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THE ANALYSIS OF INSTITUTIONS IN TECHNOLOGICAL INNOVATION SYSTEMS - A CONCEPTUAL FRAMEWORK APPLIED TO BIOGAS DEVELOPMENT IN AUSTRIA

Bernhard Truffer
Cirus, Eawag
bernhard.truffer@eawag.ch

Harald Rohracher
IFZ Graz
rohracher@ifz.tu-graz.ac.at

Jochen Markard
Cirus, Eawag
jochen.markard@eawag.ch

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The Analysis of Institutions in Technological Innovation Systems

A conceptual framework applied to biogas development in Austria

Harald Rohracher*, Bernhard Truffer**, Jochen Markard**

*) IFZ – Inter-University Research Centre for Technology, Work and Culture, Schlögelgasse 2, 8010 Graz, Austria; email: rohracher@ifz.tugraz.at, Tel.: +43 316 813909-24, Fax: +43 316 810274 (corresponding author)
**) Cirus – Innovation Research in the Utility Sectors, Eawag, Swiss Federal Institute of Aquatic Science and Technology, 8600 Dübendorf, Switzerland
email: Bernhard.truffer@eawag.ch; Jochen.Markard@eawag.ch

Abstract

The literature on innovation systems emphasises the role of institutions as a key explanatory variable for success or failure of innovations. In contrast to this high importance of institutions, there are only few systematic proposals for conducting institutional analyses. The present paper elaborates a framework for systematically identifying and assessing institutional structures in technological innovation systems (TIS). In particular, it emphasises the importance of couplings with contextual systems (regional, national, sectoral or technological) and elaborates how institutions enter into strategic considerations of TIS actors. Empirically, the framework will be applied to interpret the role of institutional structures, dynamics and strategies for biogas system dynamics in Austria. In conclusion, we outline promising research directions building on a more differentiated analysis of institutions in innovation systems.

Keywords: Innovation systems, institutions, socio-technical change, biogas

1. Basic requirements of an institutional analysis

In recent years, systemic concepts have gained increasing attention for explaining the course and success of innovation processes. Different types of innovation systems have been identified depending on the focus, level and purpose of analysis (see Chang and Chen, 2004, or Edquist and Johnson, 1997, for an overview), e.g. national innovation systems (Lundvall, 1992; Lundvall, 2007); various types of regional or territorial innovation systems (Moulaert and Sekia, 2003); sectoral innovation systems (Malerba, 2002) or technological innovation systems (Carlsson et al., 2002; Bergek et al., 2008a). A common feature of the different approaches is that institutions are identified as key explanatory factors for understanding why some innovation processes in certain regions, countries or sectors fare better than others (Edquist, 1997; Edquist, 2004).

However, the concept of institutions has turned out to be particularly challenging because different strands of research in economics and the social sciences have defined and applied the notion of institutions in different ways (see e.g. Hollingsworth, 2000; Campbell, 2004). Even in the much smaller field of innovation system studies different interpretations are abundant (Edquist and Johnson, 1997; Jacob, 2006). This conceptual vagueness has been criticized and several propositions have been made to arrive at a more straightforward concept and common understanding (e.g. {Edquist and Johnson, 1997; Edquist, 2005). Despite these efforts many analyses use the concept of institutions in innovation studies in a still very heterogeneous and often implicit way.

The present paper aims at proposing a more systematic approach to analyse the role of institutions with a focus on the development of technological innovation systems (TIS). In our analysis we follow a dynamic and actor-related concept of institutions which emphasises change and heterogeneity rather than the rigidity and independence of social structures. Generally spoken, institutions are rules or norms which regularize social behaviour – both in an enabling and in a restraining sense. They limit the range of possible (or desirable) activities and provide incentives for particular actions. Thereby they reduce uncertainty, coordinate actor strategies, facilitate the resolution of conflicts etc. By serving these functions institutions provide the stability necessary for the reproduction of society (Johnson, 1992, 26). In other words, institutions are “building-blocks of social order: they represent socially sanctioned, that is, collectively enforced expectations with respect to the behaviour of specific categories of actors or to the performance of certain activities.” (Streeck and Thelen, 2005, 9).

However, this stability is never absolute as institutions have to be constantly reconstructed and re-interpreted by individual and organizational actors (Giddens, 1984). “Only dead institutions do not change and only rarely do institutions change by themselves”, Marcussen and Kaspersen (2007, 183) write. So, institutions are not only dynamic but also subject to strategic intervention by actors. An important source for institutional change is the incoherence of settings (or fields) in which many different institutions interact. Schneiberg and Clemens (2006, 215) point out that acknowledging institutional heterogeneity as the norm rather than the exception pushes institutional analysis “to a much greater emphasis of agency, conflict, contingency and process.” Such approaches may be more realistic than models of long periods of institutional stability interrupted by short periods of institutional upheaval (Quack, 2006).

Our approach to institutional analysis should be able to fulfil the following three goals: (i) it has to propose a more differentiated and encompassing concept of institutions that act upon the course of innovation processes; (ii) it should allow addressing interdependency of a TIS with different context systems (national, regional, sectoral, technological); (iii) and finally, it should be able to reflect both the obduracy and the potential fluidity of institutional structures relative to strategies of different actors. Such a conception would represent a more stringent framework for understanding the mutual interdependencies of institutional structures and thus allow for more systematic and encompassing explanations of specific innovation trajectories.

The paper is structured as follows: Chapter 2 introduces the conceptual framework for doing institutional analysis. We first review the TIS literature with regard to their use of the concept of institutions, propose a differentiated typology of institutional structures and elaborate how couplings with different institutional context systems shape the further development options of a TIS. Chapter 3 presents a methodological procedure to sort out those institutional structures that are decisive for the future course of a technological innovation system at a certain point in time. Based on these conceptual elements, chapter 4 analyzes the recent development trajectory of biogas innovation systems in Austria and discusses the role of different institutional structures, dynamics and strategies that were important to shape its specific course. We conclude in chapter 5 by proposing a research program such a systematic analysis of institutions may entail in future work on technological (as well as other variants of) innovation systems.

2. Institutions in technological innovation systems

In the following, we shortly elaborate the way institutions have been dealt with in the TIS literature and identify shortcomings in these attempts. In a second step we introduce a more systematic concept for institutional structures and identify interactions with different contexts. Our institutional analysis of technological innovation systems thus aims at specifying different institutions and their dependency on contextual systems. This will be necessary in order to develop a strategic and dynamic approach to the role of institutions for technological innovation systems in the next chapter.

2.1 Institutions in the TIS literature

The emergence and growth of new socio-technical systems is well conceptualised under the concept of technological innovation systems, which have been defined as the "dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilization of technology." (Carlsson and Stankiewicz, 1991, 93).[1] In general, the TIS concept puts much emphasis on the role of institutions as one of the three main structural components along with actors (organisations) and networks (see e.g. Bergek et al., 2008a). Institutions are differentiated from organizations such as private firms, associations, NGOs, policy makers etc. Organizations, in contrast to institutions, can act and pursue strategies, while institutions cannot (Markard and Truffer, 2008a). They rather present the rules of the game (Edquist, 2005).

Explicit conceptual accounts on institutions can already be found in the seminal article by Carlsson and Stankiewicz (1991), in which the authors coin the term institutional infrastructure including, for example, "the political system, the educational system (including universities), patent legislation, institutions regulating labor relations" as well as "property rights, fundamental features of market organization, capital supply, collective bargaining, industrial and corporate organization, etc." (Carlsson and Stankiewicz, 1991, 109f). More recently, this focus on legal and regulatory dimensions has been extended to 'softer' institutional aspects rooted in norms, culture and cognition (frames) (Jacobsson, 2008: 1494) and the importance of institutional change and institutional alignment has been stressed as a key structural process (see also Bergek et al., 2008b) whereby new technologies gain ground. In the empirical analysis of TIS which focuses on the performance along a number of functional dimensions institutions are mainly taken into account as inducement and blocking

[1] See e.g. Markard and Truffer, 2008b for a recent review of the literature on technological (innovation) systems.

mechanisms. In a policy oriented article by Jacobsson and Johnson (2000), for example, institutions and so-called institutional failures receive a lot of attention as a key group of factors that may hinder the development and diffusion of new (energy) technologies. The TIS literature in fact holds a considerable variety with regard to the explicitness of institutional analysis and the types of institutions that are in the focus of empirical studies. As a general pattern one might say that studies with a focus on more established technological systems (e.g. Carlsson, 1997; Carlsson and Jacobsson, 1994) rather focus on institutional sectors[2] such as research and education or financial markets, whereas in the case of emerging systems (e.g. Jacobsson, 2008; Bergek et al., 2008a, Jacobsson and Bergek, 2004; Jacobsson and Johnson, 2000), the role of regulation and demand side policies together with processes of institutional alignment are more prominent. However, despite the prominent structural role assigned to institutions, institutional inducement and blocking mechanisms are identified in a rather haphazard manner in the context of specific case studies and are not systematically reviewed. As we will argue in this paper, our understanding of the growth dynamics of technological innovation systems and the opportunity structures for further development open to TIS actors could be significantly enhanced by a more systematic screening of different institutional dimensions internal and external to the TIS and by identifying couplings and interactions of the TIS with different institutional environments as a major element in the process of institutional alignment and change.

2.2. Differentiating institutional structures

Institutions as the “more enduring or recurrent features of social life” (Mohr and White, 2008: 488) are one of the fundamental concepts of social sciences which can be traced back to the middle of the nineteenth century (Scott, 2008: 428). Due to the generality and variety of phenomena this concept addresses, definitions differ between theoretical traditions and are often ‘vague, diffuse, and mutually inconsistent’ (Jessop, 2001). Campbell (2004; 2004)identifies rational choice institutionalism (important e.g. in economic neo-institutionalist approaches), organizational institutionalism and historical institutionalism as the currently dominant strands of institutional concepts with sometimes opposing views on the general nature of institutions and constitutive elements (whether e.g. cognitive schemes are institutions or not).

Drawing mainly on organizational and economic institutionalist concepts we suggest a rather pragmatic differentiation of institutional structures which on the one hand distinguishes three different institutional pillars according to Scott (2001) and on the other hand identifies two

[2] See Chapter 4 for a definition of institutional sectors.

types of coherent institutional ensembles which are of special relevance for the development of technological innovation systems. For the latter, we mainly draw on classification schemes suggested by Hollingsworth, 2000, Ostrom, 2005 and Williamson, 1998 and institutional structures highlighted in the innovation systems literature (e.g. Lundvall, 2007, Malerba, 2004).

Level 1: Institutions

Following Scott (2001), we suggest to distinguish three 'pillars' of institutions: regulative, normative and cultural-cognitive institutions.

Regulative institutions such as laws, decrees, codes of conduct, contracts or technical norms are often backed by sanctions. Regulative institutions also encompass incentive schemes (taxation, subsidies, public procurement policies etc.). As a rule of thumb, regulative institutions determine what is allowed and what is not allowed; they can also be referred to as formal institutions. Normative and cultural-cognitive institutions, on the other hand, are informal institutions.

Normative institutions encompass societal norms, values, standards of good practice, work norms, conventions etc. Norms are not backed by formal sanctions but can better be characterised as socially binding expectations. Normative institutions set out what is right and what is wrong.

Cultural-cognitive institutions include cognitive frames, mental paradigms, visions, expectations, broadly shared role models, perceptions, etc. They shape what is thinkable and what is unthinkable. In the context of innovation studies, the role of 'mental frames' such as technological paradigms (Dosi, 1982) or Leitbilder (Dierkes et al., 1996) has been emphasized. Or, studies on the dynamics of collective expectations have shown their structuring power for innovation strategies and network formation (van Lente and Rip, 1998). An example of a cognitive structure important for national innovation systems is the time horizon of agents,e.g. the prevalence of short-term or long-term orientation in economic decision making (Lundvall et al., 2002).

It should be emphasised that all these institutions have a "definite spatiotemporal extension. They emerge in specific places and at specific times, operate on one or more particular scales with specific temporal horizons of action (…)." (Jessop, 2001: 1227). In our case of analysing institutional TIS contexts, relevant formal or informal institutions are often specific to the regional, national or international level, but they also span different technologically or

functionally defined realms, such as specific technological innovation systems or sectoral systems of production and consumption. In a temporal dimension especially informal institutions such as cultural norms, frames or traditions may be stable over a very long time, while other institutions (often formal ones such as regulations, but also informal collective expectations etc.) may change more quickly.

Level 2: Institutional arrangements

Institutional arrangements are more or less aligned sets of formal and informal institutions (level 1) that structure certain action arenas (Ostrom, 2005). Of particular interest are institutional arrangements that coordinate interactions. These may be specified as markets, hierarchies, networks, associations and communities (Hollingsworth, 2000). Each of these coordination mechanisms is characterised by a specific organisational structure, rules of exchange, and individual/collective means of compliance.

An important point is that social and economic interactions are in general coordinated by more than one type of institutional arrangement. Even in the most competitive sectors not only markets exist: firms will in general work as clearly structured hierarchies, technological standards will be negotiated in professional associations, certain domains will be strongly regulated by the state and engineers will meet in clubs where they exchange experiences and new ideas. This mix of configurations of institutional arrangements provides for a certain incoherence in governance, but at the same time holds the capacity to adapt to new circumstances (Hollingsworth, 2000, 613).

Specific combinations of institutional arrangements can be used to characterise different basic styles for the coordination of economic systems: At the national level Hall and Soskice (2001) distinguish liberal and coordinated market economies in their varieties of capitalism approach,[3] whereas Dolata (2008) classifies patterns of interaction in sectoral innovation systems as competitive, cooperative, negotiation-oriented or civil-society-oriented.

Level 3: Institutional sectors

Institutional sectors are more or less coherent bundles of institutions and institutional arrangements, which produce specific (functional) outputs for society. Institutional sectors represent the highest level of aggregation in our typology. They focus our view at the institutional landscape on specific support functions (e.g. external provision of financial capital, of knowledge, of skilled labour force etc.) for innovation processes.

Examples for institutional sectors are the

[3] On the implications of these arrangements for technology development and innovation, see Werle, 2005.

- Financial system (incl. structure of the capital market)
- Research system: university research, research institutes, R&D intensity and R&D organisation (including university-industry links), research funding schemes
- Education and training
- Business system: firm structures, industrial relations system (e.g. labour markets); Inter-firm relationships, co-operation of firms (supply chain, user-producer interactions)
- Legal system

The role of institutional sectors is especially emphasized in the analysis of national system of innovation (see Lundvall, 1992; Archibugi and Michie, 1997) which in turn are an important part of the institutional context that shapes the development of technological innovation systems.

2.3. Institutional analysis of the TIS and its context

According to the innovation systems literature, relevant institutional structures shaping technological change can be found in different spatial, sectoral and technological contexts. In the following, we distinguish institutions that have emerged with a novel technology and do not exist without it (e.g. design standards, specific expectations) from institutions that are rather independent[4] of the innovation. The former will be referred to as TIS internal institutions, while the latter are external or context institutions.

For a systematic screening of institutions in the context of a TIS we thus suggest using both, the typology of institutional structures described above and a differentiation of spatial and sectoral scopes (cf. Table 1). From a spatial perspective, context institutions can be distinguished at a national, sub-national and international scale. The national scale may be characterised, for example, by a particular research and education system, a specific (e.g. entrepreneurial or political) culture or specific IPR regulations. International institutional structures include trade agreements, the Kyoto protocol, regulations of the European Union etc. Furthermore, institutions may be differentiated at a sub-national scale as they create specific regional context conditions for a certain technological trajectory, for example.

As second approach to identifying contextual institutions we may adopt a sectoral focus. Which sectors are of prime concern for the TIS can be determined by existing as well as potential relationships (e.g. input-output relations) with the core technology (Konrad et al.,

[4] This does not imply that they cannot be influenced or changed by TIS actors that promote the focal technology (see also Section 3.1).

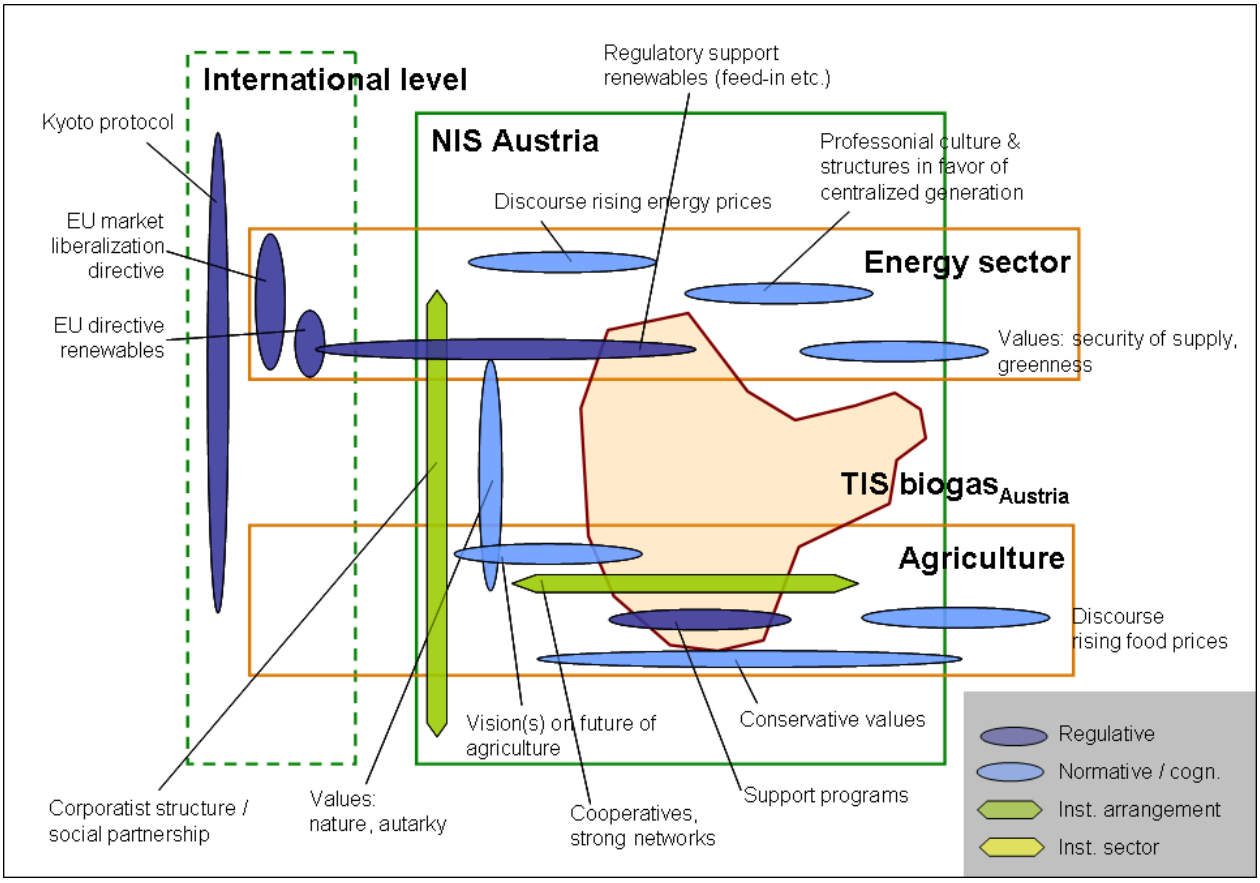
2008). Many TIS have one dominant sector of reference (e.g. wind energy TIS and the electricity sector). Other cases such as nano- or bio-technology relate to many different sectors and the corresponding institutions. Institutions at the sectoral level include specific regulations, prevailing self perceptions, dominant technological paradigms and design rules or broadly shared visions about future opportunities and threats looming for the sector (Table 1). Also, sector specific institutional arrangements may condition development potentials for a TIS. As an example, we can imagine a community oriented internal culture in a renewable energy TIS that is confronted with the regulated monopoly in the electricity sector and hierarchical institutional arrangements.

Scope	Type(s) of prevailing institutional structures	Examples
Context institutions		
International institutional regimes	Mainly regulative institutions	o International agreements (e.g. WTO, Kyoto agreement) o European Union regulations and directives
National (and/or regional) contexts	Regulative, normative and cognitive institutions	o Innovation and technology policy o Perception of environmental problems o Major mobilizing myths o Rule of law
	Mix of institutional arrangements	o Role and power of the state o Dominant orientation of product sectors o Negotiation of interests
	Institutional sectors	o Finance (e.g. availability of venture capital) o Research and education (e.g. specific research institutes, industry orientation of public research) o labor market, business system, legal system, etc.
Sectoral systems of production and innovation	Regulative, normative and cognitive institutions	o Sector specific regulations of products, environment, risks, etc. o Visions and self perceptions of dominant actors in the sector o Perception of product characteristics by producers and users
TIS internal institutions		
	Emerging internal institutions of the evolving socio-technical system (Institutional arrangements, rules and, norms, etc.)	o Coordination mechanism between innovators (e.g. community, negotiation, competition); o specific promotional policies; o establishment of major mobilizing myths to which participating actors adhere

Table 1: A scheme for analysing the institutional structure of a technology-specific innovation system and its context

The relationships between a TIS and its institutional context are manifold. A TIS may either be well aligned with and supported by institutions determined in different contexts or it can be dominated by frictions and institutional mismatch. Instances of institutional match or

mismatch are referred to as *coupling domains,* in the following.[5] We can think of the institutional context as landscape constituted by different coupling domains that provides opportunities as well as constraints for TIS development. As a TIS grows and matures its structural components change as well as the institutional landscape - partly due to strategic interventions by TIS actors (cf. section 3.1), partly due to autonomous dynamics of contextual systems. The following figure illustrates the institutional landscape of a TIS for the case of the Austrian biogas TIS at a specific point in time (derived from the analysis presented in chapter 4).



* The extent of the institution symbols indicates their relative scope of influence within the respective innovation system.

Figure 1: Technological innovation system (TIS) and different kinds of institutions in its context in spatial (national, international) and sectoral terms applied to the Austrian biogas TIS. Map is derived from the empirical analyses elaborated in chapter 4.

Summing up, our scheme for screening institutional structures differentiates institutions by their type and by different couplings with context systems. This scheme describes a potentially vast array of institutions in each and every specific empirical case. Selecting the relevant institutions depends on the TIS at hand and on the related research question. To

[5] Note that the notion of 'coupling' does not imply a supportive relationship between TIS and context. A coupling may also be characterized by frictions and barriers for specific development trajectories.

this task of selection, we will turn in the following. Furthermore, we also address the role of actors (e.g. as institutional entrepreneurs) in order to account for institutional dynamics that may be less apparent in the above representation of the institutional landscape.

3. Institutions as opportunity structures

3.1 Institutional dynamics and interactions between agency and structure

The picture of institutional structures relevant to the development and diffusion of new technologies, which we have drawn so far, is a rather static one. The literature has criticised the tendency to analyze institutions in an overly structuralist perspective and more recent work has therefore focused on processes of institutional change, on organisational heterogeneity and on the relationship between interests and institutions (see DiMaggio, 1988, Beckert, 1999, Scott, 2008). A general tenet here is that institutional structures are only seemingly constant. If analysed more closely they are continually tested and changed -- often in subtle ways masked by the stability of formal institutions (Hall and Thelen, 2009). These dynamics stem from different sources: deliberate strategies of actors and frictions among institutional structures that relate to different application contexts. As Jessop puts it, institutions "have both microfoundations and macrocontexts. They are sustained and instantiated in individual, organizational and interorganizational activities but they are also embedded in functionally differentiated institutional orders (…)." (Jessop, 2001: 1231). Effective institutional analysis has to take account of this interplay between agency and structure, culture and practice and across levels of social organization (Mohr and White, 2008: 487).

We therefore have to specify in the following how agency and institutional dynamics can be incorporated into our framework. Agency is systematically addressed in the literature on institutional entrepreneurship (DiMaggio, 1988). Institutional entrepreneurs "have an interest in specific institutional structures and (...) command resources which can be applied to influence institutionalised rules" (Beckert, 1999). From a resource dependence theory perspective Oliver (1991) has pointed out a whole repertoire of strategic responses (such as acquiescence, avoidance or manipulation) available to actors confronted with institutional demands. As Beckert (19991999) proposes, institutional entrepreneurship prevails especially in situations of high uncertainty. This is clearly the case during early growth phases of TIS or when established sectors (e.g. energy supply or agriculture) are under pressure (e.g. by issues such as climate change or security of supply).

Institutional dynamics may result from frictions among coupled institutions. In the case of emerging technologies, frictions may be especially important as novel supporting institutions do not necessarily match the prevailing institutional structures in different spatial and sectoral contexts. The institutional context to which an emerging TIS has to relate is often structured into a large number and variety of institutions. These institutions may provide incentives (e.g. through specific research programs) to develop the technology into a certain direction. Often however, context institutions represent barriers for specific technological trajectories. Innovators may either try to actively influence these to the affordance of their technology or they have to adapt their development strategy to match the requirements of the respective context system. TIS actors, in other words, "are conditioned simultaneously by multiple institutions, often in different spheres of the political economy" (Hall and Thelen, 2009: 10).

As a consequence, the institutional context and its relationship with the TIS may be interpreted as an opportunity structure for the future development of a TIS. Which strategy an innovator will perform against this background of opportunities (and constraints) depends on the actor's interests and resources, but also on its ability to influence specific contexts (e.g. by lobbying in national political arenas, by influencing regulatory processes or by getting attention in public discourses).

3.2 Selecting institutional structures with regard to their strategic relevance

This strategic interpretation of the institutional landscape can guide us in sorting out relevant institutional structures of a TIS at a specific point in time. A systematic screening of all relevant institutional structures would otherwise lead into an overwhelming thicket of specific rules, governance structures and institutional sectors that prevail in any specific empirical case. As a first selection criterion, we focus on those institutions that have a high impact on TIS performance.

Recent contributions to innovation system studies have elaborated on the system functions framework in order to assess TIS performance and to derive recommendations of how to improve the performance (Bergek et al., 2008a, Hekkert et al., 2007). Even though it has proven difficult to determine clear-cut benchmarks for well working innovation systems, system functions provide a framework with which we can analyse and group the strengths and weaknesses of a TIS. As innovation scholars are just at the beginning of unraveling the relationships among system functions and between functions and structural components - be they actors, networks or institutions - we suggest relying on expert knowledge of TIS actors as an empirical approach to identifying relevant institutions.,

Relying on a recent proposal by Bergek et al., 2008a, we propose the following procedure: As a first step, we ask experts for key factors (drivers and barriers) that, in their view, have been relevant for the development of the TIS at hand (Table 2, column 2). System functions (column 1) guide us in this search. In a second step, we analyse which structural TIS elements played a major role for each of these drivers and barriers (column 3). Here, our focus is on institutions but we also include e.g. strategic actions of TIS actors or technological particularities. Then we determine with which context domain specific structural elements are coupled. (column 4). The forth step is an assessment of how critical the influence of a driver or barrier on overall TIS performance is (column 5). This final assessment is again based on the judgement of TIS experts but also includes conceptual considerations. As a result of this analysis, we can arrange the information obtained in a tabular structure (see below).[6]

TIS-function	**Drivers and barriers**	**Structural elements involved**	**Scope of structural elements**	**Criticality**
Knowledge development and diffusion	- e.g. convergence of search routines - e.g. strong intermediaries - ...	[actors; networks; institutions]	[n/a, national; regional; international; sectoral; TIS internal]	**[++, +, 0, -, --; *]**
Resource mobilization				
...				

Table 2: Analysis of functional deficits and critical elements. Brackets "[ ]" encompass lists of qualifications that may apply to the respective drivers or barriers. Criticality is codified as: ++ positive, supportive contributions, strengths; -- major deficiencies, barriers, weaknesses; ++/-- instabilities; 0 no specific contribution; * indirect effect important

With these specifications, we may now rearrange the information in table 2 in such a way as to emphasize the relative role of different context systems (see table 3). Symbols stand here for the dependency of TIS performance on institutional structures coupled with the different contextual systems and result from the aggregate supportive (+), neutral (0) or hindering (-) contribution of these couplings to system performance. Table 3 relates the institutional couplings to those system functions that are most likely to be affected. Maps like the one represented in figure 1 may then be derived from the analysis this information.

[6] Note that this table is primarily a practical tool for organising our data. For example, we do not imply that there is a one-to-one relationship between structural elements and specific TIS functions.

contexts / *Functions*	***Internal***	***Sector 1***	***Sector 2***	***National***	***Regional***
Knowledge development and diffusion	**++/-**	**-/-/-**	**0**	**0**	**+**
Resource mobilization	**0**	**++/-**	**++/--**	**+/-**	**+***
...					

Table 3: Mapping of relative importance of different contexts (for the definition of codes in table cells see caption of table 2).

The codes in the table cells sum up the relative importance of the different internal and contextual institutions for system performance. Reading the table along the columns allows assessing the role of specific contexts for the further development of the TIS. Reading the lines emphasizes the relative importance of different contexts for a specific system function. Both readings combined allow specifying institutional strategies for improving system performance and explicit with regard to institutional couplings. Table 3 does not map a static situation, though. Rather it has to be read as a snapshot of a dynamically evolving institutional landscape and as a map of institutional couplings that may be addressed strategically by TIS actors. These actors can either adapt their favoured socio-technical configuration, expand and/or alter the composition of actors or networks or adapt/create new internal institutions. Alternatively, they can try to influence framework conditions by acting as institutional entrepreneurs.

The previous two chapters have sketched out a scheme for analysing the institutional landscape of a TIS and the dynamic interactions between a TIS and its contexts. This type of analysis could be applied with hindsight in order to explain certain institutional influences on TIS development and actor strategies. More importantly, it may serve to compare different institutional context structures synchronically (e.g. comparing different national promotional policies) or diachronically (e.g. comparing the role of institutional environments in different phases of development). It may finally also serve for prospective purposes, for instance for specifying institutional pressure fields for future development strategies. In the space of the present paper, we have to restrict ourselves to the first task namely the analysis of institutional influences on a specific TIS development trajectory at different points in time. Implications for comparative and prospective applications of this framework may only be sketched as an outlook in the final chapter.

4. The role of institutions in the Austrian biogas innovation system

We want to illustrate our approach to institutional analysis with the case of biogas digestion in Austria. Biogas is a renewable energy carrier that can be produced by different technologies and from a variety of organic substrates. In the following, we concentrate on anaerobic digestion technology, which can be used for biogas production from manure, agricultural residues, organic wastes or energy crops. The biogas can be used for the decentralized generation of electricity and heat (currently the dominant way) but it can also be refined and fed into the natural gas grid for further use.

Biogas is a well suited example as its recent development shows quite distinct patterns in different countries (Jacobsson, 2006; Raven and Gregersen, 2007; Negro, 2007, Markard et al., 2009). Countries strongly differ in the level of biogas utilization, technological configurations, main organic substrates, the actors involved and the institutional structures supporting and shaping biogas development. Furthermore, biogas technology is relevant for a number of economic sectors. These include electricity supply, gas supply, heating, agriculture, waste management and transport (fuels). So, we would expect a rather dense and diverse field of potential institutional structures that are of relevance for the TIS actors. Austria is a good application case as it has a rather lively history of biogas development over the past decade which on the one hand shares typical development patterns with other European countries but at the same time shows specific development paths (e.g. dominance of energy crops and agricultural plants) which – as we will point out below - at least to some extent can be related to the institutional characteristics of the Austrian social, economic and political context.

The case study is based on statistical material (e.g. Ulz, 2003; LEV, 2005; EurObservER, 2007) and studies of the situation of biogas as an energy carrier in Austria (e.g. Puchas, 2003; Veigl and Tretter, 2005; Ahrer et al., 2006; Braun, 2007) and on ten semi-structured interviews with key actors with respect to biogas development in Austria (e.g. chamber of agriculture, energy agencies, R&D programme management, energy companies). Interviews were analysed along our classification scheme for institutions and their impact on innovation system functions to identify the current development stage and performance of the biogas innovation system and the most important contextual influences on biogas development in Austria.

4.1 Recent developments in the biogas TIS in Austria

While the start of biogas for heat or electricity generation in Austria dates back to the oil price shocks in the late seventies and early eighties of the last century, biogas production has seen a significant growth only since the beginning of this decade and particularly with the introduction of a law on 'eco-electricity' with favourable feed-in tariffs for electricity from biogas in 2002 (respectively 2000 at provincial level). In 2007 roughly 600 biogas plants in Austria generated a total of 445 Gigawatthours (GWh) of electricity which amounts to about 0.9% of the total Austrian electricity generation. Electricity production from biogas saw a sharp rise from 2005 (70 GWh) to 2006 (410 GWh), which was mainly triggered by a revision of the feed-in conditions.[7] In 2006 Austria was ranked number 5 of EU-27 countries with respect to biogas production per capita (and no. 6 in absolute figures). Compared to other countries a very high proportion of plants use energy crops as feeding material (usually in combination with liquid manure), which means that the agricultural sector by far outweighs the waste sector in its importance. Furthermore, Austria even ranks second within the EU with regard to the absolute amount of biogas production from decentralized agricultural plants, municipal solid waste biogas and centralized co-digestion plants. (EurObservER, 2007).[8] Plant size has been continually increasing but currently centres on a medium level size of 250-500 kW.

However, in recent years the level of biogas feed-in tariffs has been discussed controversially based on mainly two issues: (1) its potential contribution to rising electricity prices (and thus financial burden on end-consumers and industry) and at the same time indirect subsidization of farmers, and (2) perceived land-use conflicts between food production and energy generation. These controversies have led to a deadlock with respect to the necessary revision of the feed-in law and a phase of regulatory uncertainty.

4.2 Institutional structures and system performance

The 'functions of innovation systems' approach provides us with a tool to analyse key performance issues and fields of activities important for the sustainable growth of the biogas technological innovation system. Table 4 assigns different statements about characteristics, strengths and weaknesses of the Austrian biogas system as identified in the interviews to the main innovation systems function they relate to (though they often affect different functions simultaneously). Moreover, these statements are categorized by the structural elements they represent and the links they have to specific context systems. Finally these issues are

[7] This sharp rise in generation figures moreover has been somewhat exaggerated by a change in data collection.
[8] Absolute figures listed by rank are Germany 980, Austria 103, Denmark 57, Italy 42, the Netherlands 29, Spain 26 (measured in MTOE). All other EU countries are below 10 MTOE.

assessed in terms of the criticality they have for the performance of the biogas TIS (see chapter 3.2).

TIS-functions	TIS-Performance, strengths / deficits	Structural elements involved	Coupling domain: Type and scope of institution	Criticality
Knowledge development and diffusion	- mature technologies; incremental improvements in efficiency and quality of different system components	Technology		+
	- more research needed (and underway) to optimise agricultural production of feeding material without compromising food production ('intermediate crops')	Actors		-
	- Intermediary organisations in place at national and regional level to facilitate knowledge flow; networking initiatives to create 'knowledge networks' on biogas	Actors/institutions	Institutional arrangement internal	++
	- Biogas research well integrated into national and international research programmes on renewable energy	Institutions	Regulative / institutional sector Other TIS (national/international)	+
	- Further research and optimisation needed downstream – methane fuelled cars, fuel cells etc.	Actors/Institutions	Regulative / institutional sector Other TIS/sectors	-
Resource mobilization	- financial support programmes for farmers who invest in biogas plants	Institutions	regulative sector (agriculture)	+
	- support structures of chamber of agriculture for finding competent planners, getting planning permissions etc. (reduction of transaction costs)	Institutions	Regulative/normative sector (agriculture)	++
	- policy support from chamber of agriculture; regional and national energy agencies and renewable energy advocacy groups	Actors		++
	- biogas as fuel exempted from energy taxation	Institutions	regulative Sector (gas)	+
	- favourable feed-in tariffs for electricity from biogas; however, tariff system has been under review for several years, uncertainty about further regulation; feed-in tariff only for CHP plants	Institutions	regulative Sector (electricity)	++ / --
	- high dependence on price of feeding materials; substitutable with food production and thus affected by high volatility of prices for agricultural products	Technology		-
	- price of bio-methane not competitive with natural gas prices	Technology		--

Influence on the direction of search	-	standardised plant designs in wide use	Institutions	Normative, cognitive internal	+
	-	vision of biogas plants integrated in regional agricultural production systems, i.e. small to medium plant size (250-1000 kW) – decentralised, farm-level biogas generation; dominance of energy crops (in combination with manure) as feeding material; focus on intermediate crops	Institutions	cognitive, cultural and institutional arrangement sector (agriculture)	+
	-	vision of making biogas production more independent from local heat demand by feeding it increasingly into the natural gas grid	Institutions	cognitive internal	+
	-	biogas seen as element of climate gas mitigation strategy and energy security (though importance of contribution disputed)	Institutions	Normative, cognitive national (energy security)	++
Market formation	-	strong market growth in European comparison (see above)	Actors/institutions	internal	+
	-	market growth so far predominantly stimulated by electricity feed-in level	institutions	regulative sectoral (electricity)	++
	-	market formation restricted by need to find local demand for heat from cogeneration and thus meet feed-in tariff criteria;	Institutions/Technology	regulative internal, sector (electricity,)	--
	-	market formation restricted by need for limited transport distances of feeding material and opportunities to feed-in biogas to existing natural gas grid	Technology		-
	-	stable development of actor-networks and competencies etc. put at risk by market volatility (e.g. prices of agro-products; changes in feed-in tariffs) resulting in a standstill of investments and reorientation of actors	Institutions	regulative internal	--
Entrepreneurial experimentation	-	rather low level of experimentation due to rather 'conservative' approach of agricultural sector (biogas rather as by-product)	Institutions	normative, cognitive sector (agriculture)	-
	-	some experimentation with feeding into gas grid etc. and new business models (utilities as plant operators; use as car fuel etc.)	Actors		+
	-	R&D and demonstration projects for feeding biogas into the natural gas grid; incremental improvements of cleaning technologies (e.g. membrane technologies)	Actors/Technology		+
Development of positive external economies	-	good knowledge flow within agricultural sector	Institutions	cognitive, institutional arrangement sector (agriculture)	+
	-	contribution to rural development	Institutions	normative national/regional	+
Legitimation	-	legitimatory policies and discourses: climate change mitigation; regional energy autarky; rural (agricultural) economic development	Institutions	Normative national (energy, climate)	++
	-	de-legitimated through linkage to rising food prices; land use competition; biofuel-controversies	Institutions	normative national (food and agriculture)	--

Table 4: Functional analysis of the biogas TIS in Austria (institutional influences in grey)

4.3 Institutional coupling domains and linking structures

Table 4 above has analysed the different structural elements (including institutions) which expert interviewees identified to have an important influence on TIS development. For each of these elements table 4 also identifies whether the influence is institutional (or e.g. mainly actor-related); which type of the context it belongs to (e.g. agricultural sectoral system or national innovation system) and how critical -- in a positive or negative sense -- the influence is on further TIS development. Table 5 re-arranges this information for institutional influences and consequently enables us to give an aggregated assessment of the relative importance of different contexts for the performance of the Austrian biogas innovation system.

	Internal	***Agriculture***	***Electricity***	***Gas***	***National / Regional***
Knowledge development and diffusion	++	-	0	0	+
Resource mobilization	0	++/+	++/--	+	+
Direction of search	+/+	+	0	+	++
Market formation	+/--	0	++/--	0	0
Entrepreneurial experimentation	0	-	0	0	0
Positive externalities	0	+	0	0	+
Legitimation	0	0	0	0	++/--

Table 5: Dependence of system performance on couplings with contextual systems.

Tables 5 shows that signals from different contexts, be they sectoral or geographical, are often contradictory and inconsistent, but they in many cases also reinforce each other: Moreover, these contexts are not always in line with emerging TIS institutional arrangements. Table 5 gives us an indication of the relative importance of different contextual systems and their institutional coupling with the biogas system:

- At the sectoral level, the institutional influence of two sectors stands out: the agricultural sector due to a close institutional integration of the biogas TIS into agricultural sector structures on the one hand, and the electricity sector (due to integration in sector regulation and feed-in tariff support system, with some further supportive influence from the gas sector. These sectoral contexts have a particularly

strong influence on resource mobilization and market formation as tables 4 and 5 indicate.

- The national level has a strong influence on search directions and the legitimation of the biogas TIS. Moreover, national institutional structures exert important indirect influences, as e.g. electricity sector regulations are part of broader national and international regulatory frameworks and traditions.
- Internal institutional structures have mainly been developed with a focus on market formation, search direction and knowledge development and dissemination.
- Moreover, table 5 draws our attention to various inconsistencies and instabilities in the coupling with institutional contexts (indicated by the simultaneous occurrence of positive and negative criticalities), especially due to the stop-and-go development of feed-in regulation at electricity sector level and to contradictory discourses and normative orientations in the perception of biogas at national level.

Based on this summarizing identification of institutional influences on the development of biogas in Austria, we will concentrate our further discussion on three groups of contextual institutions which are critical areas and thus of high relevance for actor strategies to support or prevent the further growth of biogas production:

- Regulative institutions at sectoral and national level: Supportive and stable vs regulatory volatility
- Normative and cognitive institutions at national level: Legitimatory public discourses / visions (climate change, regional development) vs de-legitimatory discourses (electricity prices; land use conflicts)
- Integration into sectoral structures (congruence of institutional arrangements as well as cognitive and normative institutions, e.g. professional cultures, visions and expectations): Alignment with agricultural vs energy (electricity, gas) system institutions

Regulatory contexts

The regulation of energy markets including support schemes for renewable energy without doubt is a critical institutional context for the further development of the Austrian biogas TIS. While favourable feed-in tariffs have been a crucial factor to make biogas use economically viable, stability of regulatory institutions turns out to be the Achilles heel of biogas development and its potential of further growth.

Institutions such as liberalised electricity markets and specific feed-in tariffs and other instruments (electricity disclosure etc.) to support renewable energy sources are well embedded at multiple levels. As nested institutional hierarchies regulatory structures are consecutively specified from an EU level regulatory framework (e.g. directives on market liberalization or on the promotion of electricity produced from renewable energy sources and cogeneration of heat and power) to national regulatory systems (e.g. the Austrian eco-electricity law) and regulations in support of specific technologies or energy sources (e.g. feed-in tariffs and regulations for electricity from biogas). The coupling between the different levels (EU, national, technology-specific) still allows for substantial margin in the design and implementation of biogas regulations, e.g. different national designs of feed-in and quota systems, or different tariff levels and support for electricity from biogas (feed-in tariff paid per kWh; guaranteed duration of this support; definition of plants qualifying for support scheme etc.).

Over the last decade the implementation of this regulatory support scheme in Austria has resulted in a stop-and-go policy about the level and specific conditions for the feed-in tariffs (and the period of time they are paid). While this initially contributed to a remarkable growth of biogas plants (plants commissioned between 2000 and 2004), this phase has been followed by a period of uncertainty with several attempts to get new regulations passed in parliament. From the perspective of biogas actors the currently suggested support levels would seriously impede further investments in electricity from biogas, and due to higher prices for agricultural products even drive many existing plants out of the market. As a consequence of this slump in plant growth beginning institutionalisation of e.g. competencies of planners could fall back on earlier levels again.

(De-)Legitimation by public discourses

The stability and future of the regulatory context of the biogas system and the public support these technologies get is to a large extent influenced by its links with national legitimatory and de-legitimatory discourses and by its integration and couplings with energy and agricultural sectoral structures. With respect to national discourses and orientations biogas support measures are legitimated by a growing awareness of the threats of climate change and resource depletion as well as favourable public attitudes to regional structures of energy generation and the perception of Austria as a ‘green country’. Such deeply entrenched self-perceptions and future visions without doubt have gained an institutional quality (as

normative institutions and cognitive orientations) which frame policy and public perception alike. These discourses are also invoked by biogas actors and their supporters in the agricultural sector to legitimise subsidies or more favourable regulation. In contrast, there exists also a discourse about the problem of rising electricity prices (due to feed-in tariffs) and the impact of increased use of biomass and biofuels production on food prices (in line with the perception of a generally highly subsidised agricultural sector). Again, different actor groups strategically invoke such discourses, e.g. the national electricity regulator warning of unduly high electricity prices used to support the agricultural system. These discourses about environment and distributional justice are linked to broader national cognitive orientations (identity, self-perception, long-term expectations etc.) and belong to the national institutional make-up.

Integration into sectoral contexts

In general, the institutional couplings and interactions of the biogas system with the Austrian agricultural sector are rather strong and affirmative. The main driver for these institutional alignments and the receptiveness of the agro-sector towards biogas lies in the long-term orientation of the sector and the need to develop new sources of income and legitimation for farmers. In the Austrian corporatist political system the agricultural sector is well integrated into Austrian legislative procedures via the chamber of agriculture and definitely uses this position to influence feed-in regulations and other support measures for biogas. The chamber of agriculture also provides administrative support infrastructure for setting up contracts, assessing economic viability of biogas projects etc. Most probably influenced by the constituency of the agro-sector, Austria was the first country to introduce a feed-in scheme for biogas from energy crops (and not only manure or bio-wastes). The specific characteristics of the agro-sector in Austria (small farm sizes with a tradition of cooperation) thus have strongly shaped the technological designs and organizational configurations in the biogas TIS and have led to a high congruence of institutional arrangements, orientations and professional cultures. As a consequence, the majority of plants are rather small and operated by single farmers or groups of farmers. However, these characteristic configurations at the same time limit further development as larger generation units or the alternative use of biogas as fuel for cars depend on the coupling of the biogas TIS with actors and institutions of the energy sector.

The energy sector consists of sub-sectors for electricity, gas and heat provision. So far, the electricity sector has shown little receptiveness for biogas due to influential regulative, normative and cognitive institutional structures, which still are geared towards central

electricity generation (e.g. professional cultures, planning procedures, normative orientation). Smaller local utilities are sometimes an exception in this respect as biogas offers an opportunity to strengthen their local/regional embeddedness. In the sub-sector of gas supply, on the other hand, expectations and visions are emerging with respect to the greening of the sector, security of supply and new business opportunities for green transport fuels (substituting petrol and not natural gas). These could work in favour of the biogas TIS and the feed-in of methane gas into the gas grid instead of producing green electricity. From the perspective of TIS actors, a closer alignment with the gas sector could provide a better distribution of biogas and other uses such as biogas as a transport fuel. However, gas suppliers planning to extend their biogas business report reservations from customer groups (e.g. taxi companies planning to switch to biogas) against biogas from agricultural products as in the current public discourse this might not be perceived as sustainable.

4.4 Strategic implications for the Austrian biogas TIS

The current situation of the biogas innovation system thus to a significant extent depends on institutional contexts and interactions at national and sectoral levels. The institutional contexts provide resources and orientation for the specific development and growth paths of the biogas system, but they also incur the TIS with often contradictory and inconsistent demands such as contradictory discourses or differing requirements of sectoral institutional alignment. These inconsistencies and distinctive demands create a tension field around the evolving biogas TIS and provide levers and inroads for strategic activities of different stakeholder groups.

In the biogas case discussed above such tensions e.g. arise from the asymmetrical integration of the emerging biogas TIS into the institutional contexts of the energy and the agricultural sector. While the energy sector still is dominated by structures favouring central electricity generation from fossil fuels and hydropower (professional culture, visions, planning procedures, management structures etc.) and thus would favour few larger biogas plants with operators from within the energy sector, the agricultural sector is oriented towards support structures for farmers in rural areas, including decentral, farm-level biogas generation and use. Biogas technologies are bridging these two sectors and actors are confronted with inconsistent institutional demands from both sides. National-level regulations such as feed-in regulations for electricity from biogas add a further layer of potential inconsistencies or institutional friction. The first phase of the Austrian eco-electricity law was a strong support for the growth of a biogas TIS as part of the electricity system, but based on

farm-level generation units. The ensuing tensions with electricity sector structures resulted in (still ongoing, but rather successful) attempts to destabilise and re-shape these institutions by e.g. reducing the level and time of feed-in support or by marking-up eligibility criteria to qualify for support. Regulatory provisions for the support of biogas are thus an example for a contested institutional field where existing institutional structures at national, international and sectoral level meet with strategies and interests of actor groups from within and outside the TIS.

Apart from such 'battles over institutions' (Jacobsson, 2008), actors from different sectoral backgrounds strive to achieve a better alignment of the biogas system with mismatching sectoral or national institutions, e.g. by developing agricultural structures to make use of 'intermediate crops' which do not compete with food production (and thus are not in conflict with national discourses about negative effects on food prices) or by seeking new alignments (and appropriate support structures and organisational solutions) with the gas sector instead of the present emphasis on electricity.

5. Conclusions and Outlook

In the present paper, we have proposed a conceptual framework for doing institutional analysis in the context of technological innovation systems by building on existing approaches to institutional and innovation system analysis. What we specifically aim at with our scheme is a more differentiated and systematic analysis of relationships between a technological innovation system and its wider institutional context. In particular, we have presented a concept of institutional analysis, which builds on an encompassing notion of institutions, including informal normative and cognitive structures, as well as aggregated institutional structures such as institutional arrangements and institutional sectors. It allows for a dynamic perspective, emphasising the constant need for maintaining and adapting institutions. Our framework wants to address institution sensitive actor strategies (e.g. institutional entrepreneurship). Furthermore, our analysis provides a structured view on institutional landscapes in which technological innovation systems are embedded, allows for the identification of institutional alignments and mismatches between TIS and its contexts, as well as to specify the institutional opportunity structures of innovators at a given point in time.

Institutional contexts thus not only structure and regularise behaviour, but also set the stage for the dynamics of institutional change and actor strategies. Mismatches between institutional structures often indicate fields of potential conflict and strategic action. While

stable institutional fields are to a great extent aligned with actor practices and strategic orientation, emerging innovation systems such as biogas may give rise to new institutional inconsistencies (e.g. decentral versus central production structures) or link so far rather unrelated sectors such as agriculture or energy supply and their institutional structures. Institutional tensions and shifts – which are rather the norm than the exception - are inextricably linked with actor strategies aiming at institutional change and realignment and bringing in interests, resource endowments and strategic orientation.

Our attempt to give more systematic consideration and attention to contextual institutional structures of evolving technological innovation systems thus is far from putting forward a static perspective or de-linking institutional analysis from strategic action – an accusation institutional theory has long been confronted with (Scott, 2008). To the contrary, a thorough analysis of institutional contexts with their interactions and inconsistencies can serve as a basis for a better understanding for the opportunity structures of different actor groups involved and for the interrelated dynamics of change of technological innovation systems and their contexts.

Although our focus has been on technological innovation systems, the framework elaborated in this paper could also be adapted and applied to other innovation system perspectives. In particular, interactions between increasingly globalized sectoral and technological systems could be specified. The same would be true for analyzing the interdependence of regional systems of innovation with their national, sectoral and technological contexts (see for instance, Asheim and Coenen, 2005 or Truffer, 2008).

However, in the present paper, we could only give a general outline of many of the key questions that would have to be resolved in a comprehensive approach. The focus of the paper and of the case study, in particular, has been more on elaborating the structural side of institutional analysis, although we continually have emphasised its link to institutional change processes (relations, alignments, mismatches). In combination with an analysis of actor strategies further empirical institutional analysis could for example be extended and specified in several ways:

- Patterns of institutional change: In a temporal perspective a more detailed analysis of the TIS development path with respect to the emergence of TIS internal institutions and the adaptations and changes of external institutions would reveal a richer picture of the factors having shaped the development of biogas technologies. Such an analysis could

put more emphasis on investigating micro-level processes of institution building and institutional change in the context of emerging technological innovation systems. A temporal analysis of institutional alignment and embedding processes could also contribute to a better understanding of coupling domains between technological and sectoral innovation systems and could result in a typology of sectoral transformation dynamics (for a similar attempt see Dolata, 2008).

- The benefits of our proposed framework should especially come to bear in comparative analyses of TIS trajectories. Here, institutionalization strategies of different actors could be evaluated relative to the prevailing contextual institutions in which these strategies are posited. A thorough analysis of the respective institutional landscapes and an assessment of successes and failures in institutionalization strategies could provide a sound basis for the transfer of successful support strategies from one national context to another.
- Finally, an analysis of institutional contexts could be a basis for identifying and assessing strategies and alternative pathways for the future development of a technological innovation system. In our analysis of the Austrian biogas system we could only touch on alternative strategic options, like a stronger orientation towards the gas sector (and, as a consequence, avoiding the high dependence on electricity feed-in laws), the need to deal with land-use conflicts between food and energy crops or options to develop a better fit with the electricity system by e.g. providing back-up power for intermittent energy carriers.

A structured and systematic analysis of institutional contexts and coupling domains as we suggest it in this paper could thus provide us with a sound and at the same time flexible framework for further empirical research to better understand the relative importance of institutional factors for the success and shape of innovation processes and to identify opportunity structures available to actors promoting the further growth of technological innovation systems.

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