Research Contributions to Organizational Sociology and Innovation Studies / Stuttgarter Beiträge zur Organisations- und Innovationssoziologie

SOI Discussion Paper 2012-01

Organising a Market

Photovoltaics in Germany

Gerhard Fuchs and Sandra Wassermann

University of Stuttgart
Germany
Institute for Social Sciences
Organizational Sociology and Innovation Studies

Gerhard Fuchs and Sandra Wassermann

Organising a Market. Photovoltaics in Germany

SOI Discussion Paper 2012-01
University of Stuttgart
Institute for Social Sciences
Department of Organizational Sociology and Innovation Studies

Prof. Dr. Ulrich Dolata
Seidenstr. 36
D-70174 Stuttgart
Tel.: ++49 (0) 711 / 685-81001
Fax: ++49 (0) 711 / 685-81006
http://www.uni-stuttgart.de/soz/oi/

Research Contributions to Organizational Sociology and Innovation Studies
Discussion Paper 2012-01 (April 2012)
ISSN 2191–4990

Gerhard Fuchs and Sandra Wassermann are scientists at the University of Stuttgart, Institute for Social Sciences, and research fellows at the Helmholtz Alliance "Future Infrastructures for Meeting Energy Demands - Towards Sustainability and Social Compatibility".

gerhard.fuchs@sowi.uni-stuttgart.de
sandra.wassermann@sowi.uni-stuttgart.de

Additional downloads from the Department of Organizational Sociology and Innovation Studies at the Institute for Social Sciences (University of Stuttgart) are filed under:

http://www.uni–stuttgart.de/soz/oi/publikationen/

Abstract

The article analyses the case of a successful innovation in the energy sector: the development of a market for Photovoltaics. It argues that - given the special characteristics of the energy sector – successful innovation depends on strong political support and an advocacy coalition. The method chosen to realize a successful innovation constituted the creation of a quickly expanding niche market especially with the help of regulatory instruments.

Zusammenfassung

Die Märkte für Energie waren lange Zeit sowohl durch ihre politische Konstitution wie durch ihre Stabilität gekennzeichnet. Unsicherheit wurde in nahezu allen Staaten reduziert durch mehr oder weniger strikte Vorgaben des Staates oder regulatorischer Einrichtungen. Die Energiemärkte befinden sich jedoch seit einigen Jahren weltweit in Bewegung. Die in Europa insbesondere von der Europäischen Kommission vorangetriebene Liberalisierung der Energiemärkte, die noch voll im Gange ist, verbunden mit den Bemühungen Klimapolitik zu betreiben und neue Diskussionen um die Sicherheit der Energieversorgung haben die Frage nach der Konstitution der Märkte und dem Umgang mit Unsicherheiten virulent werden lassen. In diesem Zusammenhang stehen verschiedene Versuche, die Bedingungen wirtschaftlichen Handelns auf den Energiemärkten auf lokaler, regionaler, nationaler wie internationaler Ebene neu zu bestimmen. Gegenstand des vorliegenden Papiers ist die Entwicklung auf einem Marktsegment des Energiebereichs, dem Markt für netzgekoppelte Photovoltaik.

Contents

1 Introduction

The energy supply system in industrialised nations is changing in ways that are often conceived of as a technological and institutional regime change. Victor (2002) sees the sector in its third structural transformation. The exact outcome of this regime change is uncertain as of yet, but one element of a future governance structure will be the increased importance of decentralised forms of electric power generation, a shift towards more environmentally sustainable technologies, such as renewable energy technologies, which in the past were pushed forward by a diverse coalition of actors. This article will focus on one of the most innovative developments in the area of renewable energy technologies: photovoltaics (PV).

We will use a broad lens in order to examine the growth of PV as a source of electric power generation and as a business sector in Germany. PV can be considered an unusual success story in which political actors' ability to make a significant impact on renewable energy production and the associated economic activity looms large.

It will be argued that the growth of renewable energy takes place within networks of governance comprising formal regimes at multiple levels, informal norms and practices, as well as market structures and processes. Actors within these networks include national and sub-national authorities, multilateral institutions, firms and NGOs. Technological development and market growth of PV are thus viewed as embedded in a broad social, economic, and political system of governance. Corporate strategies, social movements and public policy interact within, as well as constitute, the essential elements of governance in this sector. We will further argue that policy on PV in Germany is characterised by a specific mission orientation, the concentration of main actors, a long term orientation and substantive subsidies. PV is a successful, as well as a "planned" innovation, something quite uncommon in the literature on innovation. Caniels and Romijn (2008: 246) have argued that within the literature on strategic niche management there is a shortage of analyses focussing on success stories and a lack of understanding about the processes by which (policy and technological) experiments culminate in viable market niches that ultimately will contribute to a regime change in a specific sector. This article attempts to fill that gap. This article develops the main points in several steps. To set the stage, we will clarify our concept of innovation and describe the elements of the technological system of PV. Based on these introductory remarks, we will discuss the factors responsible for PV's breakthrough. It is too early to claim that PV will continue to be a success story in the future and that PV will eventually play a dominant role in the development of a new energy regime. PV is growing but it is still not in a settled and stable state – albeit already larger than many "established" sectors. The particular technological and institutional prerequisites enabling photovoltaics' achievements have not been studied in great detail. Main lessons from this unique case are reiterated in the concluding remarks.

2 Innovation and Sectoral Systems of Innovation

Before discussing German innovation policy focussing on the development and market expansion of photovoltaics, we have to establish the conceptual foundations of our analysis. We start with some general reflections on innovation and innovation policy, drawing from the literature on systems of innovation and strategic niche management on the one hand and the advocacy coalition approach on the other.

2.1 Innovation Policy

Since the 1990s a global shift in policies towards research and technology can be observed: the promotion of innovation has become a centre piece of official national as well as of supra- and sub-national policies. This shift in emphasis reflects discussions on the role of the state in promoting technology, as well as new ideas about how new technologies become successful in various markets.

The traditional model in research and technology policies either centred on the support of basic research, which eventually should bring about new technologies ripe for the markets (technology push), or opted for a mission oriented approach deciding to support a specific technology and financing its development through specific companies or research laboratories. (Hiskes and Hiskes 1986).

Innovation research, however, has shown that there is no linear development from basic research to successful technological innovation in the market. Support of basic research does not guarantee the eventual development of products that become widely accepted and thus achieve commercial success. But “market success” has become a top priority in times of increasing worldwide competition in crowded markets. The introduction of new, innovative products is considered to be a precondition for maintaining a competitive edge. In order to be commercially successful, it is of vital importance to reach a critical mass within a comparably short time frame (Rogers 1995: 313ff.).

In related discussions of the state’s influence on technological innovation processes, a dire picture has been painted, accentuating the conviction that the state is unable to pick technologies that will later succeed on the market. Along with an increasingly prevalent attitude that markets are the best innovators and should be left alone, policy instruments worldwide seem to converge, looking increasingly alike (Holzinger et al. 2007). This neoliberal understanding, the support for markets, and “the retreat of the state” (Strange 1996), emerged in the 1990s and was accompanied by new types of policies and policy instruments which also affected the design of technology policy. Research and technology policy was transformed into innovation policy and mainly focused on funding basic research and network activities, as well as joint projects between firms and research institutes in order to stimulate knowledge flow and to ensure that the results of scientific research could be used and adopted commercially (Nooteboom 1999; Edquist 2001: 18). Public actors, however, were not supposed to select a certain technology in advance and would abstain from market stimulation programmes. Networks can potentially facilitate producer-customer relationships or can even result in the creation of advocacy coalitions. These are considered an important pre-condition for successful radical innovations by most experts (Weimer-Jehle and Fuchs 2007).

Although the market discourse had achieved nearly universal legitimacy, counter tendencies have always been visible as well. Complexity theory and the literature on governance have aimed at creating a new understanding on the role of politics (Kappelhoff 2000; Werle and Schimank 2000): On the one hand, social developments are unpredictable and evolutionary, but on the other hand these evolutionary dynamics have always been accompanied by conscious planning and shaping (Czada and Schimank 2000). Thus, political actors are seen as interacting in governance networks together with other actors who also try to influence social developments. One of the measures relying more directly on the activities of public actors is the politically supported creation of niche markets. This new form of innovation policy selects a certain technology (or precursors to a technology) in advance and tries to accelerate its development. It might even help to shape the mode of its application. Such politically created niche markets work through market stimulation programmes, such as subsidies or the provision of soft loans for prospective customers, as well as through modes of legitimising the developing technology, in order to raise its public acceptance (Edler 2007). Especially in the area of environmental technologies, strategic niche management has increasingly become accepted as an instrument of innovation policy (Kemp et al 1998; Kemp 2002; Coenen 2002) in the hopes that even the transformation of entire technological regimes is a viable option (Berkhout et al. 2003: 4; Caniels and Romijn 2008).The design of national policies has to consider existing institutional frameworks and socio-cultural conditions. Work in the tradition of the Varieties of Capitalism approach claims, that if national innovation policy stresses national comparative institutional advantages, it can be more successful. In other words, a system dominated by non-market coordination will have difficulties pushing new technologies dependent on a flexible and quick functioning market mechanism. On the other hand, the support of technologies which require the non-market coordination of various actors will be difficult to put into effect in liberal market economies. Based on this highly stylised interpretation we argue that the creation of (sheltered) niche markets can be a successful policy instrument especially in coordinated market economies (hypothesis 1).

Considering the fact that photovoltaics can be seen as a technological innovation that is supported in order to transform the energy sector, the existence of political and social forces strongly opposing it for ideological as well as economic reasons (e.g. rent seeking) can be assumed. As Jänicke (1997: 7) has shown, changes in actor constellations have resulted in improved conditions for innovation in environmentally friendly products. With regard to actor constellations and situational factors enhancing policy change, the policy analysis literature refers to the role of advocacy coalitions that are crucially important in order to spur institutional or cultural changes (Litfin 2000). We will argue that the success of innovation policy depends on its ability to create and mobilise an advocacy coalition supporting the technology in question, especially if strong incumbent actors (such as the established energy providers) exist (hypothesis 2).

2.2 Innovation

Innovation can be defined as artefacts, processes, ideas and strategies, which successfully change routines and are embedded in specific contexts of development and usage. Innovation as such is not just a new idea or technical system, but one which is being successfully implemented. Innovation in this sense is not a linear process but occurs by interactive relationships and feedback mechanisms between institutional and organisational elements of science, technology, learning, production, policy, firms and potential or actual market demand. Some technologies may only become innovations due to interactions between producers and users, or the specific way, customers use and apply new technical artefacts (Malerba 2004: 24). The acceptance and use of a new technology, at any rate, plays a crucial role in the innovation process. Thus, new – and better – technologies in our context are only referred to as innovations, if their development is embedded and accompanied by the establishment of a successful industry, and if they find their way to the market.

2.3 Innovation and Uncertainty

It is generally acknowledged that economic and other activities face the problem of uncertainty (Beckert 1996). This is even more so in the case of innovations, particularly if potential new products would have to cope with incumbent products and the existing infrastructures and routines supporting them. Proven ways to cope with uncertainty are the development and reliance on routines, customs, regulations, established institutions etc.

Innovating firms may not know which application or design a new technology should be given in order for it to be successful on the market. This can lead firms to become hesitant when implementing significant changes, even as they face a volatile environment that increases pressures to introduce new products, seek new markets and introduce new technologies, practices and organisational methods into their production processes. Uncertainty can also make it more difficult for firms to obtain external funding for their innovation projects. Customers may not trust a new and unproven technology. This leads to another blocking mechanism for the diffusion of a new technology – lack of legitimacy.

Here we are confronted with the paradox that innovation, as a routine-changing mechanism, also depends on routines, albeit currently developing ones. Innovation policy can attempt to reduce uncertainty by establishing a mix of policy instruments along with a viable support coalition. Whenever innovation policy can provide technological developments with legitimacy, the financial system will become more willing to invest in innovative firms, and potential customers may feel more secure and be more inclined to purchase new technologies (Carlsson and Jacobsson 1997: 285).

The role of uncertainty can be seen very clearly in the developments of the 1990s. At one point, the German PV-industry was close to extinction and production facilities were moved, since producers could not form stable expectations as to whether the institutional framework in Germany would provide favourable conditions for the further development of the PV-industry or not.

As Edquist (2001: 17) suggests, a systemic view on innovation policy should not only analyse the role of the state but also include feedback mechanisms on how the rest of the system, social structures, routines or even discrete occurrences influence innovation policies (2001: 17). As German governance has always been characterised by close linkages and the reliance on common interests between government, industry, business associations and trade unions (Hall and Soskice 2001; Harding 2000), this established form of governance has also shaped German innovation policies and will continue to do so in the case of PV.

2.4 The Transformation of Electric Power Generation

Photovoltaics are treated as an innovation within and for the industrial sector of electric power generation. As already briefly mentioned, this sector is undergoing substantial changes in nearly all industrialized nations. The dynamics leading to these changes are also important in order to understand the case of PV, because they opened a window of opportunity which helped to push PV as a new option of energy supply.

The traditional electric power system can be looked upon as a large technical system (Mayntz and Hughes 1988), tightly coupled and run by a few, powerful incumbent actors. Energy generation is highly centralised in big power stations – open markets hardly exist. Price regulation is common and huge subsidies for the development of old and new technologies (e.g., coal, nuclear energy) make it difficult to determine “real” prices. There are suggestions that the costs of producing electricity gained out of coal or oil would double, if in transparent external costs were taken into account (Milborrow 2002). Incumbent energy technologies have received direct and indirect subsidies for decades (Jacobsson and Bergek 2004: 210). R&D expenditures in these closed markets are nevertheless low, and innovation is slow-moving and incremental. R&D expenditures depend to a very large degree on the interpretation of political signals regarding the regulation of technology.

Two trends are transforming the traditional ways: the liberalisation of infrastructures and environmental issues, in particular, concerns about “global warming”. Hopes for an effective regime to address climate change have shifted from the emphasis on a mandatory multilateral agreement, the Kyoto protocol, towards a plethora of regional, national, and sub-national programs and initiatives. Policy responses include carbon emission limits and trading systems, direct subsidies for renewable energies and Renewable Portfolio Standards that mandate the use of specific volumes of renewable energy in electricity generation. Such policy responses are required because the market will not, by itself, respond adequately to the environmental challenge. Given the rapid growth expected in global markets for low-emission technologies, the policy agenda is also driven by economic development goals, as countries vie for competitiveness and market share in these emerging fields. Liberalisation can have differing effects for renewable energies. If energy prices fall as a result of liberalisation and increased market competition (as economic theory would make us believe), the price target that renewables must meet becomes more challenging and liberalisation might prove to be an impediment for their further spread. On the other hand, policies and systems such as quotas and renewable energy certificates can be compatible with more competitive market structures as the experiences of the last years have shown – supported, for example, by a general increase in energy prices. In fact, many of the policies which have been implemented for the support of renewables operate within the framework of a transition to market liberalisation (OECD 2008).

Finally, beyond the problems of lacking transparency and the prevalence of risk-averse actors, there is the constraining factor of centralised energy infrastructures, as they have developed and have become established over decades. National grids are mainly tailored to the operation of centralised power plants and thus cement their existence. Alternative technologies like photovoltaics follow an opposite decentralised logic that does not easily fit the established technological concepts and thus face difficulties competing with incumbent technologies (Stern 2006: 355).

In sum, these conditions have led to the widely accepted conviction that policy instruments which aim to create niche markets for renewable energies are needed. Even the European Commission, which traditionally favours market instruments and is rather critical towards demand side policy actions, has opted for market stimulation programmes for renewable energy technologies (Commission of the European Communities 2005; European Parliament and Council 2001). This is true in spite of the fact that until recently the European Commission and the OECD both disapproved the German model of market stimulation, and instead had favoured quota models which use market signals in order to increase the supply of renewable energy (Busch 2005: 235).

3 Photovoltaics: Technology Characteristics

Before analysing photovoltaics as a case of successful case of innovation, we need to provide a short introduction of the technologies and applications we are talking about. Photovoltaics use solar cells to produce electric power[1]. The most common type of solar cell consists of either mono-crystalline or poly-crystalline silicon, which is conventionally produced and used in the electronics (semiconductor) industry. Crystalline silicon technologies represent 93 % of the photovoltaics world market (Solarbuzz 2007). Mono-crystalline silicon cells are characterised by their ability to convert a relatively large section of the light spectrum into electricity with an efficiency of up to 24,7 % under ideal laboratory conditions (Solarserver 2007). Polycrystalline silicon cells do not achieve such high efficiency rates, but they are less costly. The same holds for amorphous and other 'thin film' technologies that consist of cadmium telluride (CdTe) or copper indium dieseline (CIS). Due to silicon shortages since the turn of the century, research and development on non-silicon thin film technologies has become increasingly popular and remarkable reductions in production costs have been achieved.

The photovoltaic effect was first discovered by the French physicist Alexandre Becquerel in 1839. Albert Einstein's theoretical work on the photoelectric effect won him the Nobel Prize in 1921. Thus, basic research on photovoltaics has been conducted for quite some time. Yet the first applications did not appear until the 1950s, when Bell Laboratories invented the first solar cell and the US government started to use solar cells on satellites "The satellite market became the first significant commercial market and annual production rose to about 0,1 Mwp [Mega Watt peak] per year in the late 1960s." (Jacobsson et al. 2002: 10). It is striking that the first satellite project using solar power, was under US Navy management and monitored by the Department of Defense. Some authors therefore pointed out that the case of photovoltaics was one of many technological developments in which the military played a crucial role (Clark and Juma 1987: 142, Jacobsson et al. 2002: 10). Due to US export restrictions, in the 1960s the European Space Agency (ESA) had to rely on German companies such as Siemens and Telefunken to get involved in photovoltaics research and production for space programs (Jacobsson et al. 2002: 16). Since the 1970s and largely due to the oil crises, interest in the development of various terrestrial applications grew and led to further R&D activities, mainly in the U.S. and Japan. A range of off-grid applications emerged, that were mainly used for consumer electronics like calculators and watches or as stand-alone "power stations" for SOS telephones and for remote places like buoys, yachts, alpine huts and camping. Furthermore the idea of solar home systems to be employed in developing countries came up. Rather dis-

[1] Photovoltaics should not to be mixed up with solar-thermy, which uses solar radiation to produce heat.

tinct from these off-grid photovoltaics are newer forms of applications which supply electricity to the grid just as conventional power technologies. Grid-connected applications can be found as roof-top systems, ground-mounted systems or as systems integrated into house façades. However, demonstration projects which employed photovoltaics in order to supply electricity to the grid were not implemented before the 1990s. Grid-connected photovoltaics are, therefore, a rather new development and it is striking that since 1999 they have rapidly outpaced other forms of applications in International Energy Agency (IEA) reporting countries (IEA 2005).

4 Success Indicators

In this section we wish to highlight the successful development of PV with the help of quantitative indicators. In order to measure "success" we will use the indicators 'installed PV power', 'production', 'export sales', 'employees' and 'patents'. As figure 1 impressively shows, installed PV power was at a relatively low level, then doubled for the first time in 2000 and has grown continuously since then. These findings demonstrate the correlation between policy instruments that were applied by the federal Red-Green coalition government, the regulatory instrument EEG and the 100.000-roofs-programme and the expansion of the market (see below).

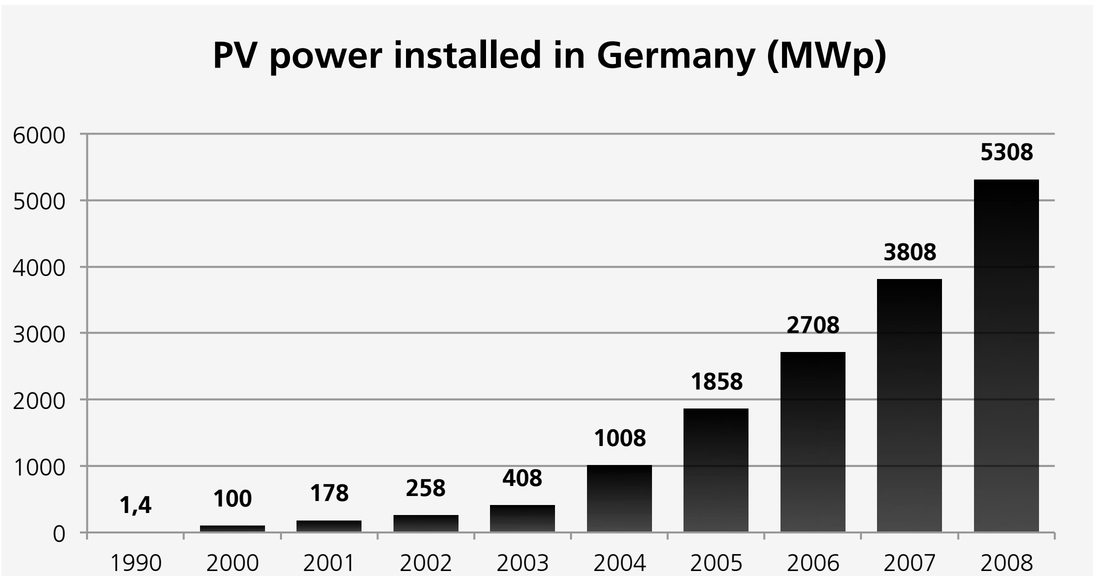

***Fig. 1**: PV power installed in Germany (MWp); (Source: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009));*

In 2005 "[…] Germany accounted for more than 93% of the EU 25" (Jäger-Waldau 2002: 75) installations. Stable political and socio-economic conditions not only convinced private households to install photovoltaic power, but solid markets also stimulate the investment in new production capacities for solar cells and modules.

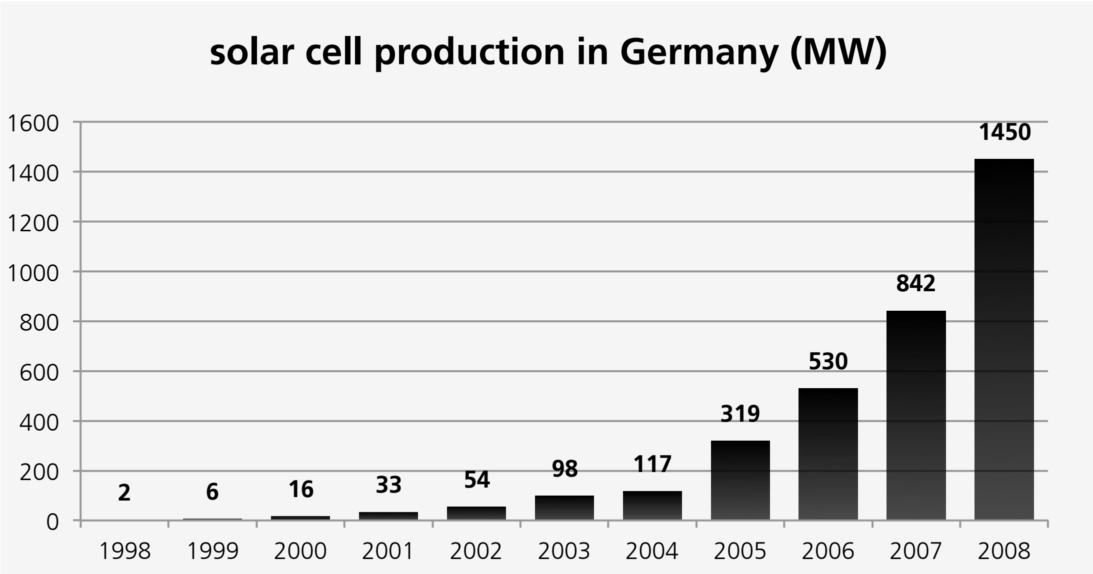

Fig. 2*: Solar cell production in Germany (MW); (Source: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009, multiple years);*

As Fig. 2 shows, cell production has grown to almost 1,500 MW annually. Sales as well as export shipments of the German photovoltaics industry have been rising with a comparable rate, as can be seen in Figs. 3 and 4.

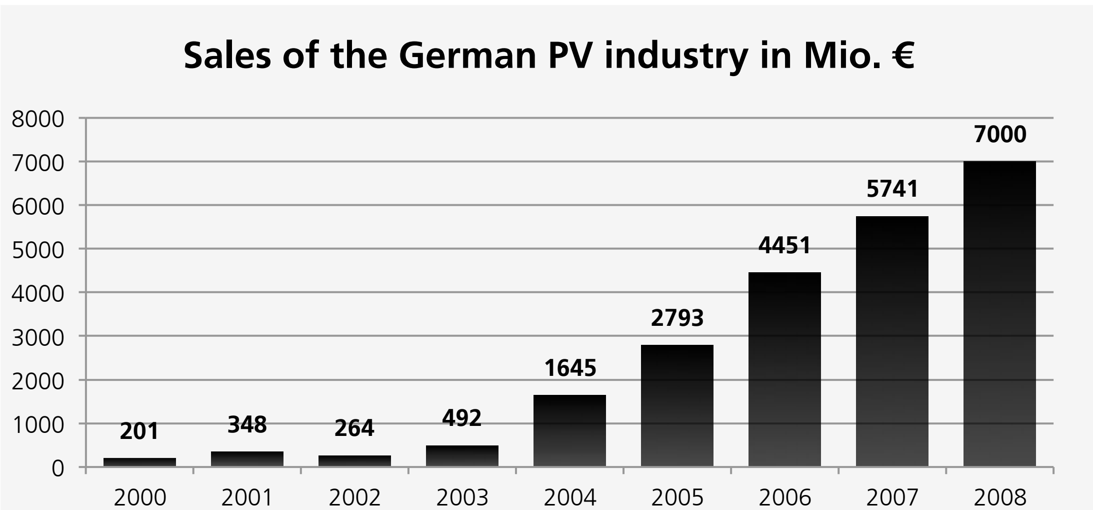

Fig. 3*: Sales of the German photovoltaics industry (Source: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2010));*

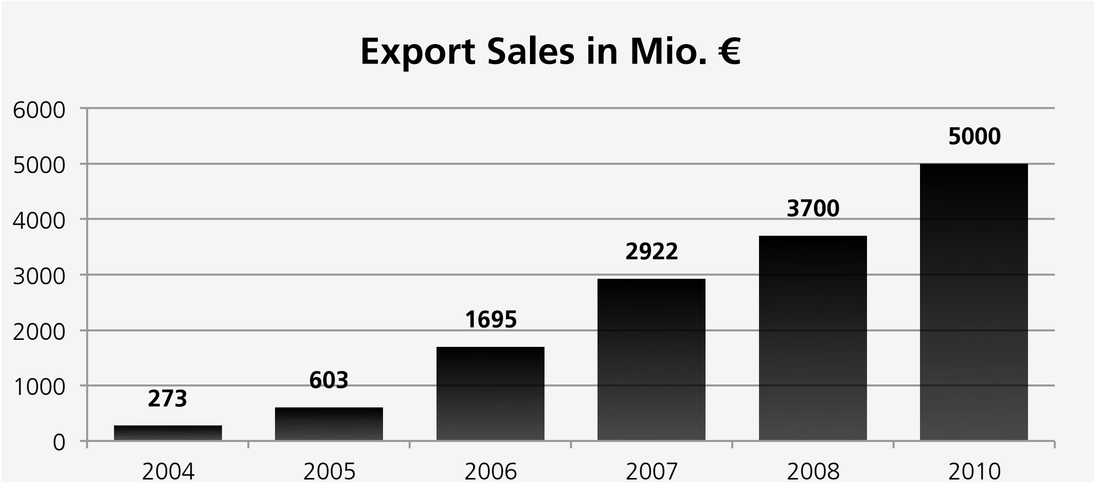

Fig. 4: *Export sales of the German photovoltaics industry (Source: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2010));*

Sales figures and numbers of photovoltaics power installed clearly show its market success. An even more common way of measuring innovation is patent data, since "[…] patents provide a uniquely detailed source of information on inventive activity" (OECD 1994: 9). As Fig. 5 shows, Japan is by far the most active nation in patent applications, followed by the U.S. and Germany.

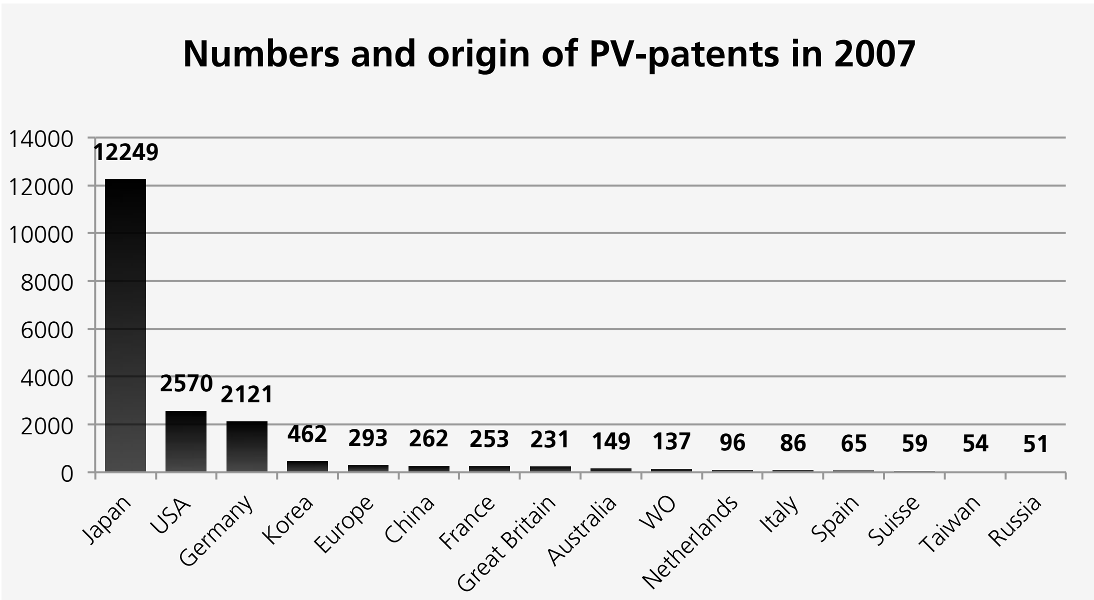

Fig. 5: *Global patent applications in photovoltaics (Source: Beucker and Fichter 2007);*

As can be seen from Fig. 6, German patent activities reflect quite well the global increase of photovoltaics patents from around 500 in the early 1990s up to around 2.000 in 2002. The numbers for Germany do not differ significantly from those for the U.S., and Germany is far ahead of other industrialised countries, such as its European neighbours. The data seems to suggest that rather than being a precondition for the further development of PV, the economic success of PV spurred hectic activities to protect intellectual property.

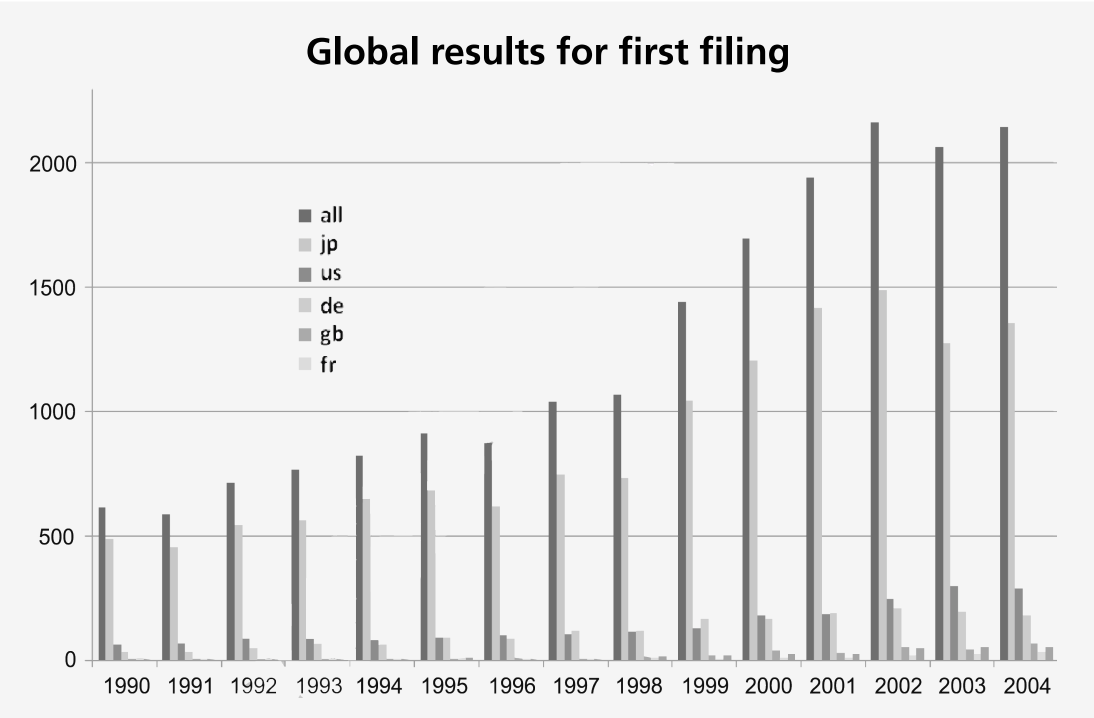

Fig. 6*: First filing of photovoltaic patents (Source: Visentin et al. 2005);*

These figures clearly prove the (at least short term) success of the PV industry. It is expanding production in Germany and off shore, it is increasing the export ratio of its production, it is employing ever more people, it is operating profitably and continually accumulates intellectual capital. Meanwhile more corporations are active in this sector and more people are employed in the sector than in many other established economic sectors (Fig 7).

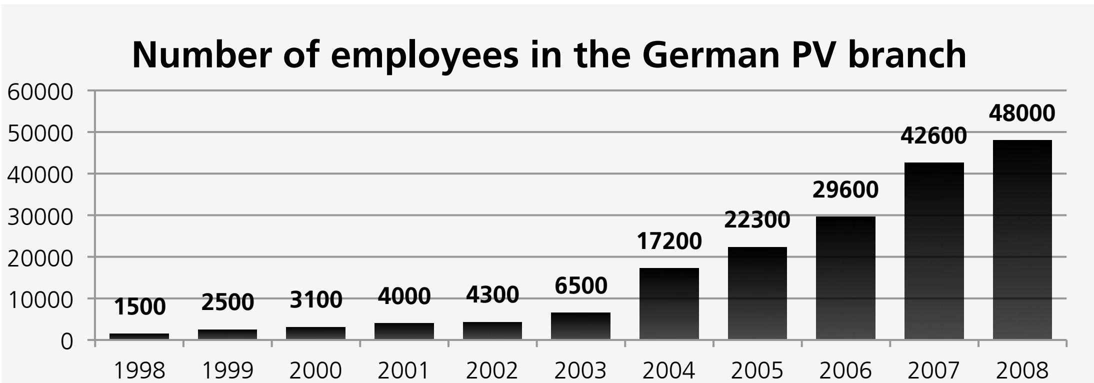

Fig. *7: Employees in the sector (Source: Bundesverband Solarwirtschaft e.V. 2010)*

5 Characteristics and development of the industry

In the following, we will analyse the development of photovoltaics based on the hypothesis that an advocacy coalition is a crucial factor for the formulation and implementation of successful innovation policies. So called advocacy coalitions supporting environmental policies consist of administrative and academic environmentalists, as well as members of environmental social movements who cooperate with industrial actors, such as manufacturers of renewable energy technologies (Jänicke 2007: 140). Lobbyism is often a conservative mechanism as it requires that the lobbyists be in a position of economic power. Therefore, one would not assume that environmentalists are able to form an effective advocacy coalition, since interest groups that support emerging technologies normally are neither well positioned financially nor do they have the ability to influence powerful political actors.

Although the photovoltaics advocacy coalition was not formed by very powerful actors and groups, it has intelligently managed to use external events to gain strong social backing for its ideas. Such support was needed as it faced powerful opponents in the incumbent energy providers. "Substituting established technologies implies, […], that new interest groups will challenge existing ones, and a realignment of the institutional framework, and a transformation of the energy provision system cannot be expected to be achieved without overcoming considerable opposition from vested interests involved with the incumbent technologies" (Jacobsson et al. 2002 : 3). In the formative stage, the PV advocacy coalition aimed to support the diffusion of the technology in order to reach the critical mass needed to achieve substantial change in the energy sector. Once this critical mass had been reached, self-stabilizing effects occurred. Consequently, the critical mass itself accounted for a further consolidation of the advocacy coalition and contributed to its success.

5.1 The Formative Stage in the 1980s

The story of PV began like many other cases in German research policy. From the early 1980s on, common instruments of public research and development funding, such as financing research departments conducting basic research on PV, were employed. The external trigger for early research had been the oil crisis in the 1970s. At that time, the ministry of research and technology (BMBT) was in charge of photovoltaics policy programmes. Initially, the support for new technology had been integrated into the unit for non-nuclear energy technologies. In 1976, a unit of its own was created (Ristau 1998: 40). Interestingly, many of the programmes financing photovoltaics projects were carried out by the ministry of economic cooperation and development, since during the 1970s the future of photovoltaics applications was seen in solar home systems for developing countries, i.e., the focus was on off-grid applications. When oil prices dropped again and the conservative-liberal coalition under Chancellor Kohl assumed power, policy actions promoting photovoltaics declined severely. In 1985 public funding of photovoltaics related research and development projects accounted to less than 53 Mio. DM. However, institutional actors involved in research on photovoltaics had been established. When external events such as the Chernobyl accident and the discussions on environmental problems and climate change emerged, these actors, together with environmentalist groups, managed to set the agenda for photovoltaics. When political actors started to attribute a higher priority on environmental problems, the Green party, on the one hand, and highly motivated researchers on the other, acted as transmission belts between external events and political and social discourses.

In the 1980s, specialized photovoltaics departments and research institutes were being created, such as the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg (in 1982), the Centre for Solar Energy and Hydrogen Research Baden-Württemberg in Stuttgart/Ulm (in 1988) or specialised physics departments, for example at the Carl von Ossietzky University in Oldenburg. The latter can be seen as a typical example of how the formation of the photovoltaics advocacy coalition depended on highly committed individual actors. They were influenced by the experiences of early anti-nuclear power activists, who were criticised for their lack of reasonable alternatives for energy provision (Gabler 2007). The formation of research groups and departments dedicated to the development of alternatives to nuclear power became the first strategic step towards the formation of an advocacy coalition supporting photovoltaics. Furthermore, the creation of specialised departments and institutes attracted environmentally committed scientists. On this foundation, local networks consisting of environmentalists and researchers emerged. This was especially the case in Freiburg, where the Fraunhofer Institute for Solar Energy Systems ISE merged with a vivid environmental scene that positively influenced network activities and enabled local strategies of niche management (Niewienda 2006).

Federal innovation policy at that time was mainly carried out in the form of direct project funding. The main recipients were the Fraunhofer Institute for Solar Energy Systems, the Hahn-Meitner-Institute, the Institute for Solar Energy Supply Techniques and two industrial actors: AEG-Telefunken and Siemens Solar. The early photovoltaics programmes "provided opportunities for universities, institutes and firms to search in many directions, which was sensible given the underlying uncertainties with respect to technologies and markets" (Jacobsson and Lauber 2006: 262). Research funding was not only given to one technology, but competing technologies, such as crystalline silicon and thin-film technologies. Additionally, research and development of inverters (to make grid-connected applications work) had begun.

Interestingly, these research projects on the one hand, and the absence of market stimulation programmes on the other hand, led to an odd situation: whereas the big two German companies engaged in photovoltaics production were able to develop internationally competitive products, and German research on photovoltaics achieved a leading position in the world, the technologies developed could not be sold at home due to a lack of domestic demand (Ristau 1998: 45). Actually, photovoltaic technologies developed in Germany were ready for testing. However, owing to the characteristics of the energy sector, coupled with the difficulties of creating private demand and the absence of political interest and financial support, at that time it looked very unlikely that photovoltaics could succeed in the German market. The supporting advocacy coalition was in its infancy, consisting only of highly committed scientists, environmental groups (Gabler 2007) and the newly founded German association for Solar Energy. In these early days the advocacy coalition was too weak, particularly as it had not yet incorporated more powerful industrial lobbies. On the other hand, very influential lobby groups supporting fossil fuels and nuclear power worked hard to prevent competition from renewable energies. They joined forces with the ministry of economics (Ristau 1998: 46), and heavily relied on old research and development contacts and networks within the ministry of research (Ristau 1998: 44). Eventually, external events, such as the nuclear accident in Chernobyl in 1986, changed public opinion and the attitudes towards nuclear power substantially, and opened a window of opportunity for a general discussion on a transformation of the energy sector. Within 2 years, opposition against nuclear energy increased from 50% to over 70% (Jahn 1992). Whereas before, only the Green party had argued against nuclear power, this position was now also adopted by the Social Democrats, who opted for phasing out nuclear power plants. In addition to the national antipathy towards nuclear energy the influence of a growing Green party as well as powerful environmental movements were important factors. Considering all these 'external events', the German government – compared to other European governments relatively early – felt compelled to support research and development as well as diffusion, of renewable energy technologies, including photovoltaics.

5.2 First Attempts at Market Stimulation in the Early 1990s

Market stimulation programmes traditionally are among the policy instruments of the ministry of economics, but they were not employed until 1991. As we have mentioned before, the ministry of economics deliberately refused to support the photovoltaics research and development projects of the ministry of research. Since the new technology was definitely not economically competitive in Germany, it either had to fail, find its markets abroad (in Southern regions, as off grid applications in the developing world), or support domestically via an artificial niche market. Finally in 1991, the situation changed when the first law regulating energy feed-ins was developed and passed. The law had been initiated by Green Party and CDU/CSU parliamentarians and it could finally pass due to cross-factional support (Ohlhorst et al. 2008: 16). In the run-up to the adoption, lobbying activities for a range of different associations had been of vital importance. Besides the newly founded renewable energy associations, the incumbent association of hydropower plants was active, so that especially Bavarian parliamentarians supported the law. In retrospect, analysts assume that at the time the future impact of the law was underestimated, allowing its passage without greater difficulties (Ohlhorst et al. 2008: 17). The law described a mechanism which required utilities to remunerate energy of renewable sources that was fed into the grid. Producers of renewable electric power received 90% of the average revenue per kilowatt hour from the utilities. Even though the first feed-in law was like a market stimulation programme, it contained a market mechanism, which, at the beginning, was not seen as critical. With declining energy prices declining throughout the 1990s (mainly due to European deregulation policies), this policy instrument was too weak to trigger market expansion for photovoltaics.

This law was accompanied by the 1.000-roofs-programme in the early 1990s, which enabled first experiences with grid-connected photovoltaics applications, an initiative that can be seen as a typical instrument of strategic niche management. The 1.000-roof-programme, starting in 1991 and ending in 1995, was a mixture of demonstration and a market stimulation programme. It offered soft loans for private households who were interested in participating in the grid-connected photovoltaics test stage. The programme was not only accompanied by electro-technical and physical tests on inverters, cell duration, etc. (Grochowski et al. 1997), but also by social research which studied customers' motives and social affiliations (Gennenig and Hoffmann 1996). This first niche programme became crucial for institutional capacity building and symbolised an initial step towards a transformation of the energy sector. Routines and motives of first movers could be revealed, and thus enabled the advocacy coalition to improve its diffusion strategy by better taking into account special needs of potential users. The accompanying social research revealed that 75% of the participants were academics, and 22% were teachers. The majority declared environmental reasons as the main motive to participate in the program. Interestingly, only 15% of the participants could be characterised as real energy savers; instead the majority did not intend to abstain from comfort, for example, by changing routines. On the other hand, 38% of the participants were extremely interested in technical aspects of their PV application and carried through technical implementations on their own. 15% of the participants admitted status reasons as their main motive when purchasing their PV application. For them it was extremely important that the technology was widely visible (Genennig and Hoffmann 1996: 111).

When the 1.000-roofs-programme ended and the German government did not immediately develop follow-up programmes, "one could observe a shift in the investment activities of the big European PV-companies from Europe towards the US" (Jäger-Waldau 2002: 40). The ministry of economics created a market launch programme for renewable energy technologies in 1995. But since it only provided 4,5 Mio. DM for photovoltaics, it did not meet the expectations of the photovoltaics industry (Ristau 1998). This is a striking example for the relationship between uncertainty and innovation. Throughout the 1990s, German policy did not systematically aim to reduce uncertainty, as the programmes were inadequately financed and were not based on long-term considerations. The result was that the development of technical innovations and marketable products came to a halt. This only changed when the Green party together with the Social Democrats came into power at the federal level in 1998.

Despite the identified shortcomings, it has to be acknowledged that the 1990s can be characterised by early (successful) investments. Publicly funded R&D, as well as the first market stimulation programmes and the first feed-in law not only led to the establishment of an initial knowledge base, it also led to the creation of an embryonic advocacy coalition consisting of scientists, an infant industry and its interest groups, as well as highly committed environmentalists. Some of them appeared as first movers on the market, i.e., they were the first costumers, taking part in the 1.000-roof-programme. Even though the programme offered soft loans and the power produced was remunerated, these first users did not benefit in a monetary sense. They did not make a return on their investment, nor did they earn money. Instead they appeared as ‘the hard core’ of the advocacy coalition, mainly acting out of ideological reasons. But there was positive feedback from the early investment, which, for example, resulted in the ability of the coalition to shape further institutional change and to initiate sectoral transformation. Taken together, these first political programmes had significant effects. For one, public awareness of the new technology rose and photovoltaics received legitimacy. Political support in the form of subsidies found broad approval in public opinion. Furthermore, a number of new, often small, firms entered the market, “among these, we find both module manufacturers and integrators of solar cells into façades and roofs, the latter moving the market for solar cells into new applications” (Jacobsson and Lauber 2006: 266). Before these developments, the market had been dominated by the two big players, Siemens and AEG Telefunken. In 1991, when the 1.000-roofs-programme was initiated 99,5 % of market demand was satisfied by these two companies. Even in 1993, once the programme was opened for European competitors like BP-Solar and the Italian firm Helios, Siemens and ASE still held a market share of 70% (Ristau 1998: 48).

5.3 Strategic Niche Management in the Mid-1990s

Throughout the 1990s, industrial solar associations were gradually founded, that aimed to improve and enhance political support of the infant technology and its commercialisation. Additionally, (local) groups and societies, like the Solar Group Aachen e.V., Eurosolar (European Association for Renewable Energies), and the German Association for the Promotion of Solar Power were founded and tried to build up political momentum. These groups discussed the suitability of political instruments, including blue prints, for a new feed-in law or another roof-programme. They were joined by local politicians that strongly favoured the idea of renewable energy and opted for more decentralised energy systems. For them, grid-connected photovoltaics applications met both of these aims. So it was a coalition of local politicians, the Green party, researchers, environmental societies, and business associations that managed to influence the federal government to improve and enhance its innovation policy for photovoltaics. Especially when the 1000-roof-programme ended, strategic niche management appeared at the local level: protagonists of the solar scene were successful in implementing local feed-in laws, inspired by the Solar Group Aachen e. V. In contrast to the federal law, which only regulated the remuneration of photovoltaics power at arm's length, the concept of the Solar Group Aachen e. V. worked with cost-covering prices. The development of a policy instrument that aimed to convince users to purchase PV for return on investment reasons changed secondary aspects of the program. Still adhering to its policy core, the PV coalition learned new ways to achieve its goal. The new mechanism paved the way for the wider diffusion of photovoltaics by making them a financially attractive investment for more than just ideologically motivated environmentalists.

These initiatives were strongly supported by the infant photovoltaics industry and its associations. The solar industry intensified its lobbying. With some of the global players that were also involved in cell production, such as Siemens and ASE, becoming part of the advocacy coalition, political pressure became more effective. Siemens was already producing in the U.S., complaining that due to the lack of domestic demand in Germany, it would not make sense to come back to Germany. ASE threatened to follow Siemens, in the case that no follow-up programme would be started. In response, the federal government started debating on the 100.000-roofs-programme. This long-term-perspective for public funding to create a niche market incentivised ASE to stay in Germany and even build new production plants. It increased its capacity from 20 to 50 MW by the end of 2002 under the name of RWE-Schott Solar (Jacobsson and Lauber 2006: 268).

In the PV coalition's formative stage significant opposition arose. Industrial organizations, especially German utilities had strongly opposed political instruments to support photovoltaics, such as the early energy feed-in law from 1991 (Wong 2005: 135). In 1994, Preussen Elektra lodged a complaint against this law on the European and the federal level. Opposition formed not only due to general criticism towards subsidising renewable energy technologies, but also because of the specific design of the feed-in law, which disadvantaged some of the utilities. Since renewable energy is mainly produced in the windy regions near the coast (wind power) and photovoltaics applications are concentrated in the sunny South, this bias meant that some Northern utilities or their customers had to finance subsidies for renewable energy technologies. The case was dismissed in the courts but the discussion did not recede.

5.4 Reaching a Critical Mass (1998 – 2009)

Sabatier (1998) argued that policy change can only be achieved following external perturbations, such as changes in the government coalition or impacts from other subsystems. This also seems to be true in the case of PV. When, in 1998, the Green party, together with the Social Democrats, formed the federal government, the photovoltaics advocacy coalition took its chance. Now, it no longer had to be content with merely influencing the rebuilding of institutional frames and policy programmes from the outside of political institutions. The Greens took over the ministry of the environment and this initiated the institutionalisation of the photovoltaics advocacy coalition within the centre of political power. The situation in the late 1990s was accompanied by international and European developments, such as the liberalisation and deregulation of the energy sector. In the wake of the Kyoto protocol, international organisations as well as the European Commission made CO_2 reduction a top-priority political goal.

As a consequence, the change in political power constellations was linked to a beginning of the restructuring of the energy sector. Institutional settings and the infrastructure of the energy sector started to become more open and fluid. Corporate structures were being reorganised and replaced by more competitive management and governance structures. Thus, innovation in photovoltaics was accompanied by the re-structuring of the energy sector and social innovations, like new management concepts, new user routines, "new roles and identities of electricity customers, new policy problems, regulatory concepts, institutions and governance arrangements" (Voß et al. 2003: 4). It can be assumed that these changes and transformation processes in the sector not only shaped the background, but, more fundamentally, have been crucial factors in triggering innovation in photovoltaics. Institutional changes, such as deregulation in the energy sector and objectives formulated by the European Union concerning the transformation of the energy sector, opened up a policy window of opportunity for the success of an advocacy coalition working against the resistance of the powerful advocates of traditional energy sources. Two policy instruments were designed and implemented, which are widely believed as being decisive for the German photovoltaics success story. The actual design of the instruments was prepared and debated by solar groups, societies and associations. Groups like Eurosolar (European Association for Renewable Energies), the German Association for the Promotion of Solar Power, and Greenpeace were extremely important for an adjusted "relaunch" of the 1.000-roofs-programme and the first feed-in law of 1991. The locally prevailing feed-in tariffs could later serve as blueprints for a new feed-in system on the federal level. Furthermore, the lobbying activities of associations and environmental groups helped to shape a novel roofs-programme on a far larger scale.

In 1999, the 100.000-roof programme was created. It was a market stimulation programme, which offered soft loans with 10 years duration and 2 years free of redemption. In 2000, the Renewable Energy Sources Act (EEG) was passed. It set a fixed feed-in tariff of around 50 cents[2] per kWh for 20 years, with a 5% decrease annually for installations after 2002. Compared to the first feed-in-law, which had been heavily opposed by the utilities, the additional costs of renewable energies were now shared and only 5% of the financial charges had to be paid by the utilities. The law was inspired by the local feed-in laws for solar power. The skills that had been achieved on the local level helped the Green Party to move the concept to the federal level. For this process, it was extremely helpful that one of the main protagonists of the local groups, who had organised local feed-in tariffs, was elected as a federal deputy in 1998 and thus could bring in experiences he had on the local level (Rosenbaum et al. 2005: 79). He was among the Green deputies who initiated a discursive process involving various actors, such as environmental groups, solar industry associations, the association of the machinery and equipment producers (VDMA), the metal workers trade union, solar cell producers and politicians from some *Länder.*

This institutionalisation of an intermediate level of conflict can be interpreted along the lines of the notion of policy learning advanced by Sabatier (Sabatier and Jenkins-Smith 1993). The panel did not intend to conduct a general discussion on the future of the German energy provision system (the policy core, still separating the coalitions). Instead, it only discussed the issue of financial support for renewable energy technologies. Hence, in 1998, the Green party acted as a policy broker, searching for compromises in secondary aspects that could be supported by the majority of actors and thus enlarge and finally stabilise the advocacy coalition in a way that it would survive even without institutional backing in the future. "The unorthodox coalition even included a major utility […]; as a result the big utilities were not united in their opposition." (Jacobsson and Lauber 2006: 267). Further innovation in PV was still funded by public research grants – albeit at a decreasing rate. Public funds were concentrated more on network and cluster projects, many of which were embedded in structural policies in order to help the economically underdeveloped regions in the East of Germany. Regional cluster and network policy is a rather new policy instrument that aims to create an innovation friendly environment by fostering collective identities and trust in order to support the formation and development of local networks (Dohse 2007). Within the past few years, the solar industry has figured out where to settle down in order to receive subsidies. What we can see nowadays, are photovoltaics clusters in East Germany, predominantly located near the small town of Thalheim, in the vicinity of Bitterfeld, Saxony-Anhalt. In particular, small start-ups, which have emerged after 2000, have settled down in the East. One of the world

[2] The exact amount is subject to size and application: electricity from roof-top systems is reimbursed higher than electricity sourced from ground mounted systems.

leaders in cell production is Q-Cells, a firm, founded in Berlin in 1999, which soon moved to Thalheim in order to start cell production in 2001. Q-Cells is an example of Germany's success story, i.e., it perfectly reflects the effectiveness of the 100.000-roofs-programme and the Renewable Energy Sources Act. By the end of 2002, it employed 82 persons; at the end of 2004 it already had 484 employees, a number which has grown to 1.700 by the year 2007.

Q-Cells is also an example of how the photovoltaics industry is increasing its ability to acquire financing and venture capital from the private sector and the equity market. Since October 2005, Q-Cells is listed on the Frankfurt stock exchange, and, since December 2005, in its technology index TecDax. The first German PV firm to be listed on the stock exchange was the Solon AG in 1998. It was soon followed by Solar World AG in 1999, Sunways AG in 2001, Solar-Fabrik AG in 2002 and many others. All these companies were young start-ups, small and medium sized companies, which differed considerably from the multinational firms, such as Siemens and ASE, which had been dominating the early PV industry.

The development and success of these new firms is evidence that the industry has left the formative stage (i.e., the niche market) and has been entering the take off stage (i.e., is ready for market expansion). Market expansion and the activities of new actors in the sector have been accompanied by a significant enlargement and diversification of the photovoltaics advocacy coalition. This applies to producers as well as to users. Whereas first producers like the Freiburg Solar-Fabrik, founded in 1996 by the environmentalist Georg Salvamoser, were embedded in local solar networks and were not solely led by return on investment thinking, motives and behaviours of producers like Q-Cells, Solar World or Solon do not differ from producers in other sectors.

Additionally, due to the Renewable Energy Sources Act (EEG), users of photovoltaics are no longer necessarily led by 'green' motives, as it has increasingly become profitable to purchase solar modules, especially for farmers, who have plenty of space on their barn roofs, which can be used as building ground for the rather cheap thin film technology (Rosenbaum et al. 2005: 85). Furthermore, this development is supported by the wide acceptance of solar energy by the German public. This trend is vividly reflected in the Christian Democratic Party, which has now firmly accepted the policy of supporting photovoltaics. So, when in 2005 the Red-Green government ended and was replaced by the grand coalition of Social Democrats and Christian Democrats, the new government did not opt to take a new path. The Renewable Energy Sources Act was not abolished and a recent amendment to the law does not entail comprehensive changes for PV support.

The take-off stage has been accompanied by organizational changes that have helped to consolidate the chosen path. In 2002, after the re-election of the Red-Green government, coalition talks assigned the ministry of the environment full responsibility for renewable energies. Whereas the beginning of the formative stage had been characterised by conflicts between the ministry of economics and the ministry of research, both being rather averse to substantially supporting photovoltaics, in 2002 the situation changed completely. The ministry of the environment is now responsible for the Renewable Energy Law as well as the public financing of photovoltaics related R&D[3].

Meanwhile the photovoltaics industry in Germany is highly differentiated, thanks to its ability to build up important links to related industries. Therefore photovoltaics related R&D is not just research on new materials and cell efficiencies. The German machine building industry has benefited from the emergence of the photovoltaics industry. At the same time, German solar producers gained advantages from the expertise of the machine building industry as innovations in photovoltaics happen mainly through cost reductions in production processes. For the German machine building sector, a strategic orientation to PV manufacturing equipment can be observed. The development of 'turn-key' facilities helped to enable mass production and facilitated the standardisation process (Dewald 2007: 132). These are crucial preconditions to achieving economies of scale and making PV applications more competitive (Auer 2008: 12).

Furthermore, architects and craftsmen, especially electricians, have adapted well to the new technology as a growth option for their businesses, and associated institutions of vocational education have managed to adjust their curricula. Thus, well-known bottlenecks that often constrain the diffusion of new technologies have been overcome. The specific dynamics of the advocacy coalition described in this article can be illustrated with an examination of the machine building industry. This industry is an actor which cannot be considered to be part of the energy policy subsystem proper but is strongly supporting the PV coalition by now. At the beginning of the formative stage, there existed a single-minded coalition supporting renewable energy technologies. At that time, it shared a joint policy core, which was the transformation of the energy sector, substituting nuclear and fossil power plants for renewable energy technologies. Learning processes during the course of this stage helped to develop new policy instruments. Radical opposition against the traditional energy sector, based on theories and visions highlighting worst case scenarios on the one hand and demonstrations and blockade actions on the other, gave way to more pragmatic considerations and helped the coalition to gain political power. The new PV policy core of the transformed coalition is now characterised not as purely oppositional to traditional forms of energy supply, but as supporting PV. Its formation has been accompanied by new theories, visions and ideas on generating demand for PV by reducing costs, increasing returns, spreading information and eventually by finding

[3] Another form of institutionalisation are the so called 'Glottertal talks', which are strategic talks on photovoltaics related R&D. These talks originated in 1987, but have gained importance particularly during the last couple of years. Researchers and representatives of the leading institutes and companies meet with members of the ministry of the environment in order to discuss future public R&D activities for PV.

ways to enlarge the coalition. These dynamics have resulted in the integration of actors like the machine building industry and even some of the utilities, who either do not belong to the policy subsystem or explicitly share another policy core and representatives of various parties from the Eastern part of Germany. At this time, when the original policy core changed to support PV, the ground has been prepared for the integration of a very heterogeneous set of actors.

6 A Future for Photovoltaics? Conclusions and Lessons

At the beginning of this chapter, we claimed that the creation of niche markets can be a successful policy instrument in coordinated market economies (hypothesis 1), if a powerful advocacy coalition can be mobilised (hypothesis 2). Our analysis has shown that the support of PV after 1998 was successful in establishing a growing and profitable economic activity. The PV industry can produce and sell its products both in Germany and abroad. The story, however, also demonstrates that the success of such a policy depends on many favourable circumstances. It does not only need broad political and public support that goes beyond the initial policy core, but also a delicate architecture of instruments that are geared towards the special characteristics of the system to be supported. The policy instruments are mostly not generic, but geared towards the specific problems of the PV industry.

The success of PV is also dependent on general conditions that offer a window of opportunity for change. The electric power sector over the last years has faced new challenges. These challenges have come from market liberalization, the expectation that the sector should contribute to environmental aims, and the development of new technologies (e.g., forms of renewable energy) that are difficult to integrate into the dominant regime of the sector. PV successfully exploited the fact that it was a decentralised, small technology, which could be connected to the grid without severe difficulties and compatibility problems. It could rely on existing scientific strengths in this area, as well as the expertise of suppliers (e.g., machine building industry). Some elements of path dependency are therefore present in the development of PV.

The political instruments that were developed offered long-term security for the industry as well as incentives to build new production units in the disadvantaged regions of the new German Länder. The users of PV-modules were guaranteed a 20 year security on their investments. Consequently, PV could serve many masters. The strength of the coalition was recently demonstrated when the federal government amended the Renewable Energy Sources Act (EEG) without implementing important changes. It achieved nearly unanimous support by a public in favour of clean technologies and was supported by an advocacy coalition comprised of scientists, politicians, environmentalists and an increasingly economic group of actors.

Taken together, the many beneficial factors and the very specific composition of the advocacy coalition also point to the difficulties in imitating this successful experiment in other areas. The lesson is not that the same policy should be and can be pursued in other cases as well. The general message, rather, is that customised innovation policies need to reflect the specific conditions and opportunities in the targeted area.

References

Auer, Josef, 2008: *Deutscher Maschinenbau macht Wirtschaft fit für die Zeit nach dem Öl*. Deutsche Bank Research, Energie und Klimawandel, Aktuelle Themen 435. Frankfurt a. M.: Deutsche Bank.

Beckert, Jens, 1996: Was ist soziologisch an der Wirtschaftssoziologie? In: *Zeitschrift für Soziologie*, 25(2), p. 125–146.

Berkhout, Frans/Smith, Adrian/Stirling, Andy, 2003: Socio-technological regimes and transition contexts. *Working Paper Series 2003/3*. Brighton: SPRU Science and Technology Policy Research.

BSW-Solar, 2010: Statistic data on the German photovoltaic industry, June 2010. http://en.solarwirtschaft.de/fileadmin/content_files/factsheet_pv_engl.pdf, retrieved 31th May 2011. German Solar Industry Association.

Beucker, Severin/Fichter, Klaus, 2007: Trends und Rahmenbedingungen für das Innovationssystem Farbstoffsolarzelle – Perspektive 2020. http://www.colorsol.de/Images/Innovations-system PV tcm294-101482.pdf, last accessed 16th April 2009.

Busch, Per Olof, 2005: Institutionalisierter Politiktransfer mit Nebenwirkungen: Die Ausbreitung von Quoten und Einspeisevergütungen. In: Tews, Kerstin/Jänicke, Martin (eds.): *Die Diffusion umweltpolitischer Innovationen im internationalen System*. Wiesbaden: VS-Verlag, p. 233–255.

Caniels, Marjolein C.J./Romijn, Henny A., 2008: Strategic niche management: Towards a policy tool for sustainable development. In: *Technology Analysis & Strategic Management*, 20(2), p. 245–266.

Carlsson, Bo/Jacobsson, Staffan, 1997: Diversity creation and technological systems: A Technology Policy Perspective. In: Edquist, Charles (ed.): *Systems of Innovation. Technologies, Institutions and Organizations*. London: Pinte, p. 266–294.

Clark, Norman/Juma, Calestous, 1987: *Long-Run Economics.* London: Pinter.

Coenen, Reinhard, 2002: Umlenken auf nachhaltige Technologiepfade. In: Grunwald, Armin (ed.): *Technikgestaltung für eine nachhaltige Entwicklung.* Berlin: edition sigma: p. 389–405.

Czada, Roland/Schimank, Uwe, 2000: Institutionendynamik und politische Institutionengestaltung: Die zwei Gesichter sozialer Ordnungsbildung. In: Werle, Raymund/Schimank, Uwe (eds.): *Gesellschaftliche Komplexität und kollektive Handlungsfähigkeit.* Frankfurt a.M.: Campus: p. 23–43.

Dewald, Ulrich, 2007: *Innovationssystem Photovoltaik in Deutschland*. In: FVS BSW-Solar Themen 2007, p. 130–135.

Dohse, Dirk, 2007: Cluster-based technology policy – The German experience. In: *Industry and Innovation*, 14(1), p. 69–94.

Edler, Jakob (ed.), 2007: *Bedürfnisse als Innovationsmotor. Konzepte und Instrumente nachfrageorientierter Innovationspolitik*. Berlin: edition sigma.

Edquist, Charles, 2001: *The system of innovation approach and innovation policy: An account of the state of the art*, Lead paper presented at the DRUID conference. Aalborg, 12-15th June 2001.

European Parliament and Council, 2001: Directive/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the international electricity market. In: *Official Journal of the European Communities*, 27th Oct 2001, L238, p. 33.

Gabler, Hansjörg, 2001: Interview at the Zentrum für Sonnenenergie- und Wasserstoff-Forschung, 9th January 2007.

Genennig, Bernd/Hoffmann, Volker U., 1996: *Sozialwissenschaftliche Begleituntersuchung zum Bund-Länder-1000-Dächer Photovoltaik-Programm*, Abschlussbericht. Leipzig: Umweltinstitut Leipzig e.V.

Grochowski, Jörg/Decker, Burchard/Kiefer, Klaus/Rössler, Eberhard, 1997: Mindererertragsanalysen und Optimierungspotentiale an netzgekoppelten Photovoltaikanlagen des 1000-Dächer-Programms. In: *Forschungsverbund Sonnenenergie*, Themen 96/97, p. 32–38.

Hall, Peter/Soskice, David (eds.), 2001: *Varieties of Capitalism: The institutional foundations of comparative advantage*. New York: Oxford University Press.

Harding, Rebecca (2000): Resilience in German Technology Policy: Innovation through Institutional Symbiotic Tension. In: *Industry and Innovation,* 7(2), p. 223–243.

Hiskes, Anne L./Hiskes, Richard P., 1986: *Science, technology, and policy decisions.* Boulder/London: Westview Press.

Hoogma, Remco/Kemp, René/Schot, Johan/Truffer, Bernhard, 2002: *Experimenting for sustainable transport. The approaches of strategic niche management*. London: Spon Press.

Holzinger, Katharina/Jörgens, Helge/Knill, Christoph (eds.), 2007: *Transfer, Diffusion und Konvergenz von Politiken. Politische Vierteljahresschrift*, Sonderheft 38. Wiesbaden: VS-Verlag.

IEA, 2005: Total photovoltaic power installed in IEA PVPS countries. In:http://www.iea-pvps.org/isr/22.htm, last accessed 12th June 2007.

Jacobsson, Staffan/Andersson, Björn A./Bangens, Lennart, 2002: *Transforming the energy system – the evolution of the German technological system for solar cells,* SPRU Paper 84. Brighton: SPRU.

Jacobsson, Staffan/Lauber, Volkmar, 2006: The politics and policy of energy system transformation – Explaining the German diffusion of renewable energy technology. In: *Energy Policy*, 34, p. 256–276.

Jäger-Waldau, Arnulf, 2002: *Status of PV sesearch, Solar cell production and market implementation in Japan, USA and the European Union.* Ispra: Institute for Environment and Sustainability, Renewable Energy Unit.

Jahn, Detlef, 1992: Nuclear power, energy policy and new politics in Sweden and Germany. In: *Environmental Politics,* 1(3), p. 383–417.

Jänicke, Martin, 1997: *Umweltinnovationen aus der Sicht der Policy-Analyse: Vom instrumentellen zum strategischen Ansatz der Umweltpolitik*. Papier, vorgelegt im Rahmen des BMBF-Projektverbundes „Abschätzung der innovativen Wirkungen umweltpolitischer Instrumente“ am 9.12.1996 in Königswinter. Berlin: Freie Universität Berlin, Forschungsstelle für Umweltpolitik.

Jänicke, Martin 2007: Trendsetter im „regulativen Kapitalismus“: Das Beispiel umweltpolitischer Pionierländer. In: Holzinger, Katharina/Jörgens, Helge/Knill, Christoph (eds.): *Transfer, Diffusion und Konvergenz von Politiken*. Politische Vierteljahresschrift, Sonderhefte 38/2007. Wiesbaden: VS Verlag, p. 131–149.

Kappelhoff, Peter, 2000: Komplexitätstheorie und Steuerung von Netzwerken. In: Sydow, Jörg/Windeler, Arnold (eds.): *Steuerung von Netzwerken.* Opladen: Westdeutscher Verlag, p. 347–389.

Kemp, René, 2002: Environmental protection through technological regime shifts. In: Jamison, Andrew/Rohracher, Harald (eds.): *Technology studies and sustainable development.* München/Wien: Profil, p. 95–126.

Kemp, René/Schot, Johan/Hoogma, Remco, 1998: Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. In: *Technology Analysis & Strategic Management*, 10(2), p. 175–195.

Litfin, Karen T., 2000: Advocacy coalitions along the domestic-foreign frontier: Globalization and Canadian climate change policy. In: *Policy Studies Journal* 28(1), p. 236–252.

Malerba, Franco, 2004: *Sectoral systems of innovation. Concepts, issues and analyses of six major sectors in Europe.* Cambridge: Cambridge University Press.

Mayntz, Renate/Hughes, Thomas P. (eds.), 1988: *The development of large technical systems*. Frankfurt a. M.: Campus.

Milborrow, David, 2002: External costs and the real truth. In: *Windpower Monthly* 18(1), p. 32.

Niewienda, Andreas, 2006: Interview at DS-Plan. Stuttgart, 17th of December.

Nooteboom, Bart, 1999: Innovation and inter-firm linkages: New implications for policy. In: *Research Policy* 28, p. 793–805.

OECD, 1994: *The measurement of scientific and technological activities*. Using patent data as science and technology indicators. Patent Manual. Paris: Organisation for Economic Cooperation and Development.

OECD, 2008: *Environmental policy, technological innovation and patents*. Paris: Organisation for Economic Cooperation and Development.

Ohlhorst, Dörte/Bruns, Elke/Schön, Susanne/Köppel, Johann (2008): Windenergieboom in Deutschland: eine Erfolgsstory. In: Bechberger, Mischa/Mez, Lutz/Sohre, Annika (eds.): *Windenergie im Ländervergleich. Steuerungsimpulse, Akteure und technische Entwicklungen in Deutschland, Dänemark, Spanien und Großbritannien.* Frankfurt a. M.: P. Lang, p. 3–60.

Ristau, Oliver, 1998: *Die solare Standortfrage. Der technologische Wettstreit zwischen den USA, Japan und Deutschland.* Bad Oeynhausen: Bröer-und-Witt-Solarthemen.

Rogers, E.M., 1995: *Diffusion of innovation*. 4th edition. New York: The Free Press.

Rosenbaum, Wolf/Mautz, Rüdiger/Byzio, Andreas, 2005: *Die soziale Dynamik der regenerativen Energien – am Beispiel der Fotovoltaik, der Biogasverstromung und der Windenergie.* Göttingen: SOFI.

Sabatier, Paul A., 1998: The advocacy coalition framework: Revisions and relevance for Europe. In: *Journal of European Public Policy* 5(1), p. 98–130.

Sabatier, Paul A./Jenkins-Smith, Hank (eds.),1993: *Policy Change and Learning: An advocacy coalition approach*. Boulder Co: Westview Press.

Siemer, Jochen, 2005: Das Orakel vom Amt. Patentanmeldungen für Photovoltaik. In: *Photon* 2005(10), p. 66–70.

Solarbuzz, 2007: Solar Cell Technologies, in: http://www.sti-studies.de/fileadmin/articles /fuchs-wassermann-sti-4-2008-02.pdf, last accessed 6th of August 2007.

Solarserver, 2007: Dünnschicht-Solartechnik: Neue Technologien zur Kostensenkung der Photovoltaik, in: http://www.solarserver.de/solarmagazin/artikeljuni2006.html, last accessed 6th of August 2007.

Stern, Nicholas, 2006: *Review on the Economics of climate change*. London: HM Treasury, http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm

Strange, Susan, 1996: *The retreat of the state: The diffusion of power in the world economy.* Cambridge: Cambridge University Press.

Victor, David G., 2002: Electric Power. In: Steil, Benn et al. (eds.): *Technological Innovation and Economic Performance*. Princeton: Princeton University Press, p. 385–415.

Visentin, Alberto/Voignier, Vincent/Königstein, Christian, 2005: *Technology trends in photovoltaics for the last decade: An analysis on the basis of patent application filing data.* Unpublished Manuscript. European Patent Office.

Voß, Jan-Peter/Fischer, Corinna/Schumacher, Katja/Cames, Martin/Pehnt, Martin/Praetorius, Barbara/Schneider, Lambert, 2003: *Innovation. An integrated concept for the study of transformation in electricity systems.* TIPS Discussion Paper 3. Frankfurt a. M.: Sozialökologische Forschung.

Weimer-Jehle, Wolfgang/Fuchs, Gerhard, 2007: Generierung von Innovationsszenarien mit der Cross-Impact Methode. In: Forum für Energiemodelle und Energiewirtschaftliche Systemanalysen in Deutschland (ed.), *Energiemodelle zu Innovation und moderner Energietechnik*. Berlin: Lit, p. 37–90.

Werle, Raymund/Schimank, Uwe (eds.), 2000: *Gesellschaftliche Komplexität und kollektive Handlungsfähigkeit.* Frankfurt a. M.: Campus.

Wong, Shiu-Fai, 2005: Obliging institutions and industry evolution: A comparative study of the German and UK wind energy industries. In: *Industry and Innovation* 12(1), p. 117–145.

Further Publications

Research Contributions to Organizational Sociology and Innovation Studies

Werle, Raymund, 2011: *Institutional Analysis of Technical Innovation. A Review*. SOI Discussion Paper 2011–04.

Dolata, Ulrich, 2011: *Radical Change as Gradual Transformation. Characteristics and Variants of Socio–technical Transitions.* SOI Discussion Paper 2011–03.

Dolata, Ulrich, 2011: *The Music Industry and the Internet. A Decade of Disruptive and Uncontrolled Sectoral Change*. SOI Discussion Paper 2011–02.

Schrape, Jan-Felix, 2011: *Der Wandel des Buchhandels durch Digitalisierung und Internet*. SOI Discussion Paper 2011–01.

Books

Dolata, Ulrich, 2011: *Wandel durch Technik. Eine Theorie soziotechnischer Transformation*. Frankfurt/New York: Campus.

Schrape, Jan–Felix, 2011: *Gutenberg–Galaxis Reloaded? Der Wandel des deutschen Buchhandels durch Internet, E–Books und Mobile Devices*. Boizenburg: Hülsbusch.

Schrape, Jan–Felix, 2010: *Neue Demokratie im Netz? Eine Kritik an den Visionen der Informationsgesellschaft*. Bielefeld: Transcript.

Journal Articles and Contributions in Edited Volumes

Dolata, Ulrich, 2011: Soziotechnischer Wandel als graduelle Transformation. In: *Berliner Journal für Soziologie* 21(2), 265–294.

Dolata, Ulrich, 2009: Technological Innovations and Sectoral Change. Transformative Capacity, Adaptability, Patterns of Change: An Analytical Framework. In: *Research Policy* 38(6), 1066–1076.

Dolata, Ulrich, 2008: Das Internet und die Transformation der Musikindustrie. Rekonstruktion und Erklärung eines unkontrollierten sektoralen Wandels. In: *Berliner Journal für Soziologie* 18(3), 344–369.

Dolata, Ulrich, 2008: Technologische Innovationen und sektoraler Wandel. Eingriffstiefe, Adaptionsfähigkeit, Transformationsmuster: Ein analytischer Ansatz. In: *Zeitschrift für Soziologie* 37(1), 44–61.

Fuchs, Gerhard/Sandra Wassermann, 2012: From Niche to Mass Markets in High Technology: The Case of Photovoltaics in Germany. In: Johannes Bauer, Achim Lang, Volker Schneider (eds.): *Innovation Policy and Governance in High-Tech Industries*. Heidelberg, Berlin: Springer, 219–244.

Fuchs, Gerhard, 2010: Path Dependence and Regional Development: What Future for Baden–Wuerttemberg? In: Georg Schreyögg/ Jörg Sydow (eds): *The Hidden Dynamics of Path Dependence. Institutions and Organizations*. Houndmills: Palgrave, 178–196.

Neukirch, Mario, 2010: Windenergienutzung in der Pionierphase (1973-1991). In: *Berliner Debatte Initial* 21(4), 117–133.

Schrape, Jan-Felix, 2011: Social Media, Massenmedien und gesellschaftliche Wirklichkeitskonstruk-tion. In: *Berliner Journal für Soziologie* 21(3), 407–429.

Schrape, Jan-Felix, 2011: Was ist die ›Markenidentität‹ der Soziologie?. In: *Sozialwissenschaften und Berufspraxis* 34(2), 141–153.

Schrape, Jan–Felix, 2010: Web 2.0 und Massenmedien: Visionen versus Empirie. In: *Forschungsjournal Neue Soziale Bewegungen*, 23(3), 72–83.

Werle, Raymund, 2012: Institutions and Systems: Analysing Technical Innovation Processes from an Institutional Perspective. In: Johannes Bauer, Achim Lang, Volker Schneider (eds.): *Innovation Policy and Governance in High-Tech Industries*. Heidelberg, Berlin: Springer, 23–47.

Werle, Raymund (et al.), 2010: Software als Institution und ihre Gestaltbarkeit. In: *Informatik Spektrum* 31(6), 626–633.

Werle, Raymund/Jürgen Feick, 2010: Regulation of Cyberspace. In: Martin Cave/ Robert Baldwin/Martin Lodge (eds): *The Oxford Handbook of Regulation*. Oxford: Oxford University Press, 523–547.