Research Policy 38 (2009) 655–667

Contents lists available at ScienceDirect

Research Policy

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

Prospective analysis of technological innovation systems: Identifying technological and organizational development options for biogas in Switzerland

Jochen Markard*, Martin Stadelmann, Bernhard Truffer

Department Cirus - Innovation Research in Utility Sectors, Eawag, Swiss Federal Institute of Aquatic Science and Technology, 8600 Dübendorf, Switzerland

ARTICLE INFO

Article history:
Available online 3 March 2009

Keywords:
Variation
Technological innovation systems
Development options
Foresight
Biogas

ABSTRACT

In this article, we put forward a concept for the identification and analysis of future development options of technological innovation systems. The key element of our approach, the so-called variation analysis, is a methodology to identify coherent socio-technical and organizational variants within a specific innovation field. Consistent combinations of these two dimensions may be interpreted as nuclei for alternative future developments of innovation systems. The method may be used in discursive foresight processes to inform strategy formulation of firms or policy makers who see a utility in furthering the innovation field. The paper has a focus on developing the theoretical background and the analytical structure of the methodology. Empirically, we illustrate the method for the innovation system of biomass digestion in Switzerland.

1. Introduction

Assessments of future development options of novel technologies or products are of key importance for firms, policy makers and other societal actors who have an interest in the diffusion of the innovation or who are influenced by it. Predictions about potential application contexts or future market shares, for example, are highly relevant in any technology evaluation endeavor. The high degree of uncertainty associated with most innovation processes, however, strongly limits the possibility of predicting actual courses of technological development. These restrictions apply all the more for innovations that are radical and/or in an early state of development. As a consequence, forecasts about innovation success trying to extrapolate from past experiences and current trends have time and again shown low predictive validity. As an alternative, foresight and scenario methods have gained considerable attention both at the level of individual strategy formulation of firms or as tools to coordinate different actors in politics or industry (de Jouvenel, 2000; Eriksson and Weber, 2008; Postma and Liebl, 2005; Ringland, 1998; van der Heijden, 2000; Truffer et al., 2008). These approaches acknowledge that the future cannot be known in advance and a broad range of developments is possible. Still, they have been criticized for often paying very little attention to the co-evolution of technological and societal processes (Elzen et al., 2004; Hofman et al., 2004), which would both be needed to reach specific end states described by the scenarios. Furthermore, scenario methods often lack a theoretical foundation that explicitly elaborates on the interaction between different actor strategies, the role of specific actor networks and institutions as well as learning processes and other cumulative effects.

The present paper addresses these gaps as it provides a theoretically substantiated basis for prospective innovation studies. It introduces and empirically illustrates a methodology that helps to analyze future development options within a chosen innovation field.[1] The proposed approach accounts for the fundamental uncertainties which are associated with radical and systemic innovation processes and therefore does not aim to predict future development states of a technology. Rather, it aims at identifying coherent technological variants and actor constellations, which – together with institutional structures – represent 'configurations that work', i.e. plausible options of how the corresponding innovation field may look like in the future. Whether and which of these alternatives will actually be realized depends, of course, not only on the strategies of actors in the innovation field (e.g. firms, associations or policy makers) but also on supportive or hindering developments in the broader context.

* Corresponding author. Tel.: +41 41 823 5671; fax: +41 41 823 5375.
E-mail address: jochen.markard@eawag.ch (J. Markard).

0048-7333/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.respol.2009.01.013

[1] We will use the term *innovation field* (or technological field) as a general reference to a domain of technological change we are interested in. The scope of such a field is essentially defined by the research interest of each particular study. The notion *technological innovation system* is used more restrictively. Firstly, it refers to an analytical concept (see section 2). Moreover, we also use the term to refer to a specific technological field in empirical terms, which exhibits a minimal degree of 'systemness' including a critical number and variety of actors, specific institutions and beginning market transactions (cf. Markard and Truffer, 2008b).

Our approach draws on recent findings from research on innovation systems (e.g. Carlsson et al., 2002; Edquist, 2005) and technological transitions (e.g. Rip and Kemp, 1998; Geels, 2002). In particular, we build on the framework of technological innovation systems (Markard and Truffer, 2008b). At the core of our approach lies what we call *variation analysis*, the identification of socio-technical and organizational variants that may form the basis of future developments within a technological innovation system. With regard to socio-technical variation, we suggest identifying potential technological designs and application contexts that are coherent. And in terms of organizational variation, how key innovation tasks may be organized and carried out by specific groups of actors in the innovation system will be analyzed. Note, that the general idea of identifying coherent variants has also been explored in studies on design spaces and fitness landscapes (e.g. Frenken, 2000; Frenken and Nuvolari, 2004).

The proposed approach is different from conventional strategic planning in firms as it takes an explicit systems perspective and emphasizes interdependencies between different actors. It also distinguishes itself from a narrow technology policy perspective by considering a range of different technological configurations, actor roles and network structures. The perspective adopted here may be a useful starting point for strategic analyses at different levels. At the level of individual firms, for instance, it may help to reflect and assess an innovation strategy against the context of a specific innovation system. And at the level of policy making, the methodology may be instructive for balancing between the promotion of specific socio-technical configurations and the maintenance of a broader portfolio of alternatives.

A recent approach with a somewhat similar ambition has been proposed by Hofman et al. (2004). Their 'socio-technical scenarios' draw on insights from the study of technological transitions (e.g. Kemp et al., 1998; Rip and Kemp, 1998) with a particular focus on the multi-level perspective (Geels, 2002). Another related approach is the Socrobust methodology (Laredo et al., 2002), which builds on similar theoretical foundations to support innovation management in the case of particularly uncertain innovations. While we are sympathetic with these concepts, we follow a more exploratory approach focusing on emerging technological innovations and the variety of development options instead of starting with a desired regime shift, or a specific future end state respectively. Both the 'emerging technology perspective' and the 'regime perspective' imply a normative stance assuming that the analysis is used in the decision about what is needed to either support the diffusion of a desired technology or to trigger the transformation of an existing regime into a more sustainable configuration. Our intention with the proposed method, however, is primarily explorative and not normative.

Empirically, we will illustrate our approach with a case study on anaerobic biomass digestion, a technology that uses substrates such as manure, agricultural residues, organic wastes or energy crops to produce biogas. Biogas can then be converted into electricity and heat or used as a fuel for cars or busses. Biomass digestion is a rather mature technology and represents a radical innovation in the field of electricity supply due to its decentralized nature. The technology has reached a phase of broader diffusion in countries where governmental support for the use of renewable energy sources has been strong such as Germany, Denmark or Austria (Markard et al., 2005; Negro and Hekkert, 2008; Raven and Gregersen, 2007). In countries where frame-conditions are less favorable, biomass digestion diffusion is much less widespread or limited to certain regions (Markard et al., 2005; Negro et al., 2007; Stadelmann, 2006). Here we present empirical findings from Switzerland, which belongs to the latter category.

The remainder of this text is structured as follows. In Section 2 we present the conceptual framework on which our approach is based and show how our approach relates to similar methods such as foresight or scenario techniques. This is followed by a presentation of the proposed methodology in Section 3. Sections 4–6 cover the empirical application of our approach with the 'basic analysis', 'context analysis' and 'variation analysis'. Section 7 finally summarizes and discusses our findings.

2. Theoretical framework of the analysis

Innovation processes are often highly complex as technological developments interact with social, economic and political dynamics. This leads to non-linearities, co-dynamics and a high degree of uncertainty, which strongly limit the possibility of predicting actual courses of technological innovation or the application of forecasting methods. Still, there is a strong need in innovation management and technology policy making to assess future development paths of innovations in order to develop effective innovation promotion strategies. How can this gap be bridged?

In theoretical terms, the non-linearities and co-dynamics of innovation processes have been explicitly addressed by scholars working with innovation system concepts (see Carlsson et al., 2002; Chang and Chen, 2004 or Edquist, 1997 for an overview). Key resources for innovation success and supportive institutions are supposed to emerge out of the interaction between different actors, i.e. through their actual commitments and innovation activities in networks. Such emergent properties are beyond the control of individual innovators and can also not just be provided by political framework conditions. An analytical focus of innovation system concepts is thus on emergent effects or system functions. Most of the attempts to formalize these meso-level concepts originated in the tradition of evolutionary economics.

The multi-level perspective, a related approach to study technological change, has also origins in evolutionary economics but additionally draws on insights from sociology and historical analyses of innovation processes (e.g. Geels, 2002; Geels and Schot, 2007). Emphasis here is on socio-technical configurations which may dominate a certain sector over a specific period in time. Such an established, coherent configuration of scientific knowledge, technological designs, user preferences and institutions is labeled as a socio-technical regime (Hoogma et al., 2002; Kemp et al., 2001). These regimes and their predominance are influenced by external, the so-called landscape factors and challenged by technological alternatives in niches that may not have yet developed a coherent set of institutions and support structures.

For the following analyses, we will use a framework that combines the innovation systems perspective on emerging technologies and the key elements of the multi-level approach. This framework has been elaborated elsewhere (Markard and Truffer, 2008b). It has a technological innovation system (TIS) at its core, which we 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 and Truffer, 2008b, p. 611).

The TIS is embedded in a context, or environment, which supports and constrains its development potentials. The context consists of established socio-technical regimes, landscape factors and competing as well as complementary technological innovation systems (see also Fig. 3). In our view, a major advantage of the combined framework is that it complements the innovation systems perspective with a much more elaborate understanding of the structures and processes in its environment. In addition, it adds a more thorough understanding of processes and functions to