Technological innovation systems in multi-scalar space : analyzing an emerging water recycling industry with social network analysis

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Analyzing an emerging water recycling industry with social network analysis

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1 Introduction

Globalization and the fast rise of emerging economies have had tremendous impact on the way innovation is generated, diffused and utilized (Carlsson 2006; Dicken 2007; Niosi & Bellon 1994). Especially for innovation in emerging environmental industries, newly industrializing countries (NICs) play an increasingly important role (Berkhout et al. 2009). NICs could even «leapfrog» currently prevailing technological configurations, thereby developing their own industrial capabilities and ultimately providing innovative environmental technologies to the world (Binz & Truffer 2012). Identifying how and where environmental technologies might develop and mature is thus increasingly complex and dependent on processes active at and between different scales, connecting distant places in technological innovation systems (TIS) – along the lines originally sketched out by Carlsson and Stankiewicz (1991).

If these new realities are to be addressed, TIS research will need to pay more attention to the international dimension. For too long, TIS studies have limited their focus on concept development and empirical research at a national or even subnational level. This «containerized view» on space risks the exclusion of the multi-scalar, international nature of contemporary technological innovation processes (Amin 2002). In fact, until recently, most TIS studies implicitly argued that the international dimension was not of major importance for innovation processes. Carlsson (2006: 65) comments on such reasoning as follows:

> «In view of the fact that most studies of innovation systems focus on national innovation systems, it is not surprising that little direct evidence is found that innovation systems are becoming global.»

This paper proposes an analytical framework which allows characterisation of the international scale of TISs in order to enable a discussion of potential errors incorporated in spatially «containerized» studies. Coenen et al. (forthcoming) call in this context for a relational conception of space that avoids pre-defined scalar hierarchies and encourages more collaboration with research in economic geography. This idea is taken up here in the proposal to conceptualize international innovation geography in TIS with a relational and multi-scalar conception of space and by using social network analysis (SNA) as a methodological approach. This method is frequently used to map the innovation networks of clusters or whole industries (McKelvey et al. 2003) and will be applied here for mapping the relational position of TIS actors in international innovation networks. Also economic geographers have recently proposed to explore this method's potential contribution to economic geography and innovation studies in more detail (Maggioni & Uberti 2011; Ter Wal & Boschma 2009).

The paper starts off with a literature overview and analysis, followed by a discussion of research gaps noticed and a proposal for inclusion of new indicators. The results of the application of the new indicators in a membrane bioreactor (MBR) TIS are presented in section 4. The paper concludes with a discussion of the consequences of the results for TIS studies in general.

2 Analyzing technological innovation systems as multi-scalar networks

The concept of TIS is rooted in evolutionary economics and developed out of a critique on spatially predefined innovation systems concepts (Carlsson & Stankiewicz 1991). A TIS is defined as

> «a set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilization of variants of a new technology and/or a new product» (Markard & Truffer 2008: 611).

Despite this geographically open definition, current TIS research has largely limited its focus on nationally delimited case studies (Coenen et al. forthcoming). This «containerization» of space and the causal priority given to the national scale is problematic as it is in strong contrast with both the general understanding of the concept and recent insights from research in economic geography.

Economic geography has a long tradition in analyzing the influence of space and place on firms and industries and on territorial development at local, regional, national and global scales (Dicken & Malmberg 2001). The effects of globalization on the spatial organization of industries and innovation have attained particularly strong scholarly interest in this realm. Recent examples comprise work on global production or value chains (HESS & YEUNG 2006), internationalization of regional innovation systems and clusters (ASHEIM & COENEN 2005; BATHELT et al. 2004; CHAMINADE & VANG 2008), or the work of COE and BUNNELL (2003), who propose to conceptualize multi-scalar innovation networks with communities of practice or transnational communities concepts. These strands of literature start from different perspectives but basically agree that innovation has to be understood as a multi-scalar process which is enacted through institutionalized networks of interaction.

In such a perspective, actors, networks and institutions will in general act at different geographic scales simultaneously and their relative importance in an innovation system may thus lie in their ability to bridge different scales (COE & BUNNELL 2003). This ability then depends on the relationships and stable cooperation pattern they build up. Innovation processes can thus be analyzed as

> «interdependent processes between territorialized, local and trans-local networks within the context of (changing) multi-level, multi-actor governance structures» (COENEN et al. forthcoming).

Such a conceptualization of space is new to TIS research. Existing approaches identify the structural components of a TIS (defined as actors, networks and institutions, see e.g. MARKARD & TRUFFER 2008) in much detail, but also in limited space, largely ignoring their (international) relational properties. Obviously, analyzing international relational properties of TIS structures poses formidable methodological challenges. It requires the inclusion of all actors, networks and institutions around the world which are relevant for a specific technological innovation. These challenges cannot be met with existing TIS analysis approaches. The proposal is thus made here to take innovation networks (in this specific case a co-publication network) as a proxy indicator for identifying relevant TIS actors and their relational positions in a wider network.

From such a network perspective, one can formulate conditions under which a national delimitation of TIS studies would make sense: firstly, boundary setting at the national scale is unproblematic if the relevant TIS structures are actually located within a specific national context. Secondly, a national focus makes sense if the underlying network is international, but disintegrates into relatively independent subsystems which are strongly concentrated in a few countries. Finally, national TIS boundaries seem appropriate if the underlying innovation network is international, but its most central actors are all located in one or a few specific countries.

3 Mapping multi-scalar innovation networks with social network analysis

Based on the above considerations, the proposal was made to analyze TIS structure based on social network analysis (SNA). The main focus of SNA lies on relationships among social entities which are analyzed as stable network structures (for an overview see WASSERMAN & FAUST 1994).

In a social network perspective, the actor network of a TIS can be analyzed at three different levels. At the first level, assessment of network coherence and density should paint a general picture of the overall «interconnectedness» of the TIS and give a basic idea of the geographic spread of relevant actors and relations. At the second level, the relational position of TIS actors may be assessed by their network «centrality». If the most central actors are concentrated on one country, a narrow spatial focus of a corresponding TIS study might be justified. If they are spread out and yet still central in diverse spatial relations, a multi-scalar perspective on the innovation system is imperative. At a third level, cohesive subgroups of close interaction in a TIS can be assessed by a measure of «clusterability». The characteristics «interconnectedness», «centrality» and «clusterability» can be operationalised with the following indicators taken from SNA:

1) «Interconnectedness»: Relations in the network can be dense or widespread, strongly integrated or split into several isolated sub-networks. Inclusiveness and mean distance can indicate the density; number of components the level of integration of actors into a network.

- Inclusiveness: Number of actors which are connected to a network expressed as a proportion of the total number of actors. If only few of the innovative actors are connected in a network, the existence of an integrated TIS in the respective field of technology is questionable.
- Mean distance: The average geodesic (shortest possible) distance between two actors. The shorter the mean distance, the tighter the overall interaction and thus the more integrated the innovation process in the TIS.
- Number of components: A component is an isolated fraction of a network. The smallest form of a component is an isolated actor. A network with many components thus indicates a fragmented TIS with either many isolated actors or several co-existing, mutually isolated subsystems. A network with only one component and dense interaction in contrast could indicate a strongly integrated TIS.

2) Centrality: Centrality of actors measures how many relations a node has with other nodes. The importance

of a TIS actor can thus be attributed to its centrality in a network structure. In this paper, centrality is assessed by the combination of «degree centrality» and «betweenness centrality».

- Degree centrality is computed by counting the number of nodes that are directly adjacent to an actor. The higher the degree centrality of an actor, the more direct connections it has to potentially complementary sources of innovation and consequently the more favourable the position of that actor in the TIS.
- Betweenness centrality: This indicator measures the extent to which an actor lies on the shortest (geodesic) path between all other pairs of nodes. An actor with high «betweenness centrality» thus potentially controls a strategic position to disseminate information in the TIS.

Once the most central actors of a TIS are identified and characterised, the next step is to map their location in order to highlight spatial concentrations.

3) Clusterability: SNA offers tools to analyse cohesive subgroups in a network. Identifying the geographic outreach of subgroups of dense interaction allows quantifying to what extent an innovation is developed in a «global» network and to what extent the respective system is just a set of loosely interrelated regional or national agglomerations of innovative activity.

Due to limited space, the focus here is on the indicators of «interconnectedness» and «centrality»; subgroups are merely identified with network visualization. A more detailed analysis of all relevant characteristics may be found in Binz and Truffer (2010).

4 The multi-scalar spatial structure of the membrane bioreactor TIS

In this section, the above described analytical framework is applied to membrane bioreactor (MBR) technology, a water purification technology which was developed in a quickly expanding wastewater treatment and recycling industry. MBR technology is based on conventional biological wastewater treatment, but makes use of a micro-porous membrane which serves as a barrier for almost all germs and solid matters larger than a water molecule. Its innovation processes are engineering-driven and strongly dependent on scientific research on new membrane materials, process optimization and improvements of operation and maintenance. Tight interaction between researchers, companies and government agencies is crucial for the development and evaluation of the technology, especially in pilot plant applications. Results of these experiments are regularly published and discussed in international academic journals and at international conferences which are often jointly organized by universities and companies.

4.1 Dataset on co-publication in MBR technology

The empirical case study is thus based on co-publication analysis. The database retrieved from ISI web of knowledge contains 417 publications, covering a timeframe from 1993-2007. Affiliation information of the listed co-authors in all publications was processed manually and the cooperation information transferred to a sociomatrix. Of the 417 publications investigated, 47% represent some form of cooperation. About half of these can be qualified as international. Only 53% of the actors are universities, the rest consists of companies, government agencies and (company owned) research institutes. Thus, despite general problems with the use of data from ISI web of knowledge (see Ter Wal & Boschma 2009), the co-publication dataset underlying the research presented here, appears to cover a sufficiently valid part of the innovation network structure of the MBR TIS. Regrettably, co-publication analysis could not be complemented with a patent analysis as MBR companies are generally reluctant to patent their innovations. The co-publication network thus has to be understood as a proxy for the actor structure and relational pattern of the TIS, not as a thorough structural TIS analysis.

4.2 Interconnectedness, centrality and clusterability of the MBR TIS

The overall interconnectedness of the TIS seems to be sufficiently high. As can be seen from the inclusiveness values in Table 1, about 80% of all actors are connected to at least one other actor. Further, the network is made up of only three major components. The main component is large with 111 actors, the other

Indicator	
Number of actors	293
Number of links	709
Inclusiveness	0.802
Mean distance	7.198
Number of components > 10	3

Tab. 1: «Connectedness» measures of the MBR TIS 1993-2007
Konnektivität des MBR TIS 1993-2007
Mesures de connectivité du système d'innovation technologique MBR, 1993-2007
Source: own design, based on data from ISI web of knowledge

	Name	Country	% int. publications	Degree Centrality	Rank	Between-ness Centrality	Rank	Rank sum
1	Seoul National University	South Korea	30	0.049	6	0.053	1	**7**
2	Technical University Berlin	Germany	22.7	0.092	1	0.036	7	**8**
3	Anjou Recherche (Veolia)	France	57.1	0.049	5	0.040	4	**9**
4	Qinghua University	China	50	0.042	7	0.044	3	**10**
5	Berlin Centre of Competence for Water	Germany	40	0.060	3	0.030	9	**12**
6	University of Montpellier	France	36.7	0.035	11	0.051	2	**13**
7	Cranfield University	UK	28.6	0.039	9	0.037	6	**15**
8	Centre International de Recherche sur l'Eau et l'Environnement (Suez)	France	87.5	0.057	4	0.024	13	**17**
9	International Institute of Infrastructure, Hydraulic & Environmental Engineering	Netherlands	100	0.032	13	0.033	8	**21**
10	Asian Technology and Research Network (Suez)	Malaysia	100	0.039	8	0.022	14	**22**

Tab. 2: Most central actors in the innovation system of MBR technology
Zentralste Akteure im Innovationssystem der MBR-Technologie
Acteurs les plus centraux du système d'innovation technologique MBR
Source: own design, based on data from ISI web of knowledge

two are much smaller (14 and 11 actors, respectively). The mean distance between actors of 7.2 is a relatively small value, indicating a close interconnectedness of the TIS. As a comparison, mean distance of 6 is usually attributed to dense «small world» networks (GRANOVETTER 2003).

The interconnectedness values thus show that the network of the MBR TIS is a well-connected structure, linking actors from 36 countries. It is not a conglomerate of loosely connected components.

Table 2 gives an overview of the centrality values in the TIS. Degree and betweenness centrality were assessed independently and actors ranked according to their sum of both indicators. The resulting list of the ten most central actors is therefore based on an equally weighted assessment of two centrality values. The ranking suggests the following: firstly, the core of the MBR TIS is dominated by two distinct sets of actors – transnational corporations which perform R&D in their own specialized research institutes, and public universities. Secondly, it is difficult to identify a geographic core of innovative activity from the given data. Germany, France and South Korea achieve the highest values among the most central actors, but no spatial concentration is visible.

In addition, the most central actors are either nationally or internationally well connected. German and South Korean actors achieve their high centrality from cooperation ties at a national or subnational level, whereas actors from Spain, Belgium, France and the Netherlands appear to be more centrally positioned in international networks. Thus it appears that in terms of centrality, this TIS does not have a clear geographic concentration of ties which would justify a national TIS case study.

The third aspect to be discussed here is clusterability. The discussion is based on Figure 1, which visualizes the innovation network of MBR technology. As may be observed, the figure reveals a fairly globalized network

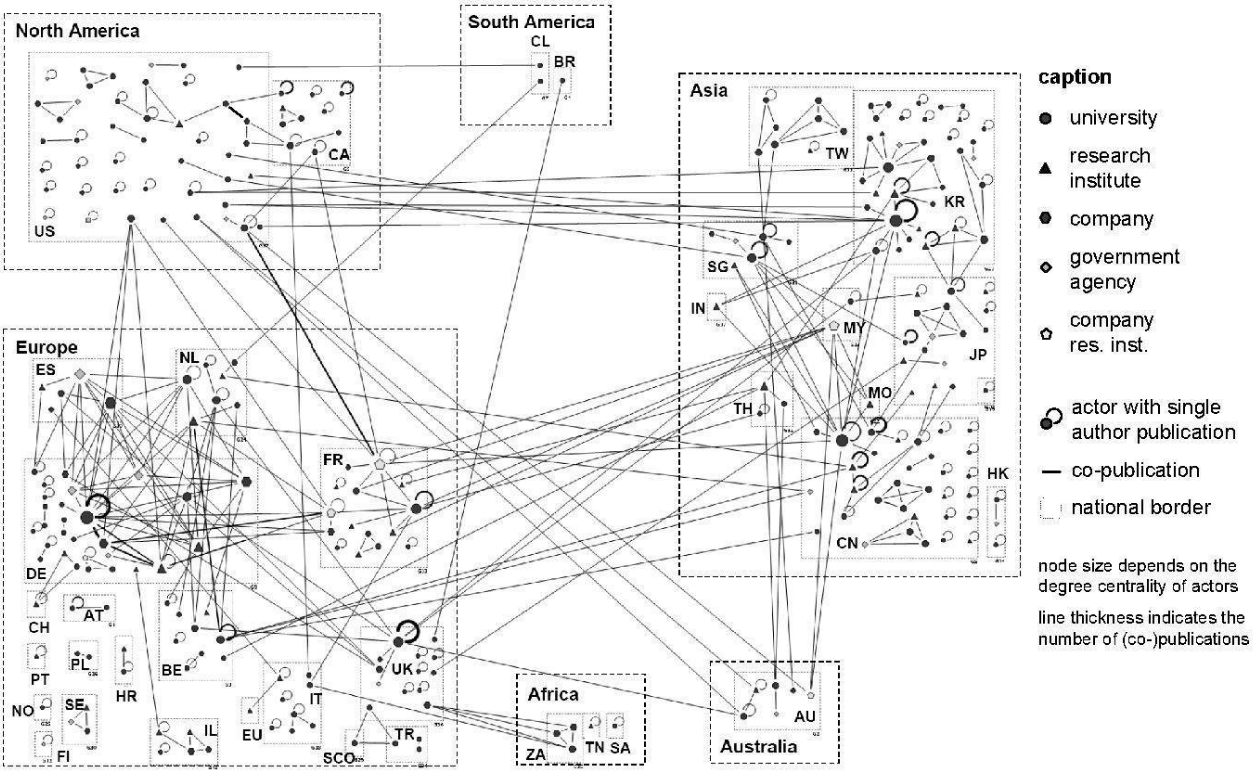

Fig. 1: Co-publication network of MBR technology, cumulated 1993-2007
Ko-Publikationsnetzwerk der MBR-Technolgie, kumuliert 1993-2007
Réseau de co-publications du système d'innovation technologique MBR, valeurs cumulées 1993-2007
Source: own design, picture generated with Net Miner 3 software

spanning predominantly between Europe and Asia. The small size of US nodes indicates that North American actors occupy a relatively peripheral position in the overall network. At the same time, tight interaction is now more visible at other geographic scales. South Korea and Germany show clustered cooperation structures. In these countries, technology development is thus embedded in a combination of national and international links and partnerships. French actors in contrast have strong ties both to European and, in particular, Asian actors. The French company owned research institutes therefore fulfill a bridging function between Asian and European actors. Finally, also on a sub-continental level, clustered innovative activity is particularly visible in the European Union.

5 Conclusions

In this paper, a set of basic characteristics of the relational and multi-scalar spatial structure of TIS was discussed based on indicators derived from social network analysis.

The presented case study shows that multi-scalarity is strong in the MBR TIS. Relevant actors interact at different spatial levels and it is hard to define one scale which is the most appropriate to characterize a «core» of this system. The presented results thus enable identification of three types of possible errors in a containerized TIS study. Firstly, an «isolation error» as in the case of the United States: Here, a nationally delimited study would retrieve valid results, as many actors and basic networks are present, indicating an emerging TIS. However, a containerized study would completely miss the fact that (seen from a relational perspective) US actors innovate decoupled from a much larger, international innovation network of the same technology. Secondly, an error of «omitted context»: In the cases of Germany and South Korea, the national scale is important, but about 30% of the innovation activity is embedded in international networks. A study focusing exclusively on German (or South Korean) actors is thus legitimate, but should be conducted with much attention to international relations. The case of France finally illustrates a «system misinterpretation error». Here, the national and subnational scales are not relevant. French actors are predominantly active in international networks developed by transnational water companies. A national delimitation of the innovation system study would thus lead to a complete misinterpretation of the most relevant scale of innovative activity of French actors.

Despite the presented advantages of applying social network analysis to TIS studies, some major caveats have to be added. Clearly, the analysis of a social network can only allow interpretations about structural and relational patterns in a TIS, it can neither directly allow assumptions about the quality of interaction nor about the important influence of institutional context factors on the innovation process (Sunley 2008). Furthermore, the use of secondary data, such as co-publications, patents, joint-venture databases or internet flows, poses some major conceptual and methodological problems which are identified in Ter Wal and Boschma (2009).

Nevertheless, it is argued here that the presented approach opens a new perspective on the conceptualization of space in TIS which provides a potentially fertile ground for future research at the interface of innovations system studies, economic geography and social network analysis. In particular, the application of this approach to technologies already investigated by containerized TIS studies could help to encourage a discussion on the validity of published results and on how to develop unbiased spatial system delimitation in future studies.

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References

Amin, A. (2002): Spatialities of globalisation. – In: Environment and Planning A 34, 3: 385-399.
Asheim, B.T. & L. Coenen (2005): Knowledge bases and regional innovation systems: comparing nordic clusters. – In: Research Policy 34, 8: 1173-1190.
Bathelt, H., Malmberg, A. & P. Maskell (2004): Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation. – In: Progress in Human Geography 28, 1: 56.
Berkhout, F., Angel, D. & A. Wieczorek (2009): Sustainability transitions in developing Asia: are alternative development pathways likely? – In: Technological Forecasting & Social Change 76, 2: 215-217.
Binz, C. & B. Truffer (2012): Conzeptualizing leapfrogging with spatially coupled innovation systems: the case of onsite wastewater treatment in China. – In: Technological Forecasting & Social Change 79, 1: 155-171.
Binz, C. & B. Truffer (2010): International technological innovation systems – a relational analysis of the innovation geography of membrane bioreactor technology. – Paper presented at the 8th Globelics international conference, 1-3 November 2010, Kuala Lumpur, Malaysia.
Carlsson, B. (2006): Internationalization of innovation systems: a survey of the literature. – In: Research Policy 35, 1: 56-67.
Carlsson, B. & R. Stankiewicz (1991): On the nature, function and composition of technological systems. – In: Journal of Evolutionary Economics 1, 2: 93-118.
Chaminade, C. & J. Vang (2008): Globalisation of knowledge production and regional innovation policy: supporting specialized hubs in the Bangalore software industry. – In: Research Policy 37, 10: 1684-1696.
Coe, N. & T. Bunnell (2003): «Spatializing» knowledge communities: towards a conceptualization of transnational innovation networks. – In: Global Networks 3, 4: 437-456.
Coenen, L., Benneworth, P. & B. Truffer (forthcoming): Towards a spatial perspective on sustainability transitions. – In: Research Policy.
Dicken, P. & A. Malmberg (2001): Firms in territories: a relational perspective. – In: Economic Geography 77, 4: 345-363.
Dicken, P. (2007): Global shift: mapping the changing contours of the world economy. – 5th edition, New York: The Guilford Press.
Granovetter, M. (2003): Ignorance, knowledge, and outcomes in a small world. – In: Science 301, 5634: 773-774.
Hess, M. & H. Yeung (2006): Whither global production networks in economic geography? Past, present and future. – In: Environment and Planning A 38, 7: 1193-1204.
Maggioni, M. & T. Uberti (2011): Networks and geography in the economics of knowledge flows. – In: Quality and Quantity 45, 5: 1031-1051.
Markard, J. & B. Truffer (2008): Technological innovation systems and the multi-level perspective: towards an integrated framework. – In: Research Policy 37, 4: 596-615.
McKelvey, M., Alm, H. & M. Riccaboni (2003): Does co-location matter for formal knowledge collaboration in the Swedish biotechnology–pharmaceutical sector? – In: Research Policy 32, 3: 483-501.
Niosi, J. & B. Bellon (1994): The global interdependence of national innovation systems: evidence, limits, and implications. – In: Technology in Society 16, 2: 173-197.
Sunley, P. (2008): Relational economic geography: a partial understanding or a new paradigm? – In: Economic Geography 84, 1: 1-26.
Ter Wal, A. & R. Boschma (2009): Applying social network analysis in economic geography: framing some key analytic issues. – In: Annals of Regional Science 43, 3: 739-756.
Wasserman, S. & K. Faust (1994): Social network analysis: methods and applications. – Cambridge: Cambridge University Press.

Abstract: Technological innovation systems in multi-scalar space. Analyzing an emerging water recycling industry with social network analysis
The technological innovation system (TIS) concept has established a strong tradition in analyzing emerging environmental industries. Despite the growing evidence of globalization of innovation activities, TIS literature has so far mostly focused on nationally bound systems. The present paper proposes an analytical framework for assessing the international dimension of TISs by adopting a relational view on actors and networks. Social network analysis provides indicators for specifying the errors which spatially «containerized» TIS studies are likely to commit. The framework is applied to a co-publication dataset on membrane bioreactor (MBR) technology, which reveals a strongly international and multi-scalar TIS structure. The findings suggest that the definition of spatial boundaries deserves much more attention in innovation studies. Economic geographers could play an important role in developing the concepts needed.

Keywords: environmental innovation, technological innovation system, relational space, social network analysis, membrane bioreactor

Zusammenfassung: Technologische Innovationssysteme in multi-skalarem Raum – Analyse einer neuen Wasserrecycling-Industrie mit Sozialer Netzwerkanalyse
Das Konzept der technologischen Innovationssysteme (TIS) hat eine lange Tradition in der Analyse von neu entstehenden Umweltindustrien. Trotz zunehmender Evidenz der Globalisierung von Innovationsprozessen hat die TIS-Literatur bisher vor allem auf national eingegrenzte Systeme fokussiert. Basierend auf einem relationalen Raumverständnis entwickelt dieser Beitrag einen analytischen Rahmen für die Untersuchung der internationalen Ebene von Innovationssystemen. Indikatoren aus Sozialer Netzwerkanalyse werden auf eine Ko-Publikationsanalyse im Innovationsfeld der Membranbioreaktor (MBR)-Technologie angewandt. Die Resultate identifizieren ein stark internationales und multiskalares Innovationssystem, welches Rückschlüsse auf drei Arten von Fehlern ermöglicht, welche in den bestehenden räumlich «containerisierten» Studien zu technologischen Innovationssystemen eingebaut sein können. Der räumlichen Abgrenzung von Innovationsstudien sollte folglich viel grössere Aufmerksamkeit gewidmet werden. Wirtschaftsgeographen könnten eine wichtige Rolle in der Entwicklung der relevanten Konzepte spielen.

Schlüsselwörter: Umweltinnovation, Technologisches Innovationssystem, Relationaler Raum, Soziale Netzwerkanalyse, Membranbioreaktor

Résumé: Systèmes d'innovation technologique dans un espace multi-scalaire. Analyse des réseaux sociaux d'une industrie émergente de recyclage de l'eau
Le concept de système d'innovation technologique (TIS) a depuis longtemps permis d'analyser les industries émergentes actives dans le champ de l'environnement. En dépit de l'évidente mondialisation des activités d'innovation, la littérature basée sur les TIS a jusqu'ici concentré ses travaux sur des systèmes nationaux. Cet article propose un cadre analytique qui permette de mesurer la dimension internationale des TIS, en adoptant une approche relationnelle des acteurs et de leurs réseaux. L'analyse des réseaux sociaux fournit des indicateurs permettant de mettre en évidence les limites des études TIS existantes, qui se bornent artificiellement aux ensembles nationaux. Le cadre analytique appliqué à la base de données des co-publications relatives à la technologie des bioréacteurs à membranes (MBR) révèle une structure fortement internationale et multi-scalaire du système d'innovation. Ces résultats suggèrent que la définition des frontières spatiales doit recevoir une attention accrue dans les études sur l'innovation. La géographie économique pourrait jouer un rôle important dans le développement de concepts appliqués à cette problématique.

Mots-clés: innovation environnementale, système d'innovation technologique, espace relationnel, analyse des réseaux sociaux, bioréacteur à membrane

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