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Picking A Winner? Innovation in Photovoltaics and the Political Creation of Niche Markets

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Abstract

Innovation theory has pointed to the complex, non-linear character of innovation processes. Heterogeneous networks of actors that include a mixed spectrum of academic, economic, and governmental actors and agencies combine to achieve innovations. Is there any role for innovation policy beyond influencing framework conditions in such a situation? The article analyses the case of a successful innovation in the energy sector: Photovoltaics. It argues that - given the special characteristics of the energy sector – successful innovation depended on strong political support and an advocacy coalition which achieved institutional backing. The method chosen to realize the innovation was the creation of a niche market with the help of regulatory instruments.

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1 Introduction

The energy provision system in industrialized nations is changing in what is conceived as an example of 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 decentralized forms of electric power generation, a shift towards more environmentally sustainable technologies, e.g. 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 both 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 characterized by a specific mission orientation, the concertation of main actors, a long term orientation and substantive subsidies. Insofar PV can be seen as a successful as well as a "planned" innovation, something quite uncommon in the literature on innovation. Caniels/Romijn (2008: 246) have argued that within the literature on strategic niche management there is a shortage of analysis focussing on success stories, i.e. a lack of understanding about the processes by which (policy and technological) experiments can culminate in viable market niches that ultimately will contribute to a regime change in a specific sector. This article attempts to fill that gap.

What will we be doing in the article step by step? To start with, we will clarify our concept of innovation and describe the elements of the technological system PV. Based on this we will discuss the factors responsible for its success. At the moment it would be foolish to claim that PV will remain 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 bigger than many "established" sectors. Only few publications have focused on the particular technological and institutional prerequisites, which enabled photovoltaics to become such a success story, and beating – from an innovation perspective – other energy technologies, such as fuel cell technologies. Since the success of specific technologies in a system as complex as the energy supply system at least partly depends on the interaction with and the development path of competing systems, we will shortly review some of the other renewables at the end of the article, just to get some ideas on what might have been the particular comparative advantages of photovoltaics.

2 Innovation and Sectoral Systems of Innovation

Before discussing German innovation policy focussing on the development and market expansion of photovoltaics, we have to lay down the conceptual framework of our analysis. We start with some general reflections on innovation and innovation policy, drawing on 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 the 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 on the 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. (cp. Hiskes/Hiskes 1986) Innovation research, however, has shown that there is no linear development of technological innovations towards success (on the market). Support of basic research does not guarantee the eventual development of products that become widely accepted and thus achieve commercial success. But specifically “market success” appears to have become the top priority in times of increasing worldwide competition on 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 of usage within a comparably short time frame (cf. Rogers 1995: 313ff.).

In parallel discussions on the state's influence on technological innovation processes a dire picture was painted, accentuating the conviction that the state is unable to chose technologies which will later be a success on the market. Along with an increasingly prevalent attitude that markets are the best innovators and should be left alone, policy instruments worldwide seemed to converge (cf. Holzinger/Jörgens/Knill 2007). This neoliberal understanding, the support of market dominance 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 now became 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 flows and to ensure that the results of scientific research can be used and adopted commercially (cf. Nooteboom 1999, Edquist 2001:18). Public actors – however, were not supposed to select a certain technology in advance and would rather abstain from market stimulation programmes. Networks instead were looked upon as potentially facilitating producer-customer relationships or creating advocacy coalitions for new technological applications. Advocacy coalitions are considered by most experts to be an important pre-condition for successful radical innovations (cf. Weimer-Jehle/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 aimed at a new understanding of the role of politics (cf. Kappelhoff 2000; Werle/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 (cf. Czada/Schimank 2000). Thus political actors are interpreted as actors interacting in governance networks, together with other actors who also try to influence social developments. One of the policy measures relying more 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 its pre-stage) in advance and tries to speed up its development, and even might 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 (cf. Edler 2007). Especially in the area of environmental technologies, strategic niche management has increasingly become accepted as an instrument of innovation policy (cf. Kemp et al 1998; Kemp 2002; Coenen 2002) in the hopes that even the transformation of entire technological regime is a viable option (cf. Berkhout et al 2003: 4; Caniels/Romijn 2008).

The actual 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 and uses 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 of market mechanisms. While 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 photovoltaics for ideological as well as economic (rent seeking) reasons can be assumed. As Jänicke has shown, changes in actor constellations have resulted in improved conditions for innovation in environmentally friendly products (cf. 1997: 7). 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 (cf. 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 provision system) exist (hypothesis 2).

2.2 Innovation

Changes in innovation policy are linked to a better understanding of processes of innovation. Innovation can be defined as artefacts, processes, ideas, 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. Including the processes of implementation, however, it becomes difficult to disentangle e.g. the technical artefact from the way it is being developed and used.

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 (cf. Malerba 2004: 24). The acceptance and the use of a new technology at any rate play a crucial role in the innovation process. Thus new – 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 every (economic) activity has to face the problem of uncertainty (Beckert 1996). This is even more so the case for innovations, particularly if potential new products would have to cope with incumbent products and 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, which is lack of legitimacy.

Here we are confronted with the paradox that innovation as a routine changing mechanism, nevertheless also depends on routines, albeit newly developing ones. Innovation policy can attempt to reduce uncertainty by establishing a mix of policy instruments along with a viable support coalition. Whenever, e.g. 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 securer and be more inclined to purchase new technologies (cf. Carlsson/Jacobsson 1997: 285).

The role of uncertainty can be seen very clearly when looking at the developments in the 1990s. At one point the German PV-industry was close to extinction and production facilities were moved, since producers had no certainty as to whether the institutional framework in Germany would provide favourable conditions for the further development of the PV industry.

As Edquist suggests, a systemic view on innovation policy should not only analyze 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 (cf. 2001: 17). As German governance has always been characterized by close linkages and the reliance on common interests between the governments, industry, business associations and unions (cf. Hall/Soskice 2001; Harding 2000), this established form of governance has also shaped German innovation policies and most probably will also do so in the case of PV.

2.4 Electric Power Generation as an Industrial Sector

Photovoltaics are treated as an innovation within and for the industrial sector of electric power generation. As already briefly mentioned this sector is undergoing severe 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 forward the new option PV.

The traditional electric power system can be looked upon as a large technical system (cf. Mayntz/Hughes 1988), tightly coupled and run by a few, powerful incumbent actors. Energy generation is highly centralized in big power stations, open markets hardly exist. Price regulation and fixation 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 hidden external costs were taken into account (cf. Milborrow 2002: 32). Incumbent energy technologies have received direct and indirect subsidies for decades (cf. Jacobsson/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 now changing the traditional ways: the liberalisation of infrastructures and environmental issues, namely "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 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 targets that renewables must meet become 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 has shown – supported e.g. 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 (Cf. 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 support their existence. Alternative technologies like photovoltaics follow an opposite decentralised logic that does not easily fit the established technological concepts and thus faces difficulties competing with incumbent technologies (cf. Stern 2006: 355).

In sum this has led to the widely accepted conviction that policy instruments which aim to create niche markets for renewable energies were 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 (cf. European Commission 2005; Directive 2001/77/EC). 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 (cf. Busch 2005: 235).

3 Photovoltaics: Technology Characteristics

3.1 Technologies

Before analyzing photovoltaics as a successful case of innovation, we need to provide a short introduction to 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 (cf. 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 (cf. Solarserver 2007). Poly-crystalline silicon cells do not achieve such high efficiency rates, but they compensate by being 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.

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

3.2 Applications

The photovoltaic effect was first discovered by the French physicist Alexandre Becquerel in 1839. Albert Einstein's theoretical work on the photovoltaic effect won the Nobel Prize in 1921. Thus basic research on photovoltaics has been conducted for quite some time. Yet the first applications did not appear before 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 per year in the late 1960s" (cf. 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 (cf. Clark/Juma 1987: 142, Jacobsson et al 2002: 10). Due to US export restrictions the European Space Agency had to rely on German companies such as Siemens and Telefunken to get involved in photovoltaics research and production for space programs in the 1960s (cf. 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 USA 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 distinct 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. Thus grid-connected photovoltaics are a rather new development. It is therefore striking that since 1999 grid-connected photovoltaics have rapidly outpaced other forms of application in IEA (International Energy Agency) reporting countries (cf. IEA 2005).

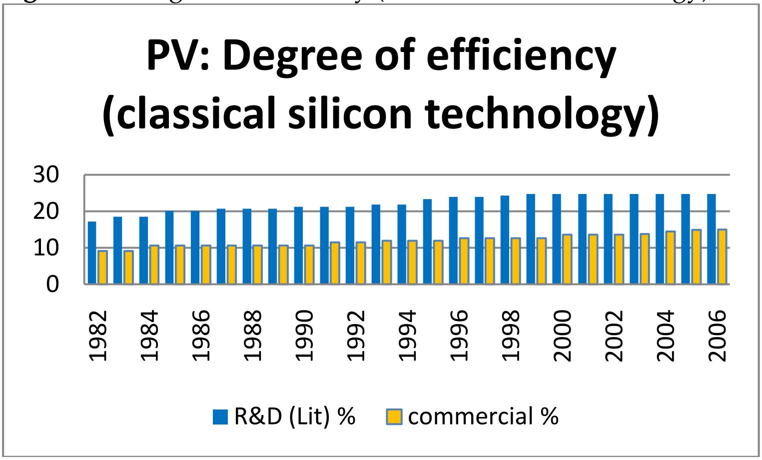
The degree of efficiency of the modules depends on the specific technology used. For all technologies it can be stated that huge differences exist between laboratory values and values that are achieved using products for the market:

Table 1: Degree of efficiency of various technologies.

	mono-Si (Silicium technology)	**poly-Si (Silicium technology)**	**CulnSe2 (CIS techno-logy)**	**CulnS2 (CIS technology**
Lab cells				
small area, 1 cm2	24,7%	20,3%	19,3%	13%
large area, 150 cm2	21,5%	17,6%	-	-
Current module production				
Optimum value	17%	14,5%	12%	-
Typical	13,5%	13%	11%	8,5% (pro-jected)
Future module production				
In 10 years	20%	18%	15%	15%
In 30-40 years	22%	22%	20%	-

Source: Krewitt et al 2005: 25

Fig. 1: PV - Degree of efficiency (classical silicon technology).



Source: own illustration based on data from: Surek (2003) and Nemet (2005)

4 Promoting Photovoltaics

In the following we will analyse the development of Photovoltaics based on the hypothesis that an advocacy coalition is a crucial mechanism behind the formulation and implementation of innovation policies. "Private firms, state agencies and other organisations often act with the objective to influence innovation policies in order to get them designed and implemented in their own interest" (cf. Edquist 2001: 20). 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 (cf. Jänicke 2007: 140). But since lobbyism is often a conservative mechanism, as it requires that the lobbyists be in a position of economic power, one would not assume that environmentalists were able to form an effective advocacy coalition, since interest groups that support emerging technologies normally are not well positioned financially, neither 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 intelligently managed to use external events to gain strong social backing for its ideas, which was needed, as it faced powerful opponents in form of incumbent energy provision systems. "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)

We will show how in the formative stage, the PV advocacy coalition aimed to support the diffusion of the technology in order to reach a critical mass, which was needed for a substantial change in the energy sector. Once this critical mass had been reached, self-stabilizing effects occurred. As a consequence, the critical mass itself accounted for a further consolidation of the advocacy coalition and contributed to its success.

4.1 The Formative Stage

The story of PV began like many other cases of German research policy. From the early eighties 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 (BMFT) 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 (cf. 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 had settled down again and as the conservative-liberal coalition under Chancellor Kohl came into 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. Albeit 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 gave environmental problems a higher priority, the Green party on the one hand and highly motivated researchers on the other hand acted as transmission belts between external events and political and social discourses.

In the 1980s specialized photovoltaics departments and research institutes had been 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 made by early anti-nuclear power activists, who were criticised for their lack of reasonable alternatives for energy provision (cf. 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 had been created and merged with a vivid environmental scene, that positively influenced network activities and enabled local strategies of niche management (cf. Niewienda 2006).

Federal innovation policy at that time became mainly 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" (cf. Jacobsson/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 the odd situation, that 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, but the technologies developed could not be sold at home due to a lack of domestic demand (cf. 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 on the German market. The supporting advocacy coalition was in its infancy, consisting only of highly committed scientists, environmental groups (cf 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 (cf. Ristau 1998: 46), and heavily relied on old research and development contacts and networks within the ministry of research (cf. Ristau 1998: 44).

But eventually external events, such as the nuclear accident in Chernobyl in 1986 changed public opinion and the attitudes towards nuclear power substantially and opened up a window of opportunity for a general discussion on a transformation of the energy sector. Within two years opposition against nuclear energy increased from 50% to over 70% (cf. 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 – at a relatively early stage felt compelled to support research, development as well as diffusion of renewable energy technologies, such as photovoltaics.

Market stimulation programmes are traditionally policy instruments of the ministry of economics and were not used before 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. And 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 supported domestically via an artificial niche market. Finally in 1991, the situation changed when the first feed-in-law 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 (cf. Ohlhorst et al. 2008: 16). In the run-up to the adoption, lobbying activities of 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 assumed that at the time the future impact of the law had been underestimated, which is why it was passed without much difficulty (cf. Ohlhorst et al. 2008: 17). The law described a mechanism which required utilities to remunerate energy of renewable sources 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 sort of a market stimulation programme, it contained a market mechanism, which at the beginning was not seen as critical, but with energy prices declining throughout the 1990s (mainly due to European deregulation policies), this policy instrument ended up being too weak to trigger market expansion for photovoltaics.

This first feed-in-law was accompanied by the 1000-roofs-programme in the early 1990s, which enabled first experiences with grid-connected photovoltaics applications and thus can be interpreted as a typical instrument of strategic niche management. The

1000 roof programme that started in 1991 and ended in 1995 was a mixture of a demonstration and 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 (cf. Grochowski et al 1997), but also by social research which studied customers' motives and social affiliations (cf. Gennenig/Hoffmann 1996). This first niche programme became crucial for institutional capacity building and symbolized 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, for example by better taking into account special needs of potential users. The accompanying social research revealed that ¾ 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 characterized 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 them 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 (cf. Gennenig/Hoffmann 1996: 111ff.). Additionally, the programme enabled photovoltaics to gain more public awareness. Backed by the feed-in-law, which obliged utilities to remunerate energy of renewable sources fed into the grid, the improvement of inverters laid down the grounds for structural changes within the energy sector, abandoning traditional centralised grid systems, giving way for decentralised, environmental friendly systems, such as grid connected photovoltaics applications.

When the 1000 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 started 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 (cf. Ristau 1998). So this is a striking example for the relationship between uncertainty and innovation, since throughout the 1990s the 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 on the federal level in 1998.

Despite its shortcomings, it still 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 did not only lead 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, which means they were the first costumers, taking part in the 1000-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, which means they did not really get anything out of their investment, neither did they earn money. Instead they appeared as 'the hard core' of the advocacy coalition, mainly acting out of ideological or reputational reasons. But there was positive feed-back from those early investments, 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 thing public awareness of the new technology rose and photovoltaics received legitimacy. Thus public and social acceptance of the technology as well as political support, i.e. subsidising it, 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 facades and roofs, the latter moving the market for solar cells into new applications" (Jacobsson/Lauber 2006: 266). Before this, the market had been dominated by the two big players, Siemens and AEG Telefunken. The following figures provide an indication of the their market dominance. In 1991, when the 1000-roofs-programme was initiated, 99,5 % of market demand was satisfied by these two companies. And 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% (cf. Ristau 1998: 48).

Throughout the 1990s, industrial (solar) associations were gradually established 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 discussed the suitability of political instruments, were developing blue prints for a new feed-in-law or another roof-programme and tried to build up political momentum. They were joined by local politicians that strongly favoured the idea of renewable energies 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-roofs-programme ended, strategic niche management appeared on 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 aims to convince users purchasing PV for return on investment reasons can be interpreted as a change in secondary aspects. Still adhering to its policy core, the PV coalition learned new ways to achieve its goal. Thus the new mechanism paved the way for the wider diffusion of photovoltaics by making them a financially attractive investment not only for ideologically motivated environmentalists.

These initiatives were strongly supported by the infant photovoltaics industry and its associations. The solar industry intensified its lobbying, and in particular due to 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. As Siemens was already producing in the USA, complaining, that due to the lack of domestic demand in Germany, it would not make sense, coming back to Germany and ASE threatened to follow Siemens, in the case that no follow up programme would be started; the federal government started a debate on the 100.000-roofs-programme. This long-term-perspective for public funding i.e. creating a niche market was the reason for ASE to stay in Germany and even build up new production plants. It increased its capacity from 20 to 50 MW by the end of 2002 under the name of RWE-Schott Solar (cf. Jacobsson/Lauber 2006:268).

In the PV coalition's formative stage significant opposition arose. Industrial organizations, especially German utilities strongly opposed political instruments to support photovoltaics, such as the early energy-feed-in-law from 1991 (cf. 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 it was also the specific design of the feed-in law, which indeed 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 respectively, had to finance subsidies for renewable energy technologies. The case was dismissed in the courts, but the discussion did not recede.

4.2 Take-Off

Following Sabatier's argument, 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 did not have to be content any more 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 trends, 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 CO2 reduction a top priority political goal.

As a consequence, the change in political power constellations was linked to a beginning restructuring of the energy sector. Institutional settings and the infrastructure of the energy sector started to become more open and fluent. Corporate structures were being reorganised and became 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" (cf. Voß et al. 2003: 4). It can be assumed that these changes and transformation processes in the sector did not only shape 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 against the opposition of the powerful advocates of incumbent 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 has been 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 1000-roofs-programme and the first feed-in-law of 1991. The locally installed feed-in-tariffs could now 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-program on a far larger scale. On this basis in 1999 the 100.000 roof programme was started. It was a market stimulation programme, which offered soft loans with 10 years duration and two years free of redemption. In 2000 the Renewable Energy Law was passed. It set a fixed feed-in tariff of around 50 Cent[2] per kWh for 20 years, with a 5% decrease annually for later installations from 2002 on. 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 five per cent 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 learning effects 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 made on the local level (cf. Rosenbaum et al 2005: 79). He was among the Green deputies, who initiated a discur-

[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.

sive 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 Sabatier's policy learning. 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 enlarging and finally stabilising 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/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 (cf. Dohse 2007). Within the last years, the solar industry has well understood 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. Particularly small start-ups, which have emerged after 2000, have settled down in the East. One of the world leaders in cell production became 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 one example of Germany's success story, i.e. it perfectly reflects the effectiveness of the 100.000-roofs programme and the Renewable Energy Law. 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 in the year 2007.

Q-Cells also can be used as an example of how the photovoltaics industry is now increasingly able 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 the Solar World AG in 1999, the Sunways AG in 2001, the Solar-Fabrik AG in 2002 and many others. All these companies were young start-ups, small and medium sized companies which considerably differ 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 can be interpreted as 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.

The market expansion and the activities of new actors in the sector have been accompanied by the 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 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 (cf. Rosenbaum et al 2005: 85f.).[3] Furthermore, this devel-

[3] The literature on strategic niche management sees the prevalence of economic motives as an impediment to the success of policies (Hoogma et al.

opment is supported by the wide acceptance of solar energy within the German public. This trend is vividly reflected in the Christian Democratic Party, which now has well 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 Law was not abolished and it is safe to say, that the recent amendment of the law does not entail comprehensive changes for PV support.

The take-off stage has also been accompanied by organizational changes, which 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 of competences between the ministry of economics and the ministry of research, both being rather averse to substantially supporting photovoltaics, in 2002 the situation had 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.[4] Meanwhile the photovoltaics industry in Germany is highly differentiated, thanks to its ability to employing diverse methods of production and in its capability to build up important links to supplier industries. Therefore photovoltaics related R&D is not just research on new materials and cell efficiencies. Especially the German machine building industry has benefited from the emergence of the photovoltaics industry, much like German solar

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2002). We are arguing that exactly the opposite mechanism (addressing economic motives) has been essential for the success of PV policies.

4 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.

producers gained advantages from the expertise of the machine building industry nearby – since; as we have stated before, 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 (cf. Dewald 2007: 132). These are crucial preconditions in order to achieve economies of scale and making PV applications more competitive (cf. Auer 2008: 12).

Furthermore architects and craftsmen, especially electricians have adapted well to the new technology as a growth option for their businesses and the institutions of vocational education managed to adjust their curricula. Thus well-known bottle-necks that often constrain the diffusion of new technologies have been overcome.

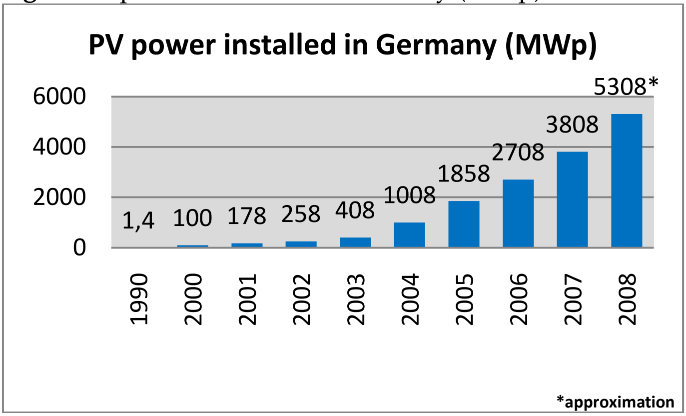
Looking at the machine building industry, an actor which cannot be considered to be part of the energy policy subsystem proper, but is strongly supporting the PV coalition by now, the specific dynamic of the advocacy coalition described in this article can be illustrated. At the beginning of the formative stage, there was 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. Then learning processes during the course of this stage, helped to develop new policy instruments. Former 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 hand, 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 pure opposition, 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 ways to enlarge the coalition. These dynamics resulted in the integration of actors like the machine building industry, even some of the utilities, who either do not belong to the policy subsystem or explicitly share another policy core and cross party members from the Eastern part of Germany. At this time, when the original policy core (transformation) was changed by the formerly secondary aspect, ‘supporting PV’, the ground was prepared for the integration of a very heterogeneous set of actors.

4.3 Success Indicators

In a next step we intend to highlight the successful development of PV with the help of some quantitative indicators. In order to measure ‘success’ we will use the indicators ‘installed PV power’, ‘production’, 'export sales’, ‘employees’ and ‘patents’.

As figure 2 impressively shows, installed PV power was on 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. 2: PV power installed in Germany (MWp).



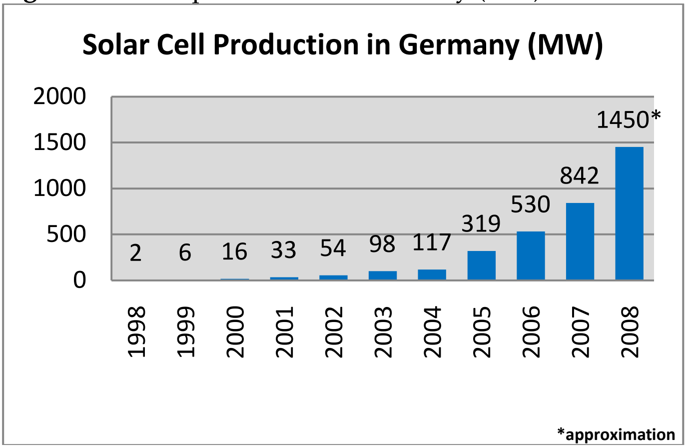
Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009)

In 2005 "…Germany accounted for more than 93% of the EU 25" (Jäger-Waldau 2006: 75) installations. The data for 2004 and 2005 are not totally reliable though, as there exist huge discrepancies in the reported data, since after the end of the 100.000 roofs programme in 2003 and the revision of the EEG in 2004, no procedure had been established to register the dramatic increase of installations (cf. Jäger-Waldau 2006: 77).

Stable political and socio-economic conditions do not only convince private households to install photovoltaic power installations, but solid markets also stimulate the investment in new production capacities for solar cells and modules.

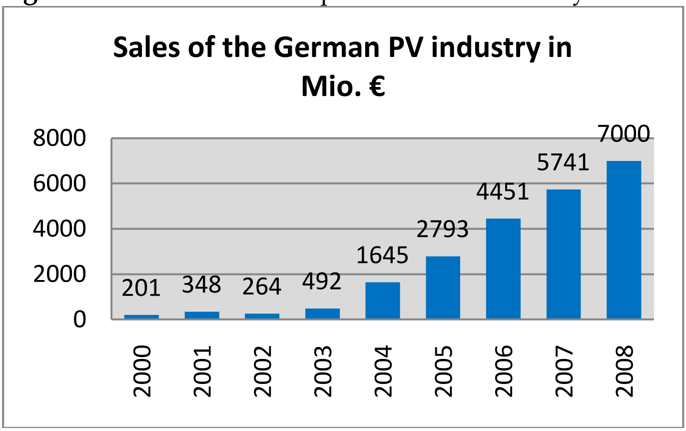
As figure 3 shows, cell production has grown to almost 1500 MW annually. Sales as well as export shipments of the German photovoltaics industry have been rising with a comparable rate, as can be seen in figures 3 and 4.

Fig. 3: Solar cell production in Germany (Mw).



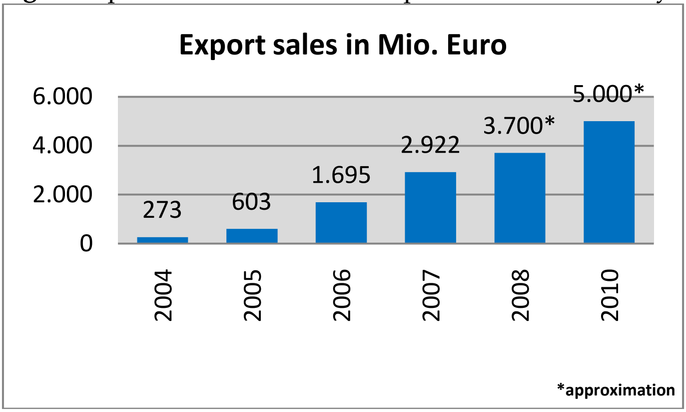
Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009)

Fig. 4: Sales of the German photovoltaics industry.



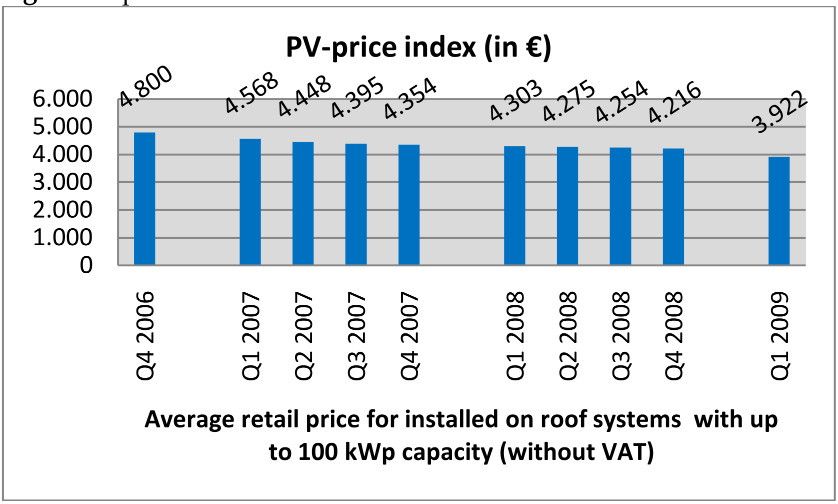
Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009)

Fig. 5: Export sales of the German photovoltaics industry.



Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009)

Fig. 6: PV-price index in €.

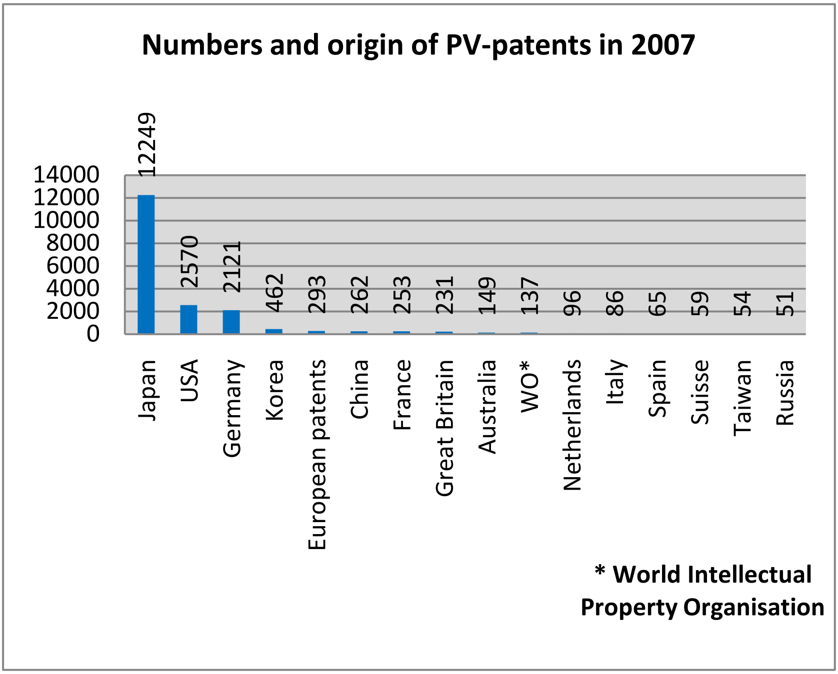


Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar) 2009

In a relative short time period the German industry was also able to improve productivity that enabled prices for installed PV modules to fall by a quarter between 4/2006 and 1/2009. (Cp. Fig. X).

Sales figures and numbers of photovoltaics power installed clearly show the market success of photovoltaics. An even more common way of measuring innovation is patent data, since "...patents provide a uniquely detailed source of information on inventive activity" (cf. OECD 1994: 9).

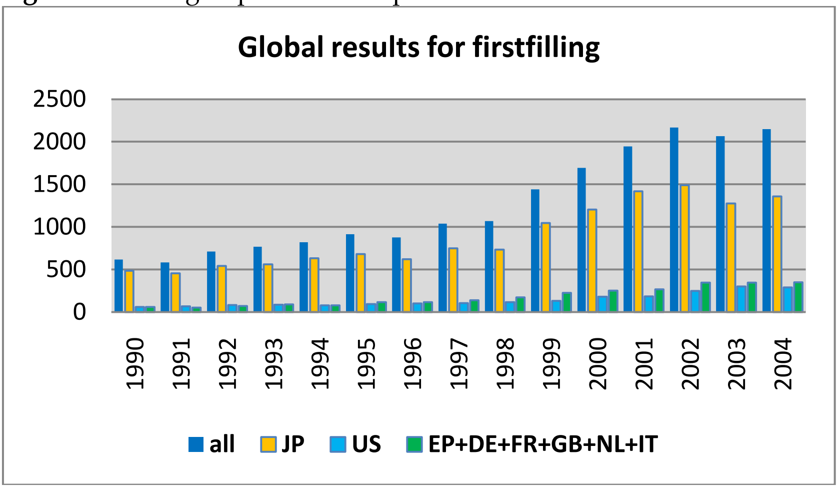
Fig. 7: Global patent applications in photovoltaics.



Source: own illustration based on data from: Beucker und Fichter (Boderstep Institut für Innovation und Nachhaltigkeit 2007)

As figure 6 shows, Japan is by far the most active nation in patent applications, followed by the USA and Germany.[5] As can be seen from figure 7 German patent activities reflect quite well the global increase of photovoltaics patents from around 500 in the early 1990s up to around 2000 in 2002. The numbers for Germany do not differ significantly from those for the USA, 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. 8: First filing of photovoltaic patents.



Source: own illustration based on data from: Visentin/Voignier/Königstein 2005

[5] It is striking that Japan accounts for 74% of all patent applications, but this is mainly due to characteristics of the Japanese patent law system, which makes the process of applying for a patent easier and cheaper than in the USA and Germany. Furthermore, in Japan normally one invention is divided into small elements and for each a patent application is filed (cf. Siemer 2005: 66). Therefore comparing German patent activities with the Japanese one has to be careful when drawing conclusions.

These figures clearly demonstrate 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.

5 Photovoltaics and Its Contenders

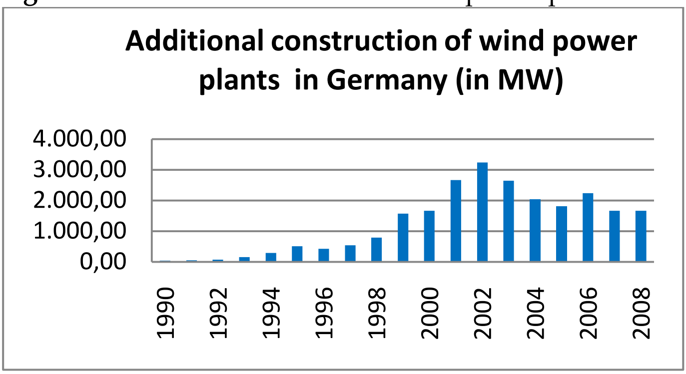
During the last years quite a number of articles have been published, describing and analysing the transformation of the energy sector. Photovoltaics, as one of the renewables, has been described and analysed before. But only few publications have focused on the particular technological and institutional prerequisites, which enabled photovoltaics to become a real success story. Since the success of specific technologies in a system as complex as the energy supply system at least partly depends on the interaction with and the development path of competing or complementary systems, we will shortly review some of the other renewables, which have be following a slightly different trajectory, in order to develop some insights on what might be the particular comparative advantages of photovoltaics.

The fuel cell and wind power technologies, just like photovoltaics have received dedicated financial support schemes and benefit(ed) from R&D programmes. But unlike photovoltaics, in the case of fuel cells support programmes failed to trigger a sufficient demand, and research and industry had to postpone several times the availability of a sufficiently stable technology. In the second case, creating a niche market for wind power technologies was extremely successful at the beginning. But over the last years, wind power technologies and especially the German industry are increasingly suffering backlashes in the sense of the development of future applications, when compared with other European countries such as Denmark or Spain. The domestic market for wind power for some years had less future potential than the market for photovoltaics applications. Since the national onshore-market for wind park installations has become increasingly limited by social non-acceptance of wind power installations: the sight of installations is sometimes considered to damage the beauty of the landscape, environmental problems are discussed, and people living next to wind power plants complain about the noise caused by wind turbines. For off-shore installations the tourism industry at the North Sea is afraid of losses resulting from wind power plants mutilating the nature and environmentalists are afraid of the consequences for animal and plant populations. Surveys show that the majority of the German population supports wind energy, wanting it to become an important energy resource in the future, its acceptance has always been significantly less pronounced than the support for photovoltaics. For example in 2003 a survey of the Allensbach Institute showed that 33 % of the respondents answered that wind turbines would disfigure landscapes whereas only 6 % of the respondents were of the same opinion concerning photovoltaics installation (cf. Bundespresseamt 2003: 4). A Forsa-survey in 2008 showed higher acceptance even for solar parks, compared to wind parks (76 % vs. 55 %) (cf. Agentur für Erneuerbare Energien e.V. 2008: 5). There are also administrative limits imposed by some federal States concerning the space between and the height of wind turbines (cf. VDI 2006: 17). Social and administrative opposition is additionally enforced by 'natural' restrictions, since open space in windy regions is limited. As a consequence, at a quite early stage the idea of alternative applications, so called offshore wind farms became widely accepted by countries like Denmark, Britain and Sweden. In contrast to these lead markets, the German wind industry initially did not follow this offshore trend and hesitated for a long time to re-direct its research and development activities. Only recently, the realisation of the first German offshore project (alpha ventus) began. The project is realised by a huge public-private syndicate, comprising public partners, associations, research institutes as well as commercial actors. Interestingly incumbent actors of the energy sector, like E.ON and Vattenfall are also among the partners (cf. BMU/Stiftung Offshore Windenergie 2007). But since activities are in its infancy, at the moment the offshore industry's technology leaders are Danish and Spanish firms. Traditional big producers of wind turbines from Germany are lagging behind (cf. Manager Magazin 2007). The reasons are a mixture of technology specific and social factors, which at the moment constrain Germany becoming a lead market for off shore wind power technologies. First of all the coast of the North Sea is well protected from becoming a wind farm due to the existence of around 700 citizens action groups opposing wind power plants. They are supported by nature societies like the Naturschutzbund, which articulated vehement protest against wind power plants close to the North Sea coast as they feared that bird sanctuaries and nature reserves will be threatened. Existing laws on nature conservation that particularly protect the Wadden Sea at the German North Sea coast back these apprehensions and resulted in complicated and long lasting approval procedures. Thus coastal off shore applications comparable to Danish, Swedish or British wind power plants will not be realised in Germany in the foreseeable future. As an alternative, German offshore applications can be realised far out in the North Sea. This strategy is backed by the renewable energy law, which says that wind farms that are built after the 1st of January 2005, get only remuneration, if they are located outside of bird sanctuaries and nature reserves (cf. dena 2005: 2). But these particularities raise costs for offshore applications tremendously and request new technological developments. Since there does not exist any experience with wind farms that are built above 20 to 40 meters deep water one would enter completely new technological territory. Furthermore, when connecting these offshore wind power plants to onshore grids, additionally high extra costs are due. The same already holds for big onshore wind power plants, as there is the risk, when feeding-in a larger quantity of wind power into the grid, that grid configurations get overloaded. So additionally, an expensive expansion and reconstruction of existing grids will be necessary in order to tap the full potential of big wind power plants. In contrast PV resembles more a “small” decentralized technology with more limited compatibility problems to the existing grid structure.

Another energy technology, which has been targeted by the German innovation policy is the aforementioned fuel cell technology. But in contrast to wind power and photovoltaics, it has not yet managed to enter the large scale market. The reasons are for one technological characteristics that constrain its market expansion. First of all, fuel cells need hydrogen as prime energy source, so the creation of a niche market, and even more the market expansion of the fuel cell technology depends on the parallel development of the hydrogen technology. Furthermore, the acceptance and expansion of fuel cells are heavily dependent on supporting infrastructures like fuelling stations offering hydrogen. If these do not exist, the technology seems unhelpful for potential end-users. Until now, the hydrogen technology is lacking innovative leaps which could have led to substantial cost reductions. Instead, the technology is still very expensive, which constrains the acceptance and diffusion of fuel cells.

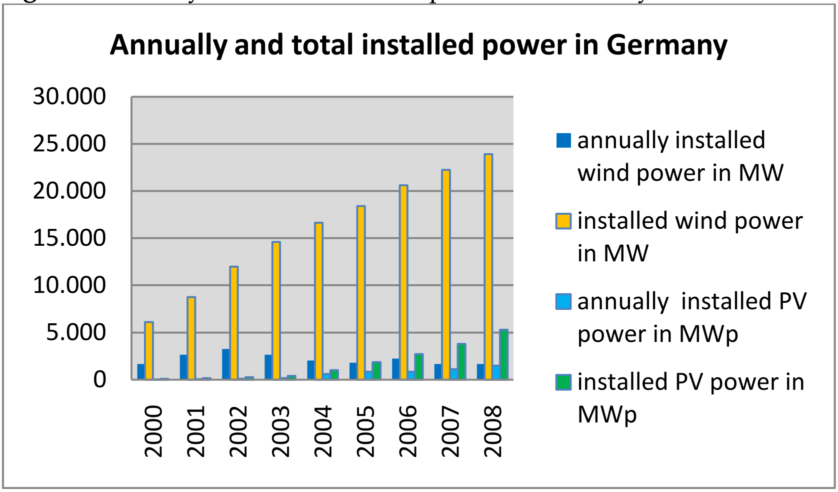
Figure eight and ten show the different trajectory of the wind power plant sector when compared with PV. After an initial steady increase – which already predated the introduction of new regulatory instruments, the new construction activities stalled somewhat after 2002. This might change again in the future given the recent amendments of the EEG.

Fig. 9: Additional construction of wind power plants in Germany.



Source: own illustration based on data from: Molly (DEWI GmbH 2008)

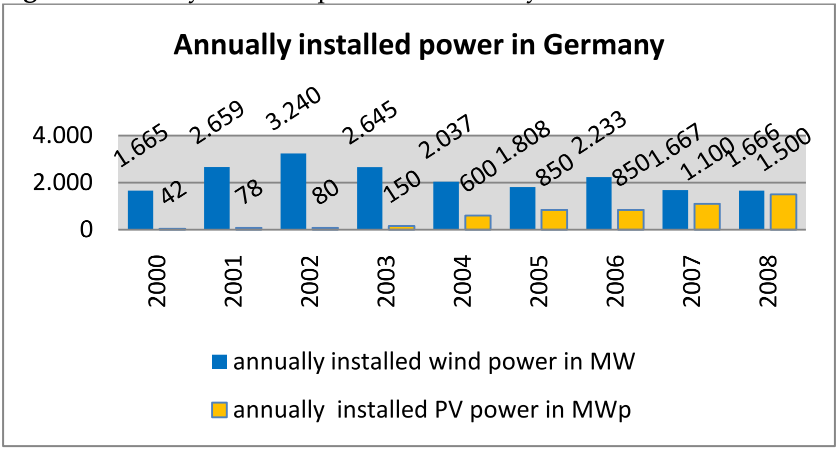
Fig. 10: Annually and total installed power in Germany.



Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009) and Molly (DEWI GmbH 2008)

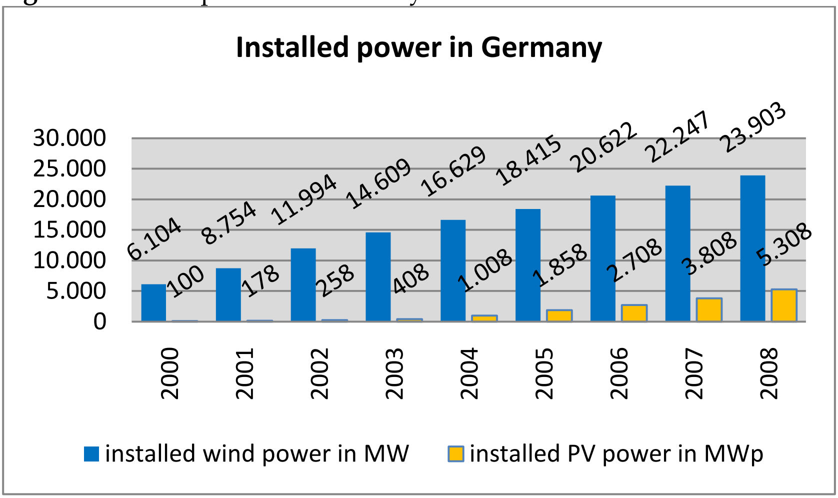
Nevertheless the overall importance of PV is far less than wind power. The amount of energy one additonal wind installation is able to produce is much higher when compared to the small, decentralised PV installations (see fig. 9).

Fig. 11: Annually installed power in Germany.



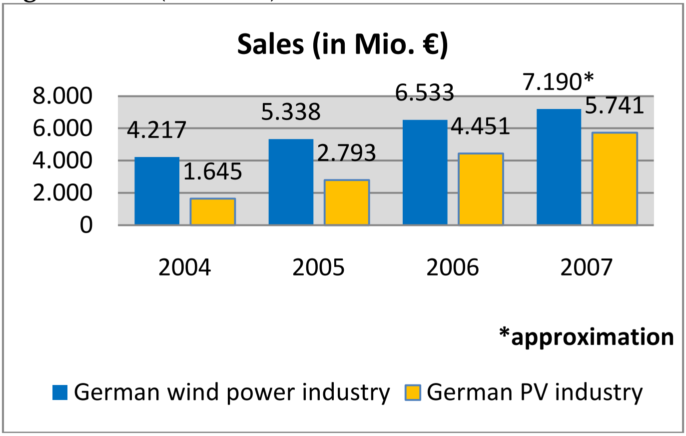
Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009) and Molly (DEWI GmbH 2008)

Fig. 12: Installed power in Germany.



Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009) and Molly (DEWI GmbH 2008)

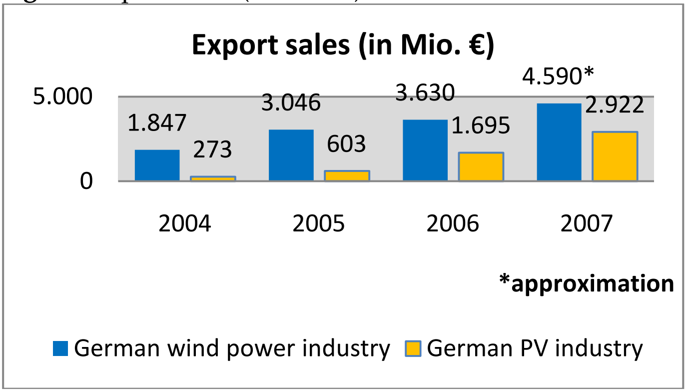
Fig. 13: Sales (in Mio. €).



Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009) and Bundesverband WindEnergie e. V. (2007)

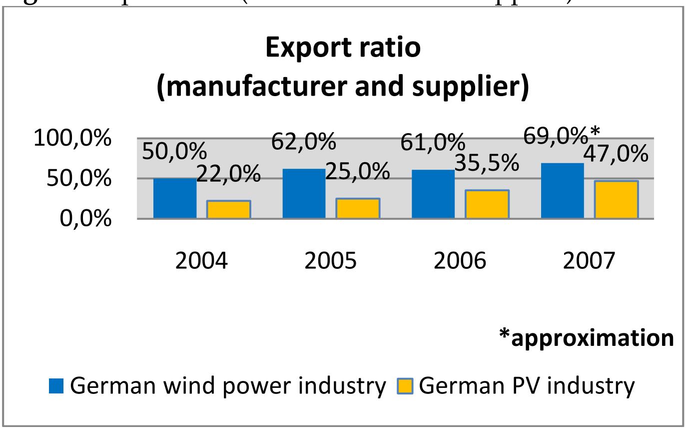
With respect to aspects of industrial policy PV is much more dominated by German producers and German technology. The PV industry might be able to overtake the wind power industry with respect to sales (see fig 12). In spite of the increasing exports of the PV industry, it is less dependent on the export markets than the wind power industry – given the unclear further development of the market (see fig 13 and 14).

Fig. 14: Export sales (in Mio. €).



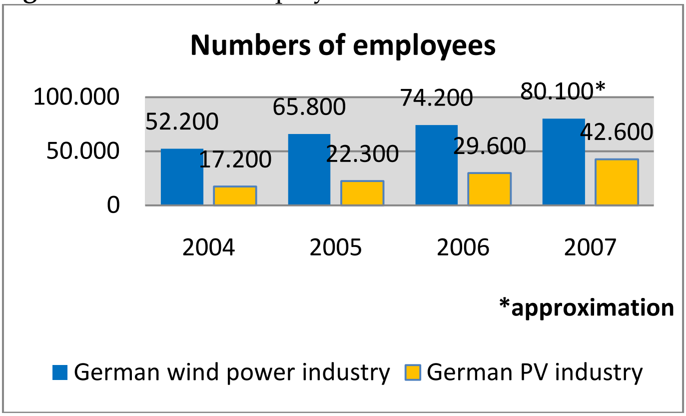
Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009) and Bundesverband WindEnergie e. V. (2007)

Fig. 15: Export ratio (manufacturer and supplier).



Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009) and Bundesverband WindEnergie e. V. (2007)

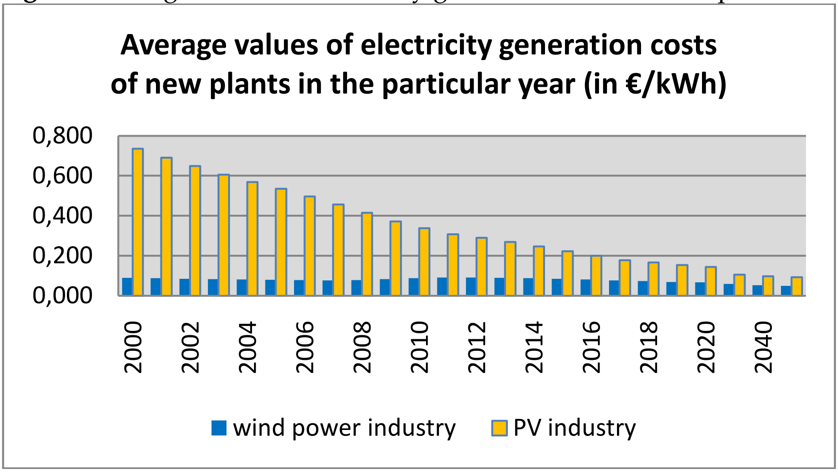
Fig. 16: Numbers of employees.



Source: own illustration based on data from: Bundesverband Solarwirtschaft e.V. (BSW-Solar 2009) and Bundesverband WindEnergie e. V. (2007)

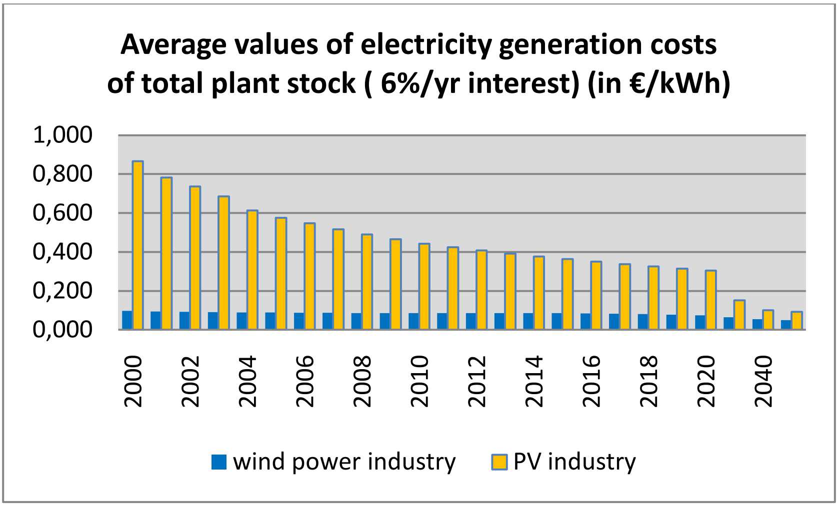
Both industries, however, are developing into important employers with the dynamic again being more pronounced in the PV than in the wind power industry (see fig. 15). This dynamic can also be seen in the development of costs of electricity generation. At the moment electricity generated by PV modules is much more expensive than wind energy. But while the costs of wind energy will decrease only slightly over next years, great cost reductions are expected in the PV industry.

Fig. 17: Average values of electricity generation costs of new plants.



Source: own illustration based on data from: BMU (2008)

Fig. 18: Average values of electricity generation costs of total plant stock.



Source: own illustration based on data from: BMU (2008)

6 A Future for Photovoltaics?

In the beginning 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, has also proven 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 linked to frame conditions, offering a window of opportunity for change. The electric power sector over the last years faced new challenges. These challenges came from a move to liberalize markets, the expectation that the sector should contribute to environmental aims and the development of new technologies (e.g. renewable energies) hard to integrate into the dominant regime of the sector. PV as an innovation successfully exploited the chances offered. A form of decentralized, small technology which could be connected to the grid without severe difficulties and compatibility problems, it achieved nearly unanimous support by a public in favour of clean technologies. It was supported by an advocacy coalition comprising scientists, politicians, environmentalists and increasingly economic actors. PV could build on the already existing scientific strengths in this area as well as the expertise of suppliers (e.g. machine building industry). Insofar some elements of path dependency are to be seen even in this case.

The political instruments 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 Laender. The users of PV-modules were guaranteed a 20 year security on their investments. Insofar PV could serve many masters. The present strength of the coalition has only recently been proven when the federal government amended the Renewable Energy Law without implementing important changes. It achieved nearly unanimous support by a public in favour of clean technologies; it was supported by an advocacy coalition comprising of scientists, politicians, environmentalists and increasingly economic actors.

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

As Rammert (1997) states, post-modern reflexive innovation policy intends to connect heterogeneous actors by avoiding negative externalities that may result from hierarchical or market forms of coordination. Such network activities are looked upon as being more suitable to innovation processes, especially under the auspices of globalisation and ongoing deregulation processes. „Initiatives must be taken to foster experiments with the new technology; these must give rise to entrepreneurial activity by either new or existing entities; economic and technological competence must be built and diffused among suppliers and users; capital must be supplied; and bridging functions must be developed – institutions and networks need to be built and knowledge must be transferred"(cf. Carlsson/Jacobsson 1997: 272). Policy effectiveness thus builds on a challenging combination of diverse activities.

References

Agentur für Erneuerbare Energien e.V. (2008): Hintergrundinformation: Bevölkerung wünscht mehr Erneuerbare Energien – hohe Akzeptanz auch im eigenen Wohnumfeld. Ergebnisse einer repräsentativen Umfrage in Deutschland, in: http://www.unendlich-viel-energie.de/uploads/media/Hintergrundinfo-forsa08_laender.pdf, zugegriffen am 17. April 2009.

BINE Informationsdienst (2005): Photovoltaik – Innovationen bei Solarzellen und Modulen, themeninfo III/05.

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

Berkhout, Frans/Smith, Adrian/Stirling, Andy (2003): Socio-Technological Regimes and Transition Contexts, Working Paper Series 2003/3, Brighton: University of Sussex – Science & Technology Policy Research Unit.

Beucker, Severin/Fichter, Klaus (2007): Trends und Rahmenbedingungen für das Innovationssystem Farbstoffsolarzelle – Perspektive 2020. http://www.colorsol.de/Images/InnovationssystemPV_tcm294-101482.pdf, last accessed 16th of April 2009.

BMU (2001): Windenergienutzung auf See. Positionspapier des BMU zur Windenergienutzung im Offshore-Bereich, Berlin.

BMU/Stiftung Offshore Windenergie (2007): Entwicklung der Offshore-Windenergienutzung in Deutschland, in: http://www.offshore-stiftung.de/, zugegriffen am 18. April 2009..

BMU (2008): Leitstudie 2008. Weiterentwicklung der Ausbaustrategie Erneuerbarer Energien. http://www.bmu.de/files/pdfs/allgemein/application/pdf/leitstudie2008.pdf, last accessed 9h of July 2009.

Bundespresseamt (2003): Allensbach-Studie zu Energieversorgung und Energiepolitik (Zusammenfassung des BPA), in: http://www.wind-energie.de/fileadmin/dokumente/Themen_A-Z/ Akzeptanz/Allensbach_energiepolitik.pdf, zugegriffen am 18. April 2009.

Bundesverband Solarwirtschaft e.V. (BSW-Solar) (2009): Statistische Zahlen der deutschen Solarstrombranche (Photovoltaik). http://www.solarwirtschaft.de/fileadmin/content_files/faktenblatt_pv_0309.pdf, last accessed 16th of April 2009.

Bundesverband WindEnergie e. V. (2007): Hintergrundinformation: Windkraft schafft Arbeit, http://www.wind-energie.de/fileadmin/dokumente/Presse_Hintergrund/HG_Arbeitsplaetze.pdf, last accessed 7h of July 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: 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: 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: Pinter: 266-294.

Casper, Steven (1999): National Institutional Frameworks and High-Technology Innovation in Germany. The Case of Biotechnology, WZB discussion paper, FS I 99-306, Berlin: WZB.

Chaminade, Cristina/Edquist, Charles (2006): Rationales for public policy intervention from a systems of innovation approach: the case of VINNOVA, Lund: Lund University CIRCLE Electronic Working Paper No 2006/04.

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: 389-405.

dena (2005): dena-info Offshore Wind 1/2005, Berlin.

Directive 2001/77/EC of the European Parliament and the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market.

Dohse, Dirk (2007): Cluster-Based Technology Policy – The German Experience, in: Industry and Innovation, 14,1: 69-94.

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

Edquist, Charles/Johnson, Björn (1997): Institutions and organisations in systems of innovation, in: Edquist (ed.): Systems of Innovation: Technologies, Institutions and Organizations, London: Pinter: 41-61.

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, June 12-15, 2001.

Edquist, Charles (2005): Systems of Innovation: Perspectives and Challenges, in: Fagerberg, Jan/Mowery, David C./Nelson, Richard R. (eds.): The Oxford Handbook of Innovation. Oxford:Oxford University Press: 181-208.

European Commission (2005): Communication from the Commission. The support of electricity from renewable energy sources, Brussels: COM.

Gabler, Hansjörg (9th of January 2007) Interview at the Zentrum für Sonnenenergie- und Wasserstoff-Forschung.

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

Hage, Jerald/Meeus, Marius (Hrsg.) (2006): Innovation, Science, and Institutional Change, Oxford: Oxford University Press.

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: 223-243.

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 (Hg.): Transfer, Diffusion und Konvergenz von Politiken. Politische Vierteljahresschrift, Sonderheft 38, Wiesbaden: VS-Verlag

IEA (2004): Renewable Energy. Market and Policy Trends in IEA Countries, Paris: International Energy Agency.

IEA (2005): Total photovoltaic power installed in IEA PVPS countries, http://www.iea-pvps.org/isr/22.htm, last accessed 12th of 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 No 84, Brighton: SPRU.

Jacobsson, Staffan/Bergek, Anna (2004): Transforming the energy sector: the evolution of technological systems in renewable energy technology, in: Jacob, Klaus/Binder, Manfred/Wieczorek, Anna (eds.): Governance for Industrial Transformation. Proceedings of the 2003 Berlin Conference on the Human Dimensions of Global Environmental Change, Environmental Policy Research Centre, Berlin: 208-236.

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 (2006): 256-276.

Jäger-Waldau, Arnulf (2002): Status of PV Research, Solar Cell Production and Market Implementation in Japan, USA and the European Union, Ispra: Institute for Environment and Sustainability, Renewable Energy Unit.

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 (Hrsg.): Transfer, Diffusion und Konvergenz von Politiken. Politische Vierteljahresschrift Sonderhefte 38/2007. Wiesbaden, VS Verlag: 131-149.

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

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: 175-195.

Kemp, René (2002): Environmental Protection through Technological Regime Shifts, in: Jamison, Andrew/Rohracher, Harald (eds.): Technology Studies and Sustainable Development, München/Wien: Profil: 95-126.

Krewitt, Wolfram/Nast, Michael/Nitsch, Joachim (2005): Energiewirtschaftliche Perspektiven der Fotovoltaik. Langfassung, Stuttgart: Deutsches Zentrum für Luft- und Raumfahrt e.V. Institut für Technische Thermodynamik Abteilung Systemanalyse und Technikbewertung.

Litfin, Karen T. (2000): Advocacy Coalitions Along the Domestic-Foreign Frontier: Globalization and Canadian Climate Change Policy, in: Policy Studies Journal 28,1: 236-252.

Malerba, Franco (2004): Sectoral Systems of Innovation. Concepts, Issues and Analyses of Six Major Sectors in Europe, Cambridge: Cambridge University Press.

Manager Magazin (2007): Deutschland von Skandinavien abgehängt, http://www.manager-magazin.de/geld/artikel/0,2828,503703,00.html, last accessed 5h of September 2007.

May, Hanne (2008): Runde Sache, in: Neue Energie Spezial. Das Magazin für erneuerbare Energien, http://www.wind-energie.de/fileadmin/ne/ne_inhalte/dokumente/ne0806_EEG.pdf, last accessed 28 th of August 2008.

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: 32.

Molly, Jens-Peter (2008): Status der Windenergienutzung in Deutschland - Stand 31.12.2008 (DEWI GmbH), http://www.windenergie.de/fileadmin/dokumente/statistiken/WE%20Deutschland/DEWI-Statistik_gesamt_2008.pdf, last accessed 7h of July 2009.

Nemet, Gregory F. (2005): Technical Change in Photovoltaics and the Applicability of the Learning Curve Model (IIASA International

Institute for Applied Systems Analysis Interim Report IR-05-029), http://www.iiasa.ac.at/Research/TNT/WEB/PUB/IR/IR-05-029_nemet.pdf, last accessed 27 th of July 2009.

Nelson, Richard R. (ed.) (1993): National Innovation Systems: A Comparative Analysis, New York: Oxford University Press.

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

Nooteboom, Bart (1999): Innovation and inter-firm linkages: new implications for policy, in: Research Policy 28: 793-805.

OECD (1994): The Measurement of Scientific and Technological Activities. Using Patent Data as Science and Technology Indicators. Patent Manual 1994, Paris.

OECD (1997): Oslo Manual: The Measurement of Scientific and Technological Activities. Proposed Guidelines for Collecting and Interpreting Technological Innovation Data, 2nd ed., Paris: OECD.

Rammer, Christian (2006): Trends in Innovation Policy: An International Comparison, in: Schmoch, Ulrich/Rammer, Christian (eds.): National Systems of Innovation in Comparison. Structure and Performance Indicators for Knowledge Societies, Dordrecht: Springer: 265-286.

Rammert, Werner (1997): Innovation im Netz. Neue Zeiten für technische Innovationen: heterogen verteilt und interaktiv vernetzt, in: Soziale Welt 48: 397 – 416.

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

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./Jenkins-Smith, Hank (eds.) (1993): Policy Change and Learning: An Advocacy Coalition Approach, Boulder, CO: Westview Press.

Sabatier, Paul A. (1998): The advocacy coalition framework: revisions and relevance for Europe, in: Journal of European Public Policy 5,1: 98-130.

Siemer, Jochen (2005): Das Orakel vom Amt. Patentanmeldungen für Photovoltaik, in: Photon 2005-10: 66-70.

Solarbuzz (2007): Solar Cell Technologies, http://www.solarbuzz.com/Technologies.htm, last accessed 6h of August 2007.

Solarserver (2007): Dünnschicht-Solartechnik: Neue Technologien zur Kostensenkung der Photovoltaik, http://www.solarserver.de/solarmagazin/artikeljuni2006.html, last accessed 6h 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, last accessed 24th of April 2007.

Surek, Tom (National Renewable Energy Laboratory) (2003): Progress in U.S. photovoltaics: looking back 30 years and looking ahead 20. In: Proceedings of 3rd World Conference on Photovoltaic Energy, http://www.nrel.gov/pv/thin_film/docs/surek_japan_talk_2003.ppt, last accessed 27 th of July 2009.

VDI (2006): Regenerative Energien in Deutschland – Stand 2006 – Statusreport des VDI-Fachausschusses FaRE, Düsseldorf.

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

Visentin, Alberto/Voignier, V/Königstein, C (2005): Technology Trends in Photovoltaics for the last decade: an analysis on the basis of patent application filing data, paper presented at the photovoltaics conference.

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, 37-90 .

Whitley, Richard (2000): The Institutional Structuring of Innovation Strategies: Business Systems, Firm Types and Patterns of Technical Change in Different Market Economies, in: Organization Studies 21,5: 855-886.

Woditsch, Peter (2000): Kostenreduktionspotenziale bei der Herstellung von PV-Modulen, in: ForschungsVerbund Sonnenenergie (ed.): Sonne – die

Energie des 21. Jahrhunderts. Strategien zur Kostensenkung von Solarzellen, Berlin.

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: 117-145.