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Doing Institutional Analysis of Innovation Systems

A conceptual framework

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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 an institutional analysis in the different innovation system approaches. Therefore key questions remain unsettled: How may relevant institutions be identified? Which relationships and interactions exist between institutions at different levels? And, how are such institutional couplings addressed by specific strategies of actors in the course of socio-technical transformation processes? The present paper elaborates a framework for doing institutional analysis of systems of innovation and production. We spell out this framework in more detail for the case of technical innovation systems and their relationship with contextual institutions at the national, international, regional and sectoral level. The framework will be illustrated by applying it to the emerging biogas innovation system in Austria.

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 technology-specific innovation systems (Carlsson et al., 2002; Hekkert et al., 2008). A rather general definition of innovation systems focuses on “elements and relations which interact in the production, diffusion and use of new, and economically useful, knowledge (...)” (Lundvall, 1992). However, there is a broad variety of definitions and interpretations of components and boundaries among the different concepts. Apart from the resources and strategies of different actors and their interplay in networks, 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).

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). Even in the much smaller field of innovation system studies different interpretations are abundant (Edquist, 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, 1997; Edquist, 2005). Despite these efforts the analysis of institutions in innovation studies is still very heterogeneous and often conducted only implicitly.

Institutions are indeed a multi-faceted phenomenon and different definitions of institutions abound. In this paper we follow a dynamic and actor-centric 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 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 exemption 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).

The present paper aims at conceptually clarifying the analysis of institutional structures within innovation systems. In particular we will elaborate a proposal for doing institutional analysis in the context of technological innovation systems (TIS) that will also be instructive for the analysis of institutions in other innovation system contexts. We suppose the following three goals which our method should be able to fulfil: (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 intersections and couplings between institutional structures at different levels (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 gives an overview of the concepts of institutions in the different strands of the innovation system literature. Chapter 3 and 4 elaborate our proposal for doing institutional analysis in detail. Chapter 3 introduces the concept of institutional coupling domains, which may be addressed for alignment and embedding strategies by specific actors. Chapter 4 specifies different kinds of institutions and proposes an integrated framework to analyse internal and contextual institutional structures of a technological innovation system. Chapter 5 illustrates the application of the framework to the case of the Austrian biogas innovation system. The proposed analytical dimensions will be expounded and an assessment of the opportunity structure of the corresponding TIS actors will be laid out. Chapter 6 concludes by proposing a research program for systematically assessing institutional structures in comparative and dynamic contexts.

2. Analysis of institutions in the innovation system literature

A common theme of system of innovation approaches is that they highlight the particular importance of institutions for innovation processes. However, there is no common understanding of how to define institutions (Edquist, 1997). An example of the challenges in this respect is the distinction between institutions and organizations (or actors) (Edquist and Johnson, 1997). One proposition is that institutions represent the rules of the game and organizations represent the players (e.g. Edquist, 2005) or that organizations can act and pursue strategies, while institutions cannot (Markard and Truffer, 2008 forthcoming). This distinction is not unanimously shared in the literature though. In the following, we briefly review the major strands in the innovation systems literature and the role they assign to institutions and institutional analysis.

Probably the most widely discussed and influential approach to a systemic analysis of innovation processes is the concept of national innovation systems (NIS). NIS studies strive to understand variations of innovative capacity and innovation patterns between nations. Their main explanation of performance variations are national differences in institutions and institutional settings, which affect the capacity and styles of firms and other actors to innovate (Balzat and Hanusch, 2004). However, there is a plurality of definitions and interpretations for national innovation systems and most authors are rather vague about the boundaries of the innovation systems (see Edquist, 1997, 15). Sometimes e.g. the economic system is separated from the innovation system, sometimes it is not. In our analysis we will adhere to the rather open and inclusive approach of Lundvall (2007) who distinguishes a core of the innovation system consisting of firms in interaction with other firms and the knowledge infrastructure, and a wider setting including, for example, structures for corporate financing (e.g. availability of venture capital), the organization of research and education in a country, the characteristics of labour markets, tax regimes or patent legislation. Beyond such rather formalized legal and regulatory structures, a number of informal institutions have been identified to be responsible for the variation in national innovation performance, such as the time horizon of agents (long-term vs short-term perspective), or the role of trust for the cooperation of different national actors (Lundvall, 1998). While the NIS concept frequently emphasises the role of institutions, a shortcoming is its inherent fuzziness and lack of structuration in this respect. There is no explicit agreement on which institutions do or do not belong to a NIS or which institutions are more important than others for the performance characteristics of national systems (Hollingsworth, 2000).

The NIS concept has been criticized early on, to tie-up the system boundaries with the national borders. Empirical research showed that many highly innovative sectors have a strong resource base in certain regions, such as Silicon Valley for the computer industry. Regional innovation systems (RIS) therefore may show considerable autonomy from their national contexts (Asheim and Coenen, 2005). Institutions play a key role in the RIS concept, where they are associated with historically grown professional competencies, shared cultural orientations, a prevalence of high levels of trust and collaborative practices, specific market structures or even relatively autonomous regulative institutions (Cooke et al., 1997).

Another level of actors and institutions structuring innovation processes are sectoral innovation systems. The concept of sectoral systems of innovation and production (SSIP) is used to explain sectoral differences in structural, organizational and dynamic terms (e.g. Malerba, 2004b). A SSIP is considered to include three main building blocks: knowledge and technologies, actors and networks as well as institutions (Malerba, 2004a). Institutions are conceptualized as norms, routines, habits, practices, rules etc. that shape the cognition, action and interaction of agents (Malerba, 2004a). It is also highlighted in the SSIP literature that institutions such as labour markets, IPRs, financial institutions, technical standards or regulations can be sector-specific and that sectoral systems therefore may differ greatly in institutional terms (Malerba, 2002; Malerba, 2004a). Key issues for research are seen in the emergence of sectoral institutions and in the relationship between national and sectoral institutions (Malerba, 2002, 257). Indeed, there are few accounts dealing with the institutional setup and dynamics of sectoral systems (a recent exemption is Dolata, 2008).

Finally, system concepts focusing on the determinants of innovation processes related to specific technologies were formulated under the technological innovation systems (TIS) concept.¹ In general, the TIS concept devotes much attention to the role of institutions but equally highlights the importance of actors and actor networks. One of the most explicit conceptual accounts on institutions can 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). And 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

¹ See Markard and Truffer, 2008 for a partial review of the literature on technological (innovation) systems.

with regard to the explicitness of institutional analysis and the types of institutions that are in the focus of empirical studies. Some articles even hardly mention institutions at all (e.g. Carlsson et al., 2002; Bergek and Jacobsson, 2003). 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 sectors² such as research and education or financial markets, whereas in the case of emerging systems (e.g. Jacobsson, 2008; Jacobsson and Bergek, 2004; Jacobsson and Johnson, 2000), the role of regulation and demand side policies together with processes of institutional alignment is more prominent. In general, inducement and blocking mechanisms as the consequence of mismatches with the institutional contexts are identified rather ad-hoc in the context of specific case studies and are not systematically reviewed. Moreover, the analytical focus of the TIS literature has turned towards system functions in recent years (e.g. Bergek et al., 2008; Hekkert et al., 2008; Bergek and Jacobsson, 2003) and an explicit analysis of institutions as one of the key (structural) components of innovation systems is not so high on the agenda.

3. Identifying institutional coupling domains

In their empirical application, the different innovation system concepts such as national, regional or sectoral innovation systems intersect and relate to each other in many respects. They offer alternative meso-level perspectives on innovation processes as they emphasise different systemic coherences of actor networks, institutions and technologies at different levels. Whether the national level is a better explanation for the innovation characteristics observed than a regional or sectoral one ultimately depends on the research question. In general, several of these levels play a role in shaping innovation processes and there is often a significant overlap of institutions among different innovation and production systems. These overlappings or 'coupling domains' may show various degrees of homogeneity or consistency. Institutions at sectoral or regional level may for example be part of a rather homogenous nation-wide institution (e.g. similar vocational training structures in different industries). However, there may also be significant institutional variation within national or international institutional structures (e.g. even in a coordinated market economy some sectors may be competitively organised through liberal market structures while others may be strongly state-coordinated), which in some cases may lead to inconsistency and friction. Finally, sector- or region-specific institutions (e.g. dominant cognitive structures related to

² See Chapter 4 for a definition of institutional sectors.

central supply of energy services) may not have equivalents in other sectors or at national level and thus do not overlap at all.

Heterogeneity (and often incoherence) within the same institutional domain is additionally produced because different innovation systems are usually not hierarchically nested, with institutions at 'lower' levels being specifications of more general, higher level institutions. Sectoral innovation systems, for example, may span several countries or even become global in scope. They may have institutional characteristics which cause frictions (or synergies), for example, with some of the national or regional innovation systems they relate to. Similarly, a technological innovation system may be part and parcel of a specific sectoral innovation system. Often however, it will span across multiple sectors and may be global in its spatial reach. Again, the overlaps of a TIS with other innovation systems will give rise to either more antagonistic or synergistic relationships (often alluded to in the literature as "barriers" or "supportive environments"). In our case study, for example, the Austrian biogas innovation system spans the agricultural and the energy sector, which are characterised by different institutional arrangements (e.g. economic coordination structures, specific interaction patterns between incumbent actors). This may create tensions, if TIS institutions have to be simultaneously aligned with both sectors.

The aim of identifying overlaps and couplings of TIS institutions with other innovation systems leads us to distinguish "internal" from "contextual" or "external" institutions that are of relevance for a specific TIS. By internal we denominate institutions, which are under direct influence of the actors (individually or conjointly) in a specific technological innovation system.³ They may therefore be adapted to the needs of the technological alternatives and actor strategies favoured within the TIS. Contextual institutions are those, which also depend on other, external actors or which are subjected to the coherence conditions of national, regional, sectoral contexts or other technological fields.

In strategic terms, contextual institutions represent potential "institutional coupling domains", which may be used as targets for TIS actors to carve out the further development of a technological innovation system. If coupling domains are characterized by institutional mismatch they may be addressed by TIS actors either trying to influence context institutions to the affordance of the technology or adapting technologies or internal institutions to better fit with the contextual institutions. The linkages of a TIS with its institutional contexts thus define opportunity structures for TIS development, i.e. the set of potentially feasible paths

³ See also Markard and Truffer, 2008 with regard to the issue of innovation system delineation and system actors vs. outsiders.

along which an innovation system could develop. Institutional structures represent framing conditions for these development paths (in the sense of opportunities and barriers) but they may also be more or less directly be influenced by these actors. Which alignment strategies will be chosen depends on the actors, i.e. their interests and resources, and on the specific characteristics of the technological alternatives favoured in the TIS.

Defined in this way, contextual institutions will encompass not only the narrowly defined “innovation” related structures. For a technological innovation system in biogas production for instance, agricultural land use regulations may be more important than agricultural research funding schemes. So we have to look at production and innovation systems in their interaction. This interpretation is very much in line with the sectoral systems of “production and innovation” of Malerba (2004a) or the dominant interpretation of regional innovation systems as intersections between a production structure and a supportive structure for knowledge generation (Cooke et al., 1997). At the national level, authors like Lundvall (1992) have advocated a very broad interpretation, which encompasses national production and regulation structures alongside the purely innovation oriented institutions. A more explicit analysis of production related institutional structures at the national level may be found in the variety of capitalism approach (Hall and Soskice, 2001), which in turn remains rather silent with regard to innovation processes (Werle, 2005). We will therefore in the following interpret contextual systems as explicitly encompassing innovation and production structures.

Figure 1 gives a schematic representation of institutional coupling domains of a technological innovation system relative to its contextual sectoral and national systems. The extent of the symbols, representing specific institutional structures, indicates the scope of relevance of a specific institution and therefore stands for the respective coherency requirement. It will be large if an institution influences a broad range of processes in the system (e.g. a standard that applies to the entire value chain of a sector) and small if it only regulates a specific component (e.g. a product standard). Institutional coupling domains can then be identified as intersections between the TIS and specific contextual institutions.⁴ This is the case, where TIS institutions are at the same time part of other coherent institutional structures at other levels. Figure 1 gives a graphic representation of the institutional coupling domains for a specific TIS and therefore maps the opportunity structure TIS actors are confronted with. This map may serve to devise specific strategies for institutional alignment or embedding into national or sectoral institutions.

⁴ Note that not just (internal) institutions but also other TIS characteristics (e.g. technological attributes) can interact with external institutions.

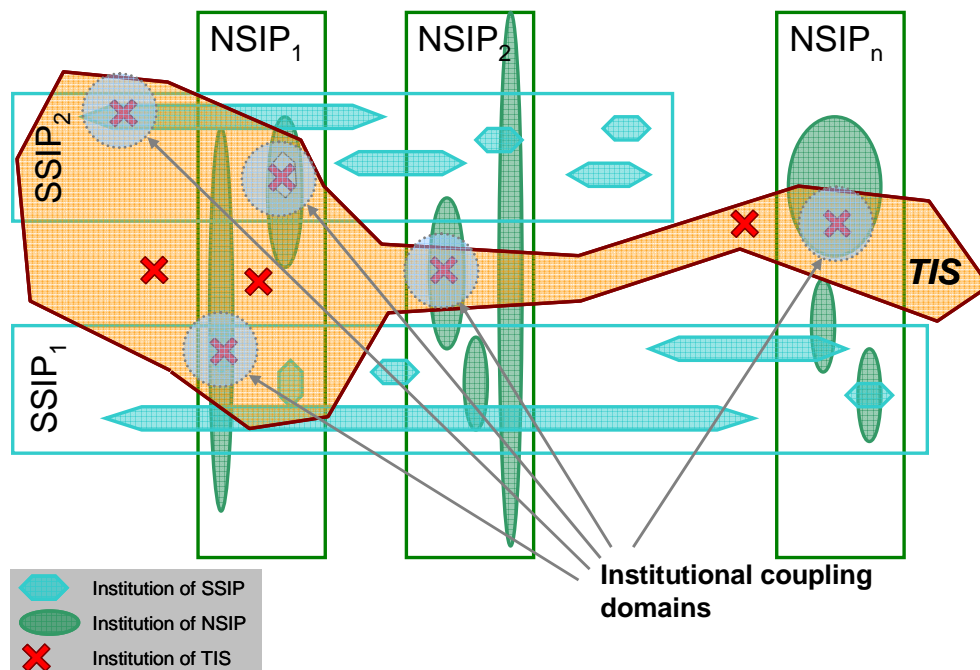


Figure 1: Institutional coupling domains between technological (TIS), sectoral (SSIP) and national (NSIP) systems of innovation (and production). The extent of the institution symbols indicates their relative scope of influence within the respective innovation system.

In order to identify coupling domains between different systems of innovation and production we have to disaggregate the institutional landscape, i.e. the complex institutional structures of these contextual systems in an appropriate way. Although our focus will be on technological innovation systems, we would like to emphasize that the framework elaborated here could also be applied by choosing a different innovation system perspective as a focus. 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).

4. *Towards a framework for doing institutional analysis of innovation systems*

4.1. Classification of institutions and institutional structures

In the following, we propose a classification of different types of institutions and institutional structures. The classification draws on a proposal for doing institutional analysis by Hollingsworth (Hollingsworth, 2000) who “develop[s] a map of what can be called the terrain of institutional analysis” (Hollingsworth, 2000, 589). Hollingsworth suggests five components or levels of institutional analysis including (i) institutions, (ii) institutional arrangements, (iii) institutional sectors, (iv) organizations and (v) outputs and performance. The first level

encompasses basic institutions such as “norms, rules, conventions, habits or values of a society” (Hollingsworth, 2000, 601). Institutional arrangements relate to the coordination of actors. These include markets, hierarchies, associations, networks, the state and communities. Institutional sectors comprise “all organizations in a society, which supply a given service or product, along with their focal organisations (e.g. major suppliers, funding sources, regulators, and so forth...” (Hollingsworth, 2000, 614). At the fourth level, Hollingsworth suggests to analyze organizations because “institutional rules, norms and conventions unfold in tandem with organizational structures” (Hollingsworth, 2000, 619). The fifth level, finally, is said to include statutes, administrative decisions and specific policies but also new products, new technologies and market strategies (Hollingsworth, 2000, 622). The five levels are arranged in descending order of stability, i.e. level 1-institutions are considered to be the most permanent, while level 5-institutions are very flexible.

While we basically embrace Hollingsworth’s taxonomy, we think that it has to be adapted for our purpose of institutional analysis of innovation systems and their context. Most importantly, we want to conceptually separate organizations, products and technologies from institutional structures as this distinction is in line with most innovation system concepts. Furthermore, we argue that institutional stability as a criterion for differentiation is rather difficult to handle. Stability, for example, depends on many context conditions and institutional couplings and institutions that were stable over longer time periods may suddenly become fluent and flexible.

We therefore propose a classification that is based on three levels of aggregation: *Institutions* in the stricter sense (*s.str.*) such as norms, values, conventions, regulations, cognitive frames or visions represent the basic elements of an institutional landscape. As certain institutions (*s.str.*) are mutually dependent and exert a specific influence through their interplay, they may be conceptualized as (semi-) coherent aggregates or institutional structures, which we will differentiate as institutional arrangements and institutional sectors.

Institutions (s.str.)

Institutions in the strict sense are rules that influence the activities and decisions of individuals, organizations or groups of actors. This includes norms, values, regulations, laws, guidelines, cognitive frames etc. Institutions may serve different functions; they may for example reduce uncertainty, help to resolve conflicts or cooperation, or provide incentives (Edquist, 1997).

Following Scott (2001), we suggest to further distinguish three sub-types of institutions (*s.str.*): 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).

Institutional arrangements

Institutional arrangements are more or less aligned sets of formal and informal institutions (*s.str.*) that coordinate the action and interactions of actors. Examples of different types of institutional arrangements are markets, hierarchies, networks, the state, 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. The criterion for favouring one institutional arrangement over another may be related to transaction cost arguments (Williamson, 1985) or to prevailing uncertainties (e.g. in the context of mutual trust or shared cultural orientations as a basis for cooperative behaviour, etc.).

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).

The specific combinations of institutional arrangements can be used to define different styles of governance: At the national level Hall and Soskice (Hall and Soskice, 2001) distinguish liberal and coordinated market economies in their varieties of capitalism approach,⁵ whereas Dolata, 2008 classifies patterns of interaction in sectoral innovation systems as competitive, cooperative, negotiation-oriented or civil-society-oriented.

Institutional sectors

Institutional sectors are more or less coherent bundles of institutions (*s.str.*) 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

- 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), science and technology capabilities, S&T strengths and weaknesses, 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 notion of an institutional sector is closely related to the concept of socio-technical regimes (in their narrow interpretation as highly aggregated rule sets, cf. Kemp et al., 2001). Also the institutional make-up of sectoral innovation and production systems may in this terminology be understood as an 'institutional sector'. The role of institutional sectors is especially emphasized in the analysis of national system of innovation (see Lundvall, 1992; Archibugi and Michie, 1997) as these sectors shape the performance and development paths of technological innovation systems.

Summing up, our institutional analysis of technological innovation systems aims at identifying i) regulatory, normative and cognitive institutions, ii) the mix of institutional arrangements by which coordination with other actors may be achieved and iii) the intersections with other institutional sectors such as the financial or research sector. These institutional levels have to be spelled out for determining the impact of "institutions" on the technology-specific innovation system.

⁵ On the implications of these arrangements for technology development and innovation, see Werle, 2005.

4.2. Operationalising institutional analysis: Linking structures and coupling domains

Based on the concepts introduced in the previous chapters, we may now introduce our framework to analyse the institutional structures which shape (i.e. orient, restrict or enable) the development of a technological innovation system. In a first step we have to disaggregate the complex institutional landscape of the TIS with regard to the relevant context systems (e.g. national, sectoral systems of innovation and production, see chapter 2) and types of institutions (chapter 4a). In a second step, we have to identify coupling domains between these external institutions and the TIS.

A first cut at contextual institutions may be oriented at specific spatial scales: national systems of innovation and production are often important in this respect, but in many cases international institutional regimes and regional innovation systems may also have a significant impact on the innovation processes analysed. For these spatially defined systems we may identify regulations, specific national policies, identities and myths that may be relevant for innovation processes located in specific regions or countries. With regard to institutional arrangements, different styles of interaction between the state and the economy may leave their imprints on TIS development. Finally, specific institutional sectors like research, education or the financial system have to be considered.

A second cut at contextual institutions may be oriented at sectoral systems of innovation and production. Which of these have to be considered depends on the dominant input-output relationships with the technology under development. Many TIS will have one single sector of reference. Other cases, like nano- or bio-technology have potential interactions with many sectors. At the sectoral level we can again distinguish different layers of institutions, which have an impact on TIS performance. With regard to institutions *s.str.*, we may look at sector specific regulations but also for self perceptions, technological paradigms or *Leitbilder* that prevail in the sector. Furthermore, visions about the future prospects of a sector may be an important source for activity for TIS actors to engage with a given sector. Finally, institutional arrangements or institutional sectors such as the financial system may have specific sectoral characteristics relevant for the TIS.

Finally, we have to consider the “internal” institutions that have specifically been built up by the actors in the TIS for their own coordination. In general, a TIS will not have a dense institutional apparatus as its socio-technical configurations will, in general, still be in a “hot” and unsettled stage (Callon, 1998). However, internal institutional structures will be decisive for the momentum a TIS may develop and define the relationship to the context innovation systems through mismatches or alignment.

National (and/or regional) Innovation Systems / International Regimes	Regulative, normative and cognitive institutions	<ul style="list-style-type: none"> ○ Innovation and technology policy ○ Perception of environmental problems ○ Major mobilizing myths ○ Rule of law
	Mix of institutional arrangements	<ul style="list-style-type: none"> ○ Role and power of the state ○ Dominant orientation of product sectors ○ Negotiation of interests
	Institutional sectors	<ul style="list-style-type: none"> ○ Finance (e.g. availability of venture capital) ○ Research and education (e.g. specific research institutes, industry orientation of public research) ○ labour market, business system, legal system, etc.
TIS-relevant Sectoral systems of production and innovation	Regulative, normative and cognitive institutions	<ul style="list-style-type: none"> ○ Sector specific regulations of products, environment, risks, etc. ○ Visions and self perceptions of dominant actors in the sector ○ Perception of product characteristics by producers and users
	Mix of institutional arrangements for production and innovation	<ul style="list-style-type: none"> ○ Organization of the value chain ○ Determination of technological standards ○ Interaction with politics (e.g. forms of lobbying) ○ Forms of co-operations in pre-competitive innovation ○
	Sector specific variations of NIS institutional sectors	<ul style="list-style-type: none"> ○ Sectoral research and education structures ○ Sector specific financing structures
TIS-specific institutional structures	Emerging internal institutions of the evolving socio-technical system (Institutional arrangements, rules and, norms, etc.)	<ul style="list-style-type: none"> ○ Coordination mechanism between innovators (e.g. community, negotiation, competition); ○ specific promotional policies; ○ establishment of major mobilizing myths to which participating actors adhere

Table 1: A scheme for analysing the institutional structure of technology-specific innovation systems and its relevant contextual innovation environments

This formal structure for doing institutional analysis is only a framework for the identification of institutions that may impact on the course of a technological innovation system or determine strategies of involved actors. In every specific instance, these institutional interfaces have to be evaluated with regard to their impact on the TIS. Which concrete institutions within the scheme above are relevant for the analysis of a specific TIS can only be empirically determined. The scheme we suggest mainly serves the purpose to systematise the potential influence of contextual institutional structures and thereby draw attention to a range of often neglected institutional influences on TIS development.

The institutional analysis we propose thus is not a full-fledged structural analysis of national or sectoral institutional systems, but is always an analysis of these systems relative to an emerging TIS. Such a relational analysis is inherently open to change processes and a more dynamic view on institutions emphasising processes of institutional change, institution building, institutional alignment or frictions caused by institutional mismatches.

The analysis of institutional contexts and interrelations has a potentially wide range of applications: it may serve for more systematic description and explanation of individual cases of TIS development or it may be used to compare different institutional context structures (e.g. those prevailing in different national promotional contexts). Our framework of analysis may also be used to evaluate alternative strategies for developing a TIS or identify current risks related to the prevailing internal institutional, technological or actor set-up. However, in the space of the present paper, we have to restrict ourselves to illustrate the benefits of a systematic descriptive framework with a concrete case. Implications for comparative, dynamic and strategic applications of the framework will only be sketched as an outlook in the final chapter.

5. Case study: Growth dynamics of the biogas innovation system in Austria

We want to illustrate our approach to institutional analysis with the case of the technical innovation system 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 out of 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 with regard to strategies chosen and actual performance characteristics (Jacobsson, 2006; Raven and Gregersen, 2007; Negro, 2007). Countries strongly differ in the level of biogas utilization, the dominant technologies and organic substrates, the actors involved and the institutional structures supporting and shaping biogas development. Furthermore, biogas has a number of sectors (or sectoral systems of innovation and production) it could interact with. These include electricity supply, gas supply, heating, agriculture and waste management. So, we would expect a rather dense and diverse field of potential institutional structures that are of relevance for the TIS actors (Markard et al., Submitted). Austria is a good application case as it has a rather lively history of biogas development over the past few years 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 system.

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 seven 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 structured along our classification scheme to identify the current development stage of the biogas innovation system and the most important contextual influences on biogas development in Austria.

5.1. Development and current status of biogas digestion 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.⁶ In 2006 Austria was ranked number 5 of EU27 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).⁷ The same statistics shows a considerable increase from 31 MTOE to 103 MTOE between 2005 and 2006. Plant size has been continually increasing but currently centres on a medium level size of 250-500 kW.

The performance of the technological innovation system of biogas technologies looks impressive. And indeed, these strong growth figures are also reflected in an increasing constituency of biogas-related actors (technology suppliers, planners, plant owners - usually

⁶ This sharp rise in generation figures moreover has been somewhat exaggerated by a change in data collection.

⁷ 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.

small groups of farmers, substrate suppliers and various intermediary organisations to organise knowledge transfer and connectivity between these actors), technological improvements (mainly incremental improvements of plant design) and a strengthening of TIS-specific institutions, such as a standardisation of planning practices, specific support systems and regulations to increase biogas use and guiding visions for the further development of the biogas TIS. However, recent changes in the Austrian feed-in tariff system also have exposed an apparently high vulnerability of the current TIS and dependency on strong regulatory support. The following investigation and discussion of institutional contexts will help to shed light on the background of this situation and the threats and opportunities for further development.

5.2. The institutional landscape of the Austrian biogas TIS

As emphasized earlier, relevant institutional contexts for the development of the Austrian biogas TIS can be found at the level of different sectors, of which the Austrian energy sector (and here mainly electricity) and the Austrian agricultural sector are the most important ones. The majority of biomass substrates comes from agriculture and a significant part of the energy is taken up by the electricity sector. In Austria, the waste sector is of minor importance as a source of substrates. Further institutional influences can be assigned to the international level (e.g. EU regulations) and the national system of innovation and production.

In a first step we will now summarize the relevant institutions in each domain along the lines of our analytical scheme, cf. tables 2-4. These key elements of the institutional landscape are then assessed in terms of the nature, strength and direction of their interrelations with the biogas TIS.

International and NIS-specific institutional contexts and influence on biogas TIS		
Institutional level	Characteristics of Austrian institutional system	Effect of institutional context on biogas TIS
<i>International regimes</i>	EU environmental regulation, Kyoto agreement: Indicative targets for electricity and share of (new) renewables enforce national regulations to support growth of renewables; EU burden sharing agreement: Austria agrees to reduce GHG emissions to -13% by 2008/12 compared to 1990 level	++ strong pressure from EU level to support renewables incl. biogas
	EU Energy market liberalisation / re-regulation: Austrian energy market liberalised at end-consumer level since 2001; new possibilities for independent energy generators to access electricity market	+ regulation allows market access of independent biogas generators
	EU research programmes: Support of collaborative research and implementation projects between several EU countries favours EU internal knowledge and technology transfer	+ biogas is part of such RTD programmes – knowledge transfer / joint development within EU
<i>NIS Regulative institutions</i>	Federal structure of Austrian state; significant legislative and executive power at the level of regions (Bundesländer), e.g. environmental legislation, building codes etc.	+/- biogas: to some extent uneven development between different regions; high importance of regional support structures (subsidies, network facilitation, knowledge transfer etc.)
<i>NIS Normative; cognitive institutions</i>	Values: sustainability, regionalism, 'autarky'	+ generally positive perception of biogas as renewable
	Public discourses about increasing fiscal load on households and general price rises	-- legitimacy of financial support systems directly paid by households (e.g. as levy on energy price) in danger
<i>NIS Institutional Arrangements</i>	Corporatist structure; social partnership as cooperative relationship between labour, commerce and agriculture; strong (and often informal) role of social partners in legislative process	+/- agriculture lobbies for biogas within corporatist system; coordination and articulation of biogas TIS shaped by these relationships
	State (and semi-public structures) more important for production system than pure market relations, high density of regulations	+ biogas TIS viable in segments where economic competition has not yet been achieved - little pressure to become economically competitive
	Dominance of SMEs in Austrian economy; high degree of organisation within 'chamber of commerce'	+/- supportive environment for the development of small and middle sized biogas producers
	Variety of state funded intermediary organisations to support and coordinate environmental and technology policy aims;	+ several organisations geared towards network facilitation, creation and management of industry clusters, knowledge and technology transfer etc.; however, resource endowment of these organisations is rather low
<i>NIS-specific institutional sectors</i>	Research & education: National research; minor role of in-house research of companies (partly due to SME dominance); strengths rather in low and medium tech industries; focus on vocational training; national programmes to strengthen university-industry links, also with respect to bio-energy	+ programmes on renewable energies and 'energy systems of tomorrow' fund biogas projects
	Finance: Focus on credit finance compared to stock markets; close and long-term ties between SMEs and credit institutes; minor role of venture capital funding	- Biogas: some concern of banks about rising prices of agricultural products / feeding material and danger of bankruptcy for biogas plants; banks have developed expertise in assessing biogas projects and are experienced in dealing with SMEs

Table 2: Contextual institutional structures of the Austrian biogas TIS at the national and international level

Energy sector-specific institutional contexts and influence on biogas TIS		
Institutional level	Characteristics of Austrian institutional system	Effect of institutional context on biogas TIS
Regulative institutions	Idiosyncratic rules and formal procedures in the electricity sector largely in favour of large generators: investment planning, investment risk assessment, management of electricity grid and planning for further grid development (focus on high voltage transmissions rather than demand management and regional generation capacities)	-- regional / decentral biogas plants are disfavoured by practices in energy sector
	Electricity market regulator (E-Control) structurally inclined towards competitive sector-organisation in contrast to 'subsidised' green electricity growth	- pressure from regulator to reduce feed-in tariffs on biogas and other renewables
	Sector-specific formalised practices (e.g. contracts with fuel suppliers) shaped by established links with fossil fuel sector (e.g. long-term contracts);	- biogas requires links with agriculture: different situation and practices in agricultural sector for supply with agricultural raw materials for biogas generation
	Regulations to increase share of renewable energies: Electricity feed-in tariffs including favourable tariffs for biogas electricity; stop-and-go politics: very successful tariff schemes from 2002-2004; interim period without guaranteed tariffs; lengthy discussions and controversies about new scheme – cap on total subsidies per year for specific energy; guaranteed tariffs reduced from 13 to ten years;	++ guaranteed tariffs provide stable framework for biogas investments 2002-2004; + planned regulation: carriers 30% of feed-in subsidies dedicated to biogas; CHP required for biogas plants to meet efficiency requirements; temporary increase of biogas tariffs to cover part of increased feeding material prices - stop-and-go policies put further development of biogas network in danger
	Regulations to increase share of biofuels in transport sector	+ new opportunities for biogas as biofuel for transport
Normative; cognitive institutions	Self-perception of utilities as sustainable energy producers because of high share of hydropower	- utilities see little need to move into biogas use for sustainability reasons
	Dominant professional cultures in electricity system oriented towards centralised generation structures;	- intermittent and decentral energy carriers perceived as problem rather than opportunity
	Electricity prices dominate discourse about liberalisation and transformation of electricity system; extra cost of feed-in tariffs used as 'scapegoat' for rising prices	- public pressure against increase of feed-in tariffs
	Green image (self-perception and perception of others) of gas supply sector and high value of the security of supply including a diversification of gas sources	+ interest of gas utilities in increasing the biogas share in the natural gas grid and new opportunities for linkages of biogas TIS with incumbent gas sector
	Normative orientation of incumbents towards renewables: traditionally engaged in large hydropower; some interest in wind energy; little interest / ignorance for biogas; few projects with involvement of incumbent utilities;	+/- electricity generation from biogas mainly enforced through law on 'eco-electricity'
	Local utilities (mainly existing in certain provinces and for cities) inclined towards regional generation capacities due to their regional orientation, ties with regional actors and limited capacity to invest in large-scale generation	+ some opportunities for biogas generation at level of local utilities
Institutional Arrangements	Despite energy market liberalisation only limited competition; dominant role of regional utilities (at level of Bundesländer), various strategies to make market entrance difficult for new generators (technical specifications etc.)	- no pro-active interest of utilities to integrate biogas generators
	Market size too small to make market entrance lucrative for international competitors; various forms of alliances of incumbent utilities to cooperate in generation etc.; local supply markets with low switching rates of household customers	- rather hostile environment for new market entrants such as biogas generators

Table 3: Contextual institutional structures of the Austrian biogas TIS at the related to the energy sector

Agricultural sector-specific institutional contexts and influence on biogas TIS		
Institutional level	Characteristics of Austrian institutional system	Effect of institutional context on biogas TIS
Regulative institutions	Environmental regulations: restrictions to disposal of agricultural waste products (manure etc.)	+ biogas as acceptable and more profitable disposal path for manure
	EU set-aside scheme for arable land; land-use for energy crops feasible without losing subsidies	+ energy crops for biogas can generate additional income from set-aside land which cannot be used for food production
Normative; cognitive institutions	Self-image of agriculture: national food supply; sustainable (high proportion of organic or high-quality products), crucial role for functioning of rural areas and maintenance of characteristic 'cultural landscape'; export of high-quality, high-value agricultural products	+ biogas is seen as a means to support rural agricultural structures
	Self-perception that new sources of income are needed;	++ Biogas generation as new source of income; vision of farmer as energy producer (in addition to food production)
	National image of agriculture rather positive (similar to self-perception), but critical discourse about high subsidies from EU and national National critique of rising prices for agricultural products; concerns about role of energy crops in driving price increases of agricultural products	+/- ambivalent view of biogas – subsidised (-) and sustainable (+) - Biogas: current supplement to feed-in tariffs due to rising feeding material prices is criticised on the grounds of undifferentiated new subsidies for farmers
Institutional Arrangements	Small farm sizes dominant; very few industrialised, large scale agricultural enterprises; low level of competition in processing of agricultural products;	+/- structure of agriculture favours small and medium sized biogas plants
	Strong role of 'chamber of agriculture' as part of Austrian 'social partnership', important role for sector-internal organisation, lobbying, consultation in legislative process; strong links with conservative party	++ Biogas: Chamber of agriculture and related organisations as major lobbyists and system builders
	Tradition of cooperation between farmers (e.g. sharing of machinery)	+ Biogas: many plants owned and operated by several farmers
Sector-specific variations of NIS institutions	Sector-specific research infrastructure – includes research on renewable energy, research on crop rotation to optimise agricultural and energy output (with respect to economic efficiency and sustainability)	+ biogas technology research perceived as reasonably financed, though not in leading role compared to e.g. Germany
	Finance: dominant role of 'Raiffeisen Group' (organised as a cooperative) with respect to ownership of food processing industry, credit supply for agricultural sector, product supply for farmers etc.	+ biogas projects financed by agricultural banks; in some cases also role as project developer
Other relevant sector-specific institutional fields	Waste management sector: restrictions for disposal of sewer sludge;	+/- tradition of biogas generation in digestion towers; growth perspective for biogas generation in this sector are rather limited in Austria

Table 4: Contextual institutional structures of the Austrian biogas TIS at the related to the agricultural and waste sectors

The collection of institutions in the three tables 2-4 shows that the complexity of institutional linkages is quite high. There is a large variety of relevant institutions at different levels and some of these do not only influence the biogas TIS but are as well shaped by the biogas TIS actors (e.g. favourable feed-in tariff level due to lobbying of agricultural actors for biogas support). The effect of some institutions is ambiguous as for example in the case of financing: On the one hand, concerns about the potential risks discourage provision of capital but on the other hand, credit assessment guidelines and other standards have been developed that make the financing of biogas plants easier for both investors and plant owners.

The big picture from reading the tables is that institutions at the national and international level as well as institutions related to the agro-sector rather work in favour of biogas, while at the level of the energy sector we see strong positive but also a number of negative influences. In fact, there are three major institutional drivers which together accounted for the boom phase in biogas production between 2002 and 2005: (i) European directives on electricity market liberalization and the support of renewable energies, (ii) regulations to increase the share of green electricity in the energy sector (feed-in law etc.) and (iii) the receptiveness of the agricultural sector for biogas plants (tradition of cooperation, strong role of chamber of agriculture in lobbying, information exchange, consulting etc.). The main barriers for TIS development appear to be a regulatory stop-and-go policy at the national level leading to unstable framework conditions for the support of biogas electricity and the 'general resistance of the electricity sector' against decentralized generation. In figure 2, the most influential institutions, their linkages and their effects on the biogas TIS are depicted.

This general picture can be derived from a more detailed analysis of the different institutional contexts at the national/international level and at the level of the two sectors. At the level of international regimes the EU directive on electricity market liberalization and especially the policy to increase the share of electricity from renewables and their translation into national law at the level of the electricity sector played a major role for the emergence of the Austrian biogas TIS. At the national level, the corporatist culture in Austria is an important institutional factor as it lays the ground for the strong influence of the chamber of agriculture on policy making (e.g. in the context of the electricity feed-in law). Further institutions at the national and international level (Table 2) have a smaller influence on the biogas TIS.

The institutional interrelations of the biogas TIS with the energy sector (table 3) reveal a rather mixed picture, which has to be further differentiated for the sub-sectors for electricity, gas and heat provision. Currently the Austrian biogas TIS is mainly oriented towards the

electricity sector where specific regulations (see above) support the feed-in of electricity from biogas. As a matter of fact, biogas plants are designed in a way as to optimize the electricity output. The production and refinement of methane gas that can be fed into the natural gas grid has not played any significant role in Austria, so far. Apart from the feed-in regulation, the electricity sector has in general shown very little receptiveness for biogas due to influential regulative, normative and cognitive institutional structures, which still are geared towards central electricity generation. However, smaller local utilities are often an exemption 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 and the security of supply. These could work in favour of the biogas TIS and the feed-in of methane gas instead of electricity. With a closer coupling to the gas sector, biogas would get better access to heat provision and could also link up with strategies to develop a better infrastructure for gas fuelled cars thus establishing additional couplings with the transport sector.

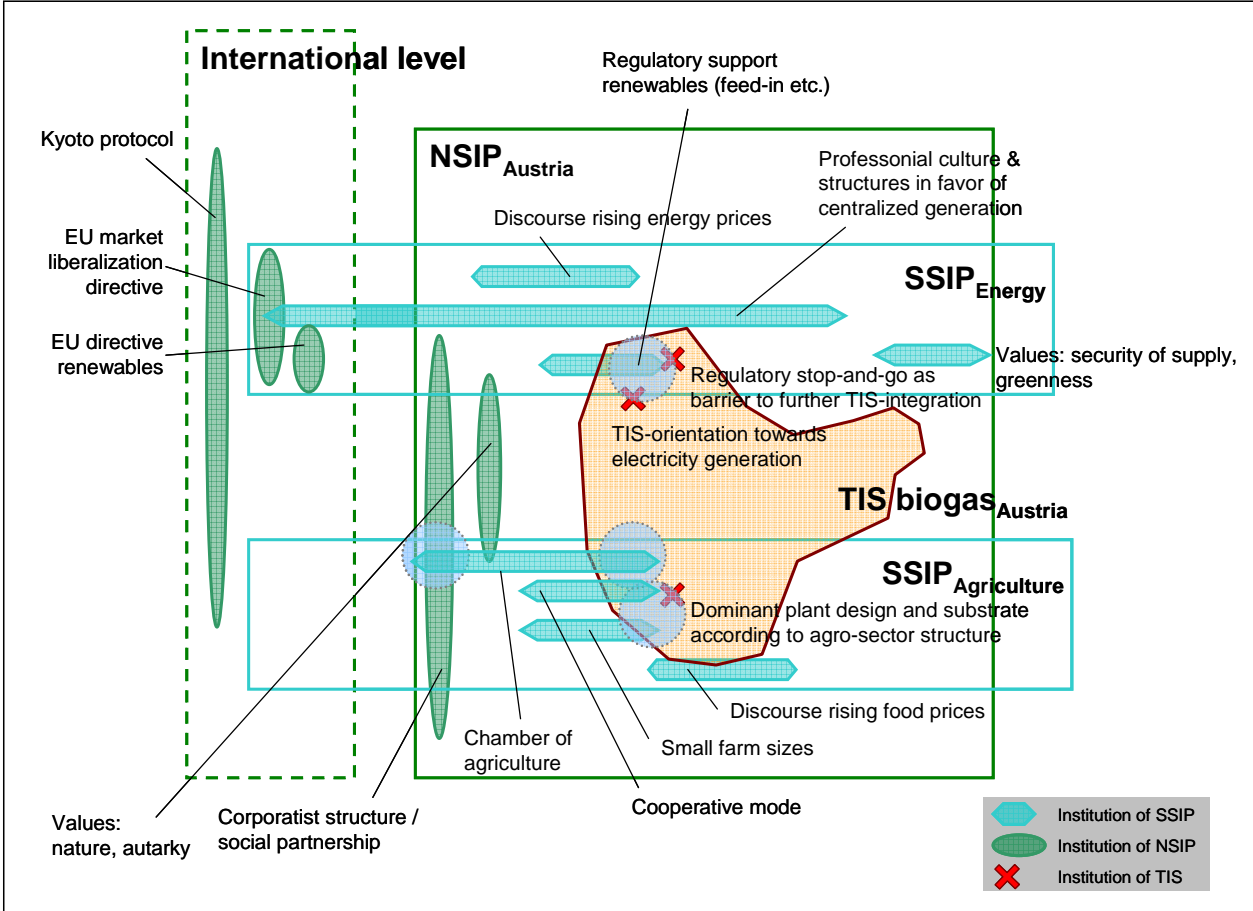


Figure 2: Institutional contexts and linkages of the Austrian biogas innovation system

The institutional contexts and interactions with the Austrian agricultural sector show a somewhat more homogenous picture of forces acting in favour of the biogas TIS. The main driver for the receptiveness of the agro-sector towards biogas is the need to develop new sources of income for farmers. As table 4 indicates, the sector is dominated by cooperative and non-market institutional arrangements and is well integrated into the Austrian legislative procedures via the chamber of agriculture (cf. influence on feed-in regulation discussed above). The chamber of agriculture also provides support with setting up contracts, assessing economic viability etc. Moreover (and 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). In terms of institutional arrangements, the agro-sector in Austria is characterized by small farm sizes with a tradition of cooperation. These structures have strongly shaped the technological designs or organizational configurations in the biogas TIS: the majority of plants are rather small and operated by single farmers or groups of farmers. Finally, the biogas innovation system has established supportive links with agriculture-specific financing and research institutions, which both provide resources for the further growth of the TIS.

5.3. Discussion of institutional dynamics and evaluation of the opportunity structure

Against the background of these institutional relationships with the context, the development of the Austrian biogas TIS can roughly be reconstructed as follows (see also fig. 2).⁸ Due to international treaties, EU directives and national policy priorities, an electricity feed-in law has been introduced in Austria that led to a rapid development of the biogas TIS and a significant diffusion of biogas plants between 2002 and 2005. The agricultural sector showed a high degree of receptiveness due to increasing concerns related to the income of farmers. A socio-technical design emerged that was strongly shaped by the institutional make-up of the agricultural sector: The biogas system is dominated by small to medium scale plants optimized for electricity generation. The major stream of substrate are energy crops complemented by manure. Plants are operated by single farmers or cooperations of farmers. The chamber of agriculture provided strong institutional support in several regards: lobbying for attractive feed-in tariffs and regulations that allowed the use of energy crops, provision of information and advice etc. Due to the highly decentralized nature of the dominant biogas plant design in Austria, the interest of larger electric utilities in biogas never increased and several barriers remained in the electricity sector. This was also a consequence of its dominant orientation and culture towards centralized electricity generation on the basis of hydropower.

⁸ Note that institutional influences can just explain a part of the „story“ as the various actors and their strategies are not included.

After the highly successful first years, the regulation suffered from a series of abrupt policy changes, which made a continuous planning for developers and producers very difficult and seriously hampered the development prospects of the TIS. This regulatory unsteadiness is at least to some extent triggered by national discourses about the problem of rising electricity prices. Moreover, the strong link with agriculture invoked national discourses (and resistance) about 'over-subsidization' and rising prices for agricultural products. So far, neither the emerging biogas TIS constituency nor the established institutions in the agro-sector have been influential enough to bring regulatory feed-in support back on track.

While such an analysis of the institutional embedding of a technological innovation system along with its histories of institution building and institutional change provides us with a rich picture of reasons and influences on the current shape and situation of the biogas system in Austria, such an analysis can also be used as a starting point for the assessment of opportunities and challenges for the future development of the biogas TIS. Actors of the biogas TIS could deliberately establish new institutional alignments and/or try to modify the existing institutional context. Our cursory case study for example points to a number of strategies to 'unlock' the high dependence on feed-in tariffs. These include a) the possibility of strengthening linkages with the natural gas sector (feeding into natural gas grid; establishing institutions, e.g. an accounting system for biogas tracking, similar to green electricity support institutions) and transport sector (fuel supply for CNG-cars), b) developing institutional fits in new market niches in the electricity market, e.g. by providing back-up power for intermittent energy carriers and the electricity system in general due to storage possibilities of biogas, or c) developing strategies to better deal with land-use conflicts between food and energy crops (e.g. new crop rotation strategies with intermediate crops for energy production) to take some heat out of discourses about undue price rises of electricity and agricultural products because of renewable energies.

6. Conclusions and Outlook

In the present paper, we have proposed a conceptual framework for doing institutional analysis in the context of technological innovation system analysis by building on different existing approaches to institutional and innovation system analysis. What we specifically aim at with our scheme of institutional analysis is a more differentiated and systematic analysis of relationships between a technological innovation system and its wider institutional environment. This will help to better understand processes of institutional embedding (and

thereby the shaping forces of TIS development) and to identify opportunities for forging new alignments and adapting institutional structures. 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. As a consequence our framework is also able to address actor strategies aimed at influencing institutional structures (such as institutional entrepreneurship). And, finally our analysis provides a structured view on institutional environments of technological innovation systems, institutional alignments and mismatches with the context, as well as favourable corridors and opportunity structures for further development. Hence, we argue that our framework fulfils the three ambitions set-out in the introductory chapter.

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 elaborate for 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. The influence of institutions could moreover be specified with respect to their impact on different innovation system functions such as orientation, knowledge generation, resource mobilisation or market formation (e.g. Bergek et al., 2008). Comparative empirical analysis could help identify strategies to increase the performance of different innovation system functions.

- Finally, an analysis of institutional contexts could be a basis for identifying and assessing strategies and alternative pathways for the further development of a technological innovation system. In our analysis of the Austrian biogas system (chapter 5), we could only touch on alternative strategic options, like a stronger orientation towards the gas sector (and, as a consequence, avoid 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 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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