus. Hist. Rev. 66, 51–94.

da Costa Gomez, C., 2004. Editorial: Nach dem EEG ist vor dem EEG. Biogas Journal 02/04, 3.

da Costa Gomez, C., 2008. Endlich Klarheit für das EEG. Biogas Journal 02-08, 12–14.

da Costa Gomez, C., 2010a. Editorial: Von Missgunst. Neid und davon schwimmenden Fellen. Biogas Journal 01/10, 3.

da Costa Gomez, C., 2010b. English Special: Efficient use of biogas within a stable framework. Biogas Journal 04/10, 3.

da Costa Gomez, C., 2011. Editorial: Qualität zählt! Biogas Journal 01/11, 3.

DBFZ, 2014. Stromerzeugung aus Biomasse. Deutsches Biomasseforschungszentrum/German Biogas Research Centre, Leipzig.

Deephouse, D.L., Suchman, M.C., 2008. Legitimacy in organizational institutionalism. In: Greenwood, R., Oliver, C., Suddaby, R., Sahlin, K. (Eds.), The SAGE Handbook of Organizational Institutionalism. Sage, Thousand Oaks, CA, pp. 49–77.

DiMaggio, P.J., Powell, W.W., 1983. The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. Am. Sociol. Rev. 48, 147–160.

Emmann, C.H., Theuvsen, L., 2012. Einfluss der Biogasproduktion auf den regionalen Pachtmarkt – Empirische Erhebung in fünf niedersächsischen Landkreisen mit hoher Anlagendichte. Berichte über Landwirtschaft. Z. Agrarpolit. Landwirtsc. Band 90, 84–112.

Fligstein, N., McAdam, D., 2011. Toward a general theory of strategic action fields. Sociolog. Theory 29, 1–26.

Friedmann, H., 2011. Editorial: Biogas will in die Zukunft – aber wie? Biogas Journal 02/11, 3.

Fuenfschilling, L., Truffer, B., 2014. The structuration of socio-technical regimes – conceptual foundations from institutional theory. Res. Policy 43, 772–791.

Funk, J.L., Methe, D.T., 2001. Market- and committee-based mechanisms in the creation and diffusion of global industry standards: the case of mobile communication. Res. Policy 30, 589–610.

Garud, R., Gehman, J., Karnoe, P., 2010. Categorization by association: nuclear technology and emission-free electricity. In: Sine, W.D., David, R. (Eds.), Research in the Sociology of Work. Emerald Group Publishing Ltd., Bingley, UK, pp. 51–93.

Garud, R., Hardy, C., Maguire, S., 2007. Institutional entrepreneurship as embedded agency: an introduction to the special issue. Organ. Stud. 28, 957–969.

Garud, R., Jain, S., Kumaraswamy, A., 2002. Institutional entrepreneurship in the sponsorship of common technological standards: the case of sun microsystems and java. Acad. Manag. J. 45, 196–214.

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31, 1257–1274.

Geels, F.W., Schot, J., 2010. The dynamics of sociotechnical transitions – a socio-technical perspective. In: Grin, J., Rotmans, J., Schot, J. (Eds.), Transitions to Sustainable Development. Routledge, pp. 9–101.

Geels, F.W., Verhees, B., 2011. Cultural legitimacy and framing struggles in innovation journeys: a cultural-performative perspective and a case study of Dutch nuclear energy (1945–1986). Technol. Forecast. Soc. 78, 910–930.

Graf, W., 1996. Biogas für Österreich. Bundesministerium für Land- und Forstwirtschaft, Wien. Bundesministerium für Umwelt, Jugend und Familie, Wien, Wien.

Hargrave, T.J., Van de Ven, A.H., 2006. A collective action model of institutional innovation. Acad. Manag. Rev. 31, 864–888.

Harris-Lovett, S.R., Binz, C., Sedlak, D.L., Kiparsky, M., Truffer, B., 2015. Beyond user acceptance: a legitimacy framework for potable water reuse in California. Environ. Sci. Technol. 49, 7552–7561.

Hekkert, M., Suurs, R.A.A., Negro, S., Kuhlmann, S., Smits, R., 2007. Functions of innovation systems: a new approach for analysing technological change. Technol. Forecast. Soc. 74, 413–432.

Hughes, T.P., 1987. The evolution of large technological systems. In: Bijker, W., Hughes, T.P., Pinch, T. (Eds.), The Social Construction of Technological Systems. , pp. 51–82, Cambridge, MA.

Jensen, D., Bensmann, M., Horbelt, A., 2012. Festschrift 20 Jahre Fachverband Biogas e.V. Fachverband Biogas e.V., Freising.

Johnson, C., Dowd, T.J., Ridgeway, C.L., 2006. Legitimacy as a social process. Annu. Rev. Sociol. 32, 53–78.

Jonsson, S., Greve, H.R., Fujiwara-Greve, T., 2009. Undeserved loss: the spread of legitimacy loss to innocent organizations in response to reported corporate deviance. Adm. Sci. Q. 54, 195–228.

Kabasci, S., Ehrenstein, U., Strauch, S., Linneweber, V., Schweizer-Ries, P., Hildebrand, J., 2012. Abschlussbericht zum Projekt Imageanalyse und Imagewandel der Biogastechnologie unter Einbeziehung sozialwissenschaftlicher und technologischer Aspekte. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Berlin.

Kaplan, S., Murray, F., 2010. Entrepreneurship and the construction of value in biotechnology. In: Phillips, N., Sewell, G., Griffiths, D. (Eds.), Research in the Sociology of Organizations – Technology and Organization: Essays in Honour of Joan Woodward. Emerald Group Publishing, pp. 107–147.

Kemp, R., Schot, J., Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. Technol. Anal. Strateg. Manag. 10, 175–195.

King, A.A., Lenox, M.J., 2000. Industry self-regulation without sanctions: the Chemical Industry's Responsible Care program. Acad. Manag. J. 43, 698–716.

Köberle, S., (Dissertation) 1994. Konfliktmanagement in der Technikgenese. Universität Bielefeld, Fakultät für Soziologie, Bielefeld.

Lange, K., 2009. Institutional embeddedness and strategic leeway of actors: the case of the German therapeutical biotech industry. Socio-Econ. Rev. 7, 181–207.

Lawrence, T.B., Wickins, D., Phillips, N., 1997. Managing legitimacy in ecotourism. Tour. Manag. 18, 307–316.

Leprich, U., Grashof, K., Guss, H., Klann, U., Weber, A., Zipp, A., Bofiner, P., Ritzau, M., Kremp, R., Schemm, R., Schuffelen, L., 2013. Stromsystem-Design: Das EEG 2.0 und Eckpfeiler eines zukünftigen Regenerativwirtschaftsgesetzes: Endbericht. IZES gGmbH, Universität Würzburg, BET Büro für Energiewirtschaft und technische Planung GmbH, Saarbrücken, Würzburg, Aachen.

Linhart, E., Dhungel, A.K., 2013. The public discourse on increased cultivation of maize in Germany. Ber. Landwirtsch. 91.

Linzbach, A., (Master thesis) 2011. Political Discourse on Biogas and its Reflection in Regulatory Institutionalization – A Discourse Analysis of Biogas' Special Role in the German Political Arena. University of Twente.

LNV BW, BLHV, LBV, 2003. Für eine umweltgerechte Energieversorgung. Neue wirtschaftlichen Perspektiven für Bauern und den ländichen Raum. Landesnaturschutzverband Baden-Württemberg e.V., Arbeitsgemeinschaft der Badisch-Württembergischen Bauernverbände, Stuttgart.

Maciejczyk, M., 2009. Editorial: Biogas kann's. Biogas Journal 03/09, 3.

Maciejczyk, M., 2010. Editorial: "Qualität beginnt beim Menschen, nicht bei den Dingen". Biogas Journal 03/10, 3.

Markard, J., Stadelmann, M., Truffer, B., 2009. Prospective analysis of innovation systems. Identifying technological and organizational development options for biogas in Switzerland. Res. Policy 38, 655–667.

Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Policy 41, 955–967.

Markard, J., Hekkert, M., Jacobsson, S., 2015. The technological innovation systems framework: response to six criticisms. Environ. Innov. Soc. Trans. 16, 76–86.

Markard, J., Truffer, B., 2006. Innovation processes in large technical systems: market liberalization as a driver for radical change? Res. Policy 35, 609–625.

Markard, J., Truffer, B., 2008. Technological innovation systems and the multi-level perspective: towards an integrated framework. Res. Policy 37, 596–615.

Meyer, J.W., Rowan, B., 1977. Institutionalized organizations: formal structure as myth and ceremony. Am. J. Sociol. 83, 340–363.

Olzem, B., 2008. Unschuldiger Prügelknabe. Biogas Journal 01/08, 24–26.

Ott, M., 2003. Editorial: EEG, EEG, immer wieder EEG! Biogas Journal 01/03, 3.

Ott, M., 2004. Editorial: Endlich geht es los! Biogas Journal 01/04, 3.

Ott, M., 2007. Editorial: Liebe Mitglieder, liebe Leser. Biogas Journal 02/07, 3.

Pellmeyer, J., 2006. Editorial: Wirtschaftliche Alternative zur konventionellen Landwirtschaft. Biogas Journal 03/06, 3.

Pellmeyer, J., 2008. Editorial: Mit kühlem Kopf und spitzem Bleistift. Biogas Journal 04/08, 3.

Pellmeyer, J., 2009a. Editorial: Mit den wärmsten Empfehlungen: Biogas! Biogas Journal, 3 (Special Issue "Grüne Wärme").

Pellmeyer, J., 2009b. Editorial: Planungssicherheit erhalten! Biogas Journal 04/09, 3.

Penna, C.C.R., Geels, F.W., 2012. Multi-dimensional struggles in the greening of industry: a dialectic issue lifecycle model and case study. Technol. Forecast. Soc. 79, 999–1020.

Pfeffer, J., Salancik, G.R., 1978. The External Control of Organizations: A Resource Dependence Perspective. Harper & Row, New York.

Rao, H., 1994. The social construction of reputation: certification contests, legitimation, and the survival of organizations in the american automobile industry: 1895–1912. Strateg. Manag. J. 15, 29–44.
Rao, H., 2002. 'Tests tell': constitutive legitimacy and consumer acceptance of the automobile:1895–1912. In: Ingram, P., Silverman, B.S. (Eds.), The New Institutionalism in Strategic Management. Emerald Group Publishing, Bingley, pp. 307–335.
Rao, H., 2004. Institutional activism in the early American automobile industry. J. Bus. Ventur. 19, 359–384.
Ruef, A., Markard, J., 2010. What happens after a hype? How changing expectations affected innovation activities in the case of stationary fuel cells. Technol. Anal. Strateg. Manag. 22, 317–338.
Sandén, B.A., Hillman, K.M., 2011. A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden. Res. Policy 40, 403–414.
Sarasini, S., 2013. Institutional work and climate change: corporate political action in the Swedish electricity industry. Energy Policy 56, 480–489.
Schmidt, A., Ivanova, A., Schäfer, M.S., 2013. Media attention for climate change around the world: a comparative analysis of newspaper coverage in 27 countries. Global Environ. Change 23, 1233–1248.
Schnell, H.-J., 2006. Editorial: Aufbruch in die Zukunft. Biogas Journal 04/06, 3.
Schnell, H.-J., 2007. Editorial: Nur gemeinsam geht es weiter. Biogas Journal 03/07, 3.
Schuh, H., 2011. Biostrom, nein danke!. Die Zeit, Hamburg, pp. 35–36.
Schulz, H., 1996. BIOGAS-PRAXIS: Grundlagen, Planung, Anlagenbau, Beispiele. ökobuch, Staufen bei Freiburg.
Scott, W.R., 2008. Institutions and Organizations: Ideas and Interests, 3rd ed. Sage Publications, Thousand Oaks.
Sperling, F., 2012. The angry countryside – the installation of biogas plants as a contested issue in a German region. In: Welz, G., Sperling, F., Blum, E.-M. (Eds.), Negotiating Environmental Conflicts: Local Communities, Global Policies. Kulturanthropologie Notizen, vol. 81, Frankfurt am Main.
Stiehler, W., Decker, T., Menrad, K., 2012. Side effects of biogas plants perceived by German citizens – an analysis of German (mass)media and an online survey in Bavaria. In: 20th European Biomass Conference and Exhibition, Milano.
Suchman, M.C., 1995. Managing legitimacy: strategic and institutional approaches. Acad. Manag. Rev. 20, 571–610.
Sühlsen, K., Hisschemöller, M., 2014. Lobbying the 'Energiewende', assessing the effectiveness of strategies to promote the renewable energy business in Germany. Energy Policy 69, 316–325.
Swanson, E.B., Ramiller, N.C., 1997. The organizing vision in information systems innovation. Organ. Sci. 8, 458–474.
Trojecka, A.E., 2007. Landwirte als Energiewirte? Bedingungen einer ökologischen Modernisierung der Landwirtschaft am Beispiel der Biogaserzeugung. Dissertation an der Universität Osnabrück, Köln.
Turnheim, B., Geels, F.W., 2012. Regime destabilisation as the flipside of energy transitions: lessons from the history of the British coal industry (1913–1997). Energy Policy 50, 35–49.
Van de Ven, A.H., 2005. Running in packs to develop knowledge-intensive technologies. MIS Q. 29, 365–378.
van Lente, H., Rip, A., 1998. Expectations in technological developments: an example of prospective structures to be filled in by agency. In: Disco, C., Van der Meulen, B. (Eds.), Getting New Technologies Together: Studies in Making Sociotechnical Order. , Berlin.
Wirth, S., Markard, J., Truffer, B., Rohracher, H., 2013. Informal institutions matter: professional culture and the development of biogas technology. Environ. Innov. Soc. Trans. 8, 20–41.
Wooten, M., Hoffman, A.J., 2008. Organizational fields: past, present and future. In: Greenwood, R., Oliver, C., Suddaby, R., Sahlin, K. (Eds.), The SAGE Handbook of Organizational Institutionalism. Sage, Thousand Oaks, CA, pp. 130–147.
Zimmerman, M.A., Zeitz, G.J., 2002. Beyond survival: achieving new venture growth by building legitimacy. Acad. Manag. Rev. 27, 414–431.
Zschache, U., Cramon, T., Theuvsen, L., 2010. Öffentliche Deutungen im Bioenergiediskurs: Eine qualitative Medienanalyse. Berichte über Landwirtschaft. Z. Agrarpolit. Landwirtsc. 88, 502–512.