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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 including a mixed spectrum of many and diverse academic, economic, and governmental agencies combine to achieve innovations. Is there any role for innovation policy beyond influencing framework conditions in such a situation? The article analyzes 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.

1 Introduction

The energy system in industrialized nations is changing in what can be seen 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. But one element of a future new governance structure will be an increasing 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 coalition of diverse actors. One of the innovative developments in the area of renewable energy technologies will be analyzed in this article: 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 as an unusual success story in which the ability of state authorities to strongly influence renewable energy production and associated economic activity becomes apparent.

It will be argued that the growth of renewable energy proceeds within networks of governance, which comprise formal regimes at multiple levels, informal norms and practices as well as market structures and processes. These networks involve 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 constitute this sector's essential elements of governance. We will further argue that PV policy in Germany is characterized by a commitment to a specific mission, a concertation of the main actors, a long term orientation and substantive subsidies. Insofar PV appears as a successful "planned" innovation, rarely found in the relevant literature. Caniels/Romijn (2008: 246) have argued that the literature on strategic niche management is short of success stories. Thus, we know little about the processes by which (policy and technological) experiments can ultimately culminate in viable market niches that ultimately will contribute to a regime change in a specific sector. The present article will try to fill this gap.

We will start with a clarification of our concept of innovation and then describe the elements of the technological system PV. Based on this we will discuss the ingredients of the success story. At the moment it would be foolish to claim that PV will remain a success story in the future and eventually play a dominant role in the development of a new energy regime. PV is growing but it is still in its infant 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 a real success story, outcompeting – from an innovation perspective – other energy technologies.

2 Innovation and Sectoral Systems of Innovation

Before discussing the German innovation policy focussing on the development and market expansion of photovoltaics, we have to outline 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 policy-shift 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 promoting a specific new technology and financing its development by certain companies or research laboratories. (cf. Hiskes/Hiskes 1986)

Innovation research, however, has shown that there is no linear development of technological innovation towards successful adoption and diffusion (cf. Van de Ven et al. 1999). Support of basic research does not guarantee the eventual development of products that become widely accepted and thus achieve commercial success. But exactly "success on the market" seems to become top priority in times of increasing worldwide competition on crowded markets. The introduction of new, innovative products is considered to be a precondition for keeping a competitive edge.

In parallel discussions on the steering capacities of the state a dire picture was painted, accentuating the conviction that the state cannot successfully choose 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 conception of technology policy. Research and technology policy has now turned into innovation policy and mainly focuses on funding basic research and networking activities – in particular joint projects between firms and research institutes – in order to stimulate knowledge flows and to ensure that results in scientific research may be used and adopted commercially (cf. Nooteboom 1999, Edquist 2001:18). Networks may facilitate producer-customer relationships or even result in the creation of an advocacy coalition, which experts consider an important pre-condition for successful radical innovations (cf. Weimer-Jehle/Fuchs 2007).

Although the market discourse has achieved nearly universal legitimacy, counter tendencies have always been visible as well. 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, like subsidies or the provision of soft loans for prospective customers, as well as through modes of legitimizing 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) with the hope that even a transformation of a whole technological regime can be enabled (cf. Berkhout et al 2003: 4; Caniels/Romijn 2008).

But in both cases the actual design of national policies has to consider existing institutional frameworks and socio-cultural conditions. Studies in the tradition of the Varieties of Capitalism approach (Hall/Soskice 2001) claim, 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 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 which strongly oppose photovoltaics due to ideological and economic (rent seeking) reasons can be assumed. As Jänicke has shown, changes in actor constellations have resulted in improved terms 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). Therefore we argue that the success of innovation policy depends on its ability to create and mobilise an advocacy coalition supporting the aimed technology, especially if strong incumbent actors (like in the established energy system) exist (hypothesis 2).

2.2 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 use of a new technology at any rate plays a crucial role in the innovation process. Thus new – better – technologies in our context are only referred to as innovations, 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 in the case of 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 to be successful in the market. This can lead firms to hesitate 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 mechanism blocking the diffusion of a new technology, which is lack of legitimacy.

We are here confronted with the paradox that innovation as a routine changing mechanism, nevertheless also depends on routines, albeit newly developing ones. Therefore innovation policy can aim 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 more safe and be more induced to purchase new technologies (cf. Carlsson/Jacobsson 1997: 285).

The role of uncertainty can be seen very clearly if we look at the developments in the 1990s when the German PV industry was close to become extinct. Production facilities were moved, since producers considered it uncertain whether the institutional framework in Germany could provide favourable conditions for the further development of the PV industry.

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

2.4 The Transformation of Electric Power Generation

Photovoltaics is 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 to understand the case of PV, because they opened up a window of opportunity, which helped to push forward this new option.

The traditional electric power system can be characterized as a large technical system (cf. Mayntz/Hughes 1988) with tightly coupled components 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" prizes. It is suggested that the costs of producing electricity, gained out of coal or oil would double, if intransparent 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 to a very large degree depend on the interpretation of political signals regarding the regulation of technology.

Two trends that challenge the traditional ways of power generation can be observed: the liberalisation of infrastructures and environmental issues such as the "global warming". Hopes that an effective regime to address climate change will emerge have shifted from the emphasis on a mandatory multilateral agreement, the Kyoto protocol, to a plethora of regional, national, and sub-national programs and initiatives. Policy responses include carbon emission limits and trading systems, direct subsidies for renewables, and renewable portfolio standards that mandate the use of specific volumes of renewable energy in electricity generation. Such policy initiatives 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. Liberalization can have diverging effects on renewable energies. If energy prices fall as a result of liberalization and increasing market competition (as the pure theory would make us expect) the price targets that renewables must meet become more challenging and liberalization might prove to be an impediment for their further spread. On the other hand, policies and systems such as quotas and renewable energy certificates can be compatible with more competitive market structures as the experiences of the last years have shown when energy prices increased considerably. In fact, many of the policies that have been implemented to support renewables operate within the framework of liberal markets. (Cf. OECD 2008)

Finally, beyond the problems of a lack of transparency and the prevalence of risk-averse actors, there is the constraint of centralized energy infrastructures, which have developed and become established throughout decades. National grids are mainly tailored to the operation of centralized power plants and thus support their existence. Alternative technologies like photovoltaics follow an opposite decentralised logic that does not easily fit into the established technological concepts. Thus, PV has difficulties competing with the incumbent technologies (cf. Stern 2006: 355).

In sum this has led to the widely accepted conviction that policy instruments to create niche markets for renewable energies were needed. Even the European Commission, traditionally favouring market instruments and being quite 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 had 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: Characteristics of the technology

Analysing the photovoltaics success story, we need to give 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 a 93 % share 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 per cent under ideal laboratory conditions (cf. Solarserver 2007). Poly-crystalline silicon cells do not achieve such high efficiencies, but they compensate it with price-advantages. The same holds for amorphous and other 'thin film' technologies that consist of cadmium telluride (CdTe) or copper indium diselenide (CIS). Due to silicon shortages for several years now, research and develop-

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

ment on non-silicon thin film technologies has become increasingly popular and remarkable reductions in production costs have been achieved.

The French physicist Alexandre Becquerel first discovered the photovoltaic effect in 1839. Albert Einstein's theoretical work on the photovoltaic effect won the Nobel Prize in 1921. This illustrates that basic research on photovoltaics has been carried out for decades. But first applications did not appear until the 1950s, when Bell Laboratories invented the first solar cell and the US government started to use solar cells for 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 photovoltaics was just the case of another technology for which the role of the military was crucial in the innovation process (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 like 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 owing 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 in remote places like alpine huts and camping sites. Beyond this the idea of solar home systems for developing countries came up. Rather distinct from these off-grid photovoltaics are newer forms of applications that 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, early projects demonstrating how to use photovoltaics in order to supply electricity to the grid did not appear before the 1990s. Thus grid-connected photovoltaics is a rather new development. It is therefore striking that since 1999 in IEA (International Energy Agency) reporting countries grid-connected photovoltaics has rapidly outpaced other applications (cf. IEA 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 have an economic power position, one would not assume that environmentalists were able to form an effective advocacy coalition. Interest groups, which support emerging technologies, are normally neither well positioned financially nor do they have access to powerful political actors.

Even though the advocacy coalition for photovoltaics was not formed by 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 opposition by the incumbent energy producers.

> "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 system cannot be expected to be achieved without overcoming considerable opposition from vested interests involved with the incumbent technologies." (Jacobsson et al 2002: 3)

4.1 The formative stage (1970s – 1990s)

The story of PV began like many other cases of German research policy. Starting in the early eighties the common instruments for the public funding of research and development like institutional funding of relevant research departments doing basic research were used. 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 programs. Initially the support for new technology had been integrated into the unit for non-nuclear energy technologies. In 1976, an independent unit was created (cf. Ristau 1998: 40). Interestingly, many of the programs to finance photovoltaics projects, were carried out by the ministry of economic cooperation and development, because 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.

First steps towards an advocacy coalition in the 1980s

When oil prices had settled down again and with the beginning of the conservative-liberal coalition under Chancellor Kohl, policy actions in order to promote photovoltaics declined severely. In 1985 public funding of photovoltaics related research and development projects did not account for more than 53 Mio DM. Albeit institutional actors involved in research on photovoltaics had been established and later on, when other external events like the Chernobyl accident occurred and discussions on environmental problems or on climate change appeared, they managed, together with environmentalist groups, to set the agenda for photovoltaics. When political actors put environmental problems higher on the political agenda, 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, like the Fraunhofer Institut für Solare Energiesysteme in Freiburg (in 1982), the Zentrum für Sonnenenergie- und Wasserstoff-Forschung in Stuttgart/Ulm (in 1988) or specialized physics departments, for example at the Carl von Ossietzky University of 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 criticized 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 specialized departments and institutes attracted environmentally committed scientists, and later local networks consisting of environmentalists and researchers emerged. A prominent case is Freiburg, where the Fraunhofer Institut für Solare Energiesysteme 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 programs "(…) 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 dedicated to one technology. Rather, competing technologies, such as crystalline silicon and thin-film technologies were supported. And additionally, research and development of inverters (to make grid-connected applications work) had started.

Interestingly, these research projects on the one hand, and the absence of market stimulation programs on the other hand, led to the weird situation, that the big two German companies engaged in photovoltaics production managed to develop internationally competitive products. German research on photovoltaics achieved a leading position alongside Japan and the United States, but the technologies developed could not be sold at home due to a lack of domestic demand (cf. Ristau 1998: 45). Actually, photovoltaics 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 it was 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 a first association, the newly founded Deutsche Gesellschaft für Solar (DGS). In these early days the advocacy coalition was too weak, particularly as it had not yet incorporated more powerful industrial lobbies. At the same time 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 then external events such as the nuclear accident in Chernobyl in 1986 changed public opinion and attitudes towards nuclear power substantially. These events opened 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). While prior to Chernobyl 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 have clearly to be mentioned. Considering all these circumstances, 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 in the early 1990s

Market stimulation programs are traditionally policy instruments of the ministry of economics, but these instruments have not been applied until 1991. As we have mentioned before, the ministry of economics deliberately refused to support the photovoltaics research and development projects of the ministry of research. And since the new technology could definitely not be 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 get domestic support in terms of an artificial niche market. Finally in 1991, the situation changed when the first feed-in-law was developed and passed. It described a mechanism based on which utilities were obliged 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 program, 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 emerged as being too weak to trigger market expansion for photovoltaics.

This first feed-in-law was accompanied by the 1000-roofs-program 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. This program that started in 1991 and ended in 1995 was a mixture of demonstration and market stimulation. It offered soft loans for private households, which were interested in participating in the grid-connected photovoltaics test stage. The program was not only accompanied by electro-technical and physical tests on inverters, cell duration etc., but also by social research which studied customers' motives and social affiliations (cf. Gennenig/Hoffmann 1996). This first niche program 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. In addition, the program helped 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 the grounds for structural changes within the energy sector, abandoning traditional centralised grid systems, giving way to decentralised, environmental friendly systems, such as grid connected photovoltaics applications.

When the 1000-roofs-program ended and the German government did not immediately develop follow-up programs, "(…) 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 (BMWi) started a market launch program for renewable energy technologies in 1995. But since this program only provided 4.5 Mio. DM for photovoltaics, it did not meet the expectations of the photovoltaics industry (cf. Ristau 1998). This is a striking example for the relationship between uncertainty and innovation. Throughout the 1990s the German policy did not systematically target at uncertainty. Its programs were inadequately financed and not based on long-term considerations. As a result 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 in 1998.

Despite these shortcomings, it has to be admitted, that the 1990s can be characterised by early (successful) investments. Public funded R&D, as well as the first market stimulation programs and the first feed-in law did not only lead to the build-up of an initial knowledge base. It also enabled the creation of an embryonic advocacy coalition consisting of scientists, an infant industry and its interest organisations, as well as highly committed environmentalists. Some of them appeared as first movers on the market, which means they were the first costumers participating in the 1000-roof program. Even though the programme offered soft loans, and the power produced was remunerated, these first users did not benefit from their investment in a monetary sense. Instead they appeared as 'the hard core' of the advocacy coalition, mainly acting out of ideological reasons. But the early investments and the ideological commitments triggered positive feedbacks, which for example resulted in the ability of the coalition to shape further institutional change and to initiate sectoral transformation. Taken together the first political programs had significant effects. First of all public awareness of the new technology rose and photovoltaics was provided with legitimacy. Public and social acceptance as well as political support of the technology was achieved, subsidies became widely approved. 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). Prior to this, the two big players, Siemens and AEG Telefunken dominated the market. Just to give an idea: in 1991, when the 1000-roofs-program was launched, 99.5% of the induced market demand was satisfied by these two companies. And even in 1993 when the program was opened for European competitors like BP-Solar and the Italian firm Helios, Siemens and ASE still held a 70% market share (cf. Ristau 1998: 48).

Strategic niche management in the 1990s

Throughout the 1990s, industrial (solar) associations were gradually founded, which aimed to improve and enhance political support of the infant technology and its commercialization. Additionally, (local) groups and societies, like the Aachen Solarverein, Eurosolar and Förderverein Solarenergie were founded and discussed the suitability of political instruments. They developed blue prints for a new feed-in-law or another roof-program and tried to build up political momentum. Local politicians, who strongly favoured the idea of renewable energies and opted for more decentralised energy systems, joined them. To them, grid-connected photovoltaics applications met both of these aims. 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-program 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 Aachen Solarverein. In contrast to the federal law, which only regulated the remuneration of photovoltaics power at arm's length, the concept of the Aachen Solarverein provided 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 has learned new ways to achieve its goal. Thus the new mechanism provided an opportunity for the wider diffusion of photovoltaics in a way that was not only attractive to ideological environmentalists as potential users, but photovoltaics became also an interesting option for non-ideological customers (beyond the initial advocacy coalition) to earn money.

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, like Siemens and ASE becoming part of the advocacy coalition, political pressure began to become more effective. Siemens, which was already producing in the USA, complained, 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 if no follow up program would be started. In reaction the federal government started a debate on the 100.000-roofs-program. 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 at the European and the German federal level. Opposition was not only voiced as a general critique of subsidizing renewable energy technologies, but it was also targeted at 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 nearby the coast (wind power) and photovoltaics applications are concentrated in the sunny South, the bias led to the situation, that some of the Northern utilities or their customers respectively, had to finance subsidies for renewable energy technologies. The case was dismissed, but the discussion did not stop.

4.2 Take-off (1998 - 2007)

Following Sabatier's argument, policy change can only be achieved acommodating external perturbations, such as changes in the government coalition or impacts from other subsystems. This seems also to be true for 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. Rather than trying to have an impact on energy policy from outside it now could directly influence the rebuilding of institutional frames and policy programs. The Greens took over the ministry of the environment and this initiated the institutionalization 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 liberalization and deregulation of the energy sector and an increased focus of international institutions as well as the European Commission on CO2 reduction as a political target with top priority, initiated by the Kyoto protocol.

As a consequence of the change in political power constellations a re-structuring of the energy sector began. Institutional settings and the infrastructure of the energy sector became more open and fluent. Corporate structures were being reorganised and replaced by more competitive management and governance structures. Thus innovation in photovoltaics was accompanied by the re-structuring of the energy sector and social innovations like new management concepts, new user routines, "new roles and identities of electricity customers, new policy problems, regulatory concepts, institutions and governance arrangements" (cf. Voß et al. 2003: 4). These transformation processes have been crucial factors to trigger innovation in photovoltaics because they opened the window of opportunity for the success of an advocacy coalition against the resistance of the powerful advocates of incumbent energy sources.

The stabilisation of the advocacy coalition

Two policy instruments were designed and implemented, which are widely appreciated as having been 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, Förderverein Solarenergie and Greenpeace were extremely important for an adjusted 'relaunch' of the former 1000-roofs-program.

In 1999 the program, which aimed at a market stimulation, was launched. It offered soft loans with 10 years duration and the redemption starting in the third year. In 2000 the Renewable Energy Law was passed. It set a feed-in tariff of around 50 Cent[2] per kWh fixed 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 as the learning effects which had been achieved on the local level helped the Greens 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, which had organized 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 discursive process involving various actors, such as environmental groups, solar industry associations, the association of the machinery and equipment producers VDMA, the metalworkers trade union, solar cell producers and politicians from some *Länder.* This institutionalization of an intermediate level of conflict can be interpreted referring to Sabatier's concept of policy learning. The panel did not intend to conduct a general discussion on the future of the German energy 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. This facilitated the enlargement and stabilization of the advocacy coalition in a way that guaranteed its survival 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)

Besides innovation in PV was still supported by public research money – albeit in a decreasing manner. Public money became concentrated on network and cluster projects, many of them part of 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 to support the formation and elaboration 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. Several photovoltaics clusters have been established in East Germany especially in the small town of Thalheim nearby Bitterfeld in Saxony-Anhalt. Particularly small start-ups, which emerged after 2000, have settled down in the Eastern regions. 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*. It perfectly reflects the effectiveness of the 100.000-roofs-program and the Renewable Energy Law. At the end of 2002 Q-Cells employed 82 persons, at the end of 2004 it already had 484 employees, a number which has grown to 1.700 at the end of 2007.

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

Q-Cells also can serve as an example on how the photovoltaics industry is now increasingly able to get 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 it is included in the technology index TecDax of the German stock exchange. This shows that the industry has left the formative stage, i.e. the niche market and has been entering the take off stage – ready for market expansion.

Market expansion and growing public acceptance

The take-off stage is characterized by a significant enlargement and diversification of the photovoltaics advocacy coalition. This applies to producers as well as to users. Whereas first producers like the Freiburg Solar-Fabrik, founded in 1996 by the environmentalist Georg Salvamoser, were embedded in local solar networks and were not solely led by return on investment thinking, motives and behaviours of producers like Q-Cells do not differ from producers in other sectors. Additionally, due to the Renewable Energy Law, users of photovoltaics are not any 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 development is accompanied 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 strategy of creating a niche market for photovoltaics. Thus, 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 for striking a new path. The Renewable Energy Law was not abolished and it is save to say, that the 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, the coalition parties agreed that the ministry of the environment should obtain 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, and both being rather averse to substantially supporting photovoltaics, in 2002 the situation completely changed. 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, as concerns the command of competing technologies and in the capability to set up important links to surrounding industries. Therefore photovoltaics related R&D is not just research on new materials and cell efficiencies. An increasing number of projects is funded which carry out research on inverters. This also holds true for the firms, which produce the technology.

[3] The literature on strategic niche management sees the prevalence of economic motives as an impediment to the success of policies (Hoogma et al. 2002). We are arguing that exactly the opposite mechanism (addressing economic motives) has been essential for the success of PV policies.

[4] Other elements of institutionalization 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.

„For instance, in 2000, there were ten firms showing roof integrated solar cells at an exhibition (…) and Germany is seen as the world leader in roof integrated solar cells." (Jacobsson/Lauber 2006: 268)

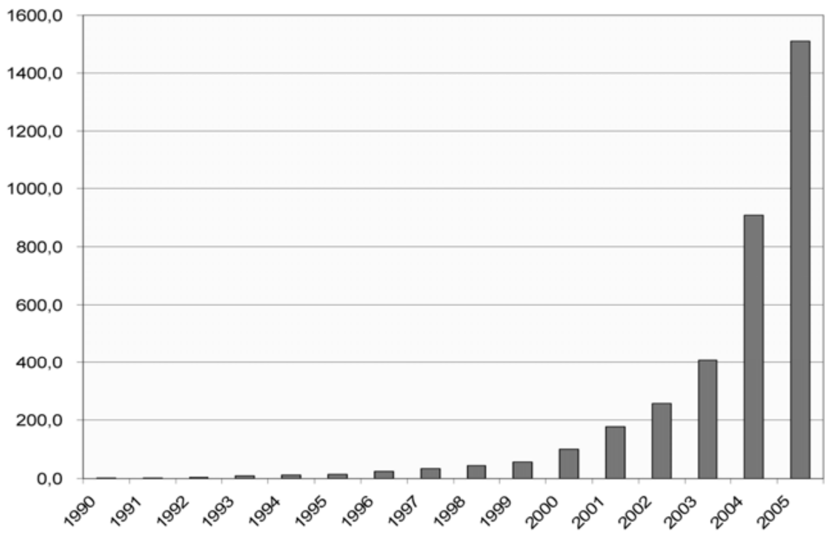
Especially the German machine building industry has benefited from the emergence of photovoltaics. Likewise German solar producers took advantage of the expertise of the machine building industry, since, as mentioned above, many innovations in photovoltaics are geared to cost reductions in the production processes.

Architects and craftsmen, especially electricians have well adapted to the new technology as a growth option for their businesses and surrounding 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.

A new coalition

The specific dynamic of the advocacy coalition can be revealed if we look at the machine building industry. This industry, which cannot be considered to be part of the original energy policy subsystem proper, is strongly supporting the PV coalition. In its early formative stage the coalition exclusively focused on promoting renewable energy technologies. It shared a joint policy core, which aimed at the transformation of the energy sector through substituting nuclear and fossil power plants for renewable energy technologies. Ensuing learning processes 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 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 on finding ways to enlarge the coalition. As a result the machine building industry could be integrated into the coalition. Even some utilities, which either do not belong to the policy subsystem or explicitly share another policy core became affiliated to the coalition. Thus, the policy changes towards a concentration on positive support of PV prepared the ground for the inte-

Figure 1: PV power installed in Germany (MWp)



gration of a heterogeneous set of allies.

4.3 Success Indicators

The success story can be further illustrated by providing some quantitative indicators. In order to measure 'success' we will use the indicators 'installed PV power', 'production', 'export sales', 'employees' and 'patents'.

As figure 1 impressively shows, installed PV power was 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 legal instruments supporting PV, and the expansion of the market.

In 2005 "(…) Germany accounted for more than 93% of the EU 25" (Jäger-Waldau 2006: 75) installations. Stable political and socio-economical 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 can be seen from figure 2, cell production now amounts to more than 500 MW annually. Sales as well as export shipments of the German photovoltaics industry have been rising at a comparable rate, as it is shown in figure 3 and 4.

Sales figures and numbers of photovoltaics power installed can show the market success of photovoltaics. But even more common to measure innovation are patent data, since "(…) patents provide a uniquely detailed source of information on inventive activity" (cf. OECD 1994: 9). As figure 5 shows, Japan is far ahead in patent applications, followed by the USA and Germany.[5] German patent activities well reflect the global increase of photovoltaics patents from around 500 in the early 1990s up to around 2000 in 2002. The numbers for Germany are not much different from those of the USA, and Germany is far ahead of other industrialized countries, such as its European neighbours. Rather than being a precondition for the further development of PV the data seem to suggest that the economic success of PV spurred hectic activities to protect intellectual property.

Altogether these figures clearly prove the (at least short term) success of the PV industry. It is expanding production in Germany and off shore, it is increasing the export ratio of its production, it is employing ever more people, it is working profitable and it accumulates intellectual capital. Meanwhile more companies are active in this sector and more people working there than in many established economic sectors.

5 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 has proved to be successful in establishing a growing, profitable economic activity. The PV industry can produce and sell its products both in Germany and abroad. The story, however, has also proved that the success of such a policy depends on many favourable circumstances. It does not only need broad political and

[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 would be biasing.

Figure 2: Solar cell production in Germany (Mw)

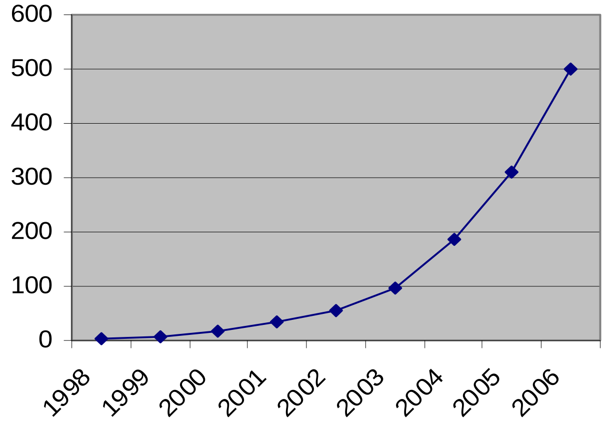


Figure 3: Sales of the German photovoltaics industry (Mio. Euro)

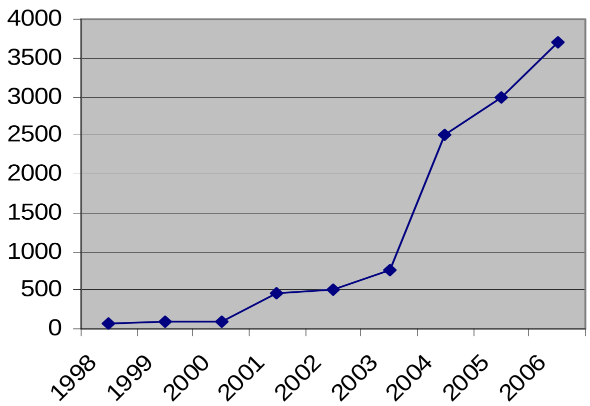


Figure 4: Export sales of the German photovoltaics industry (Mio. Euro)

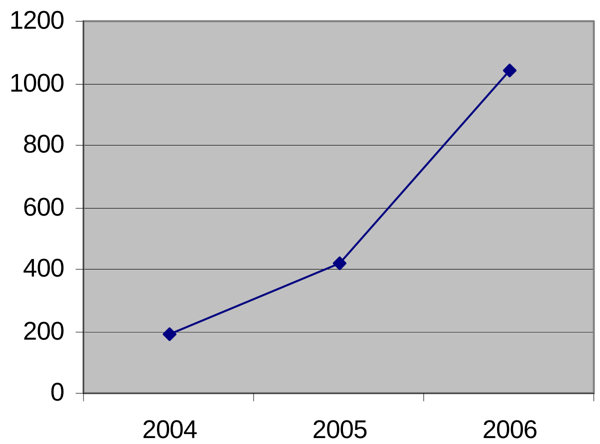
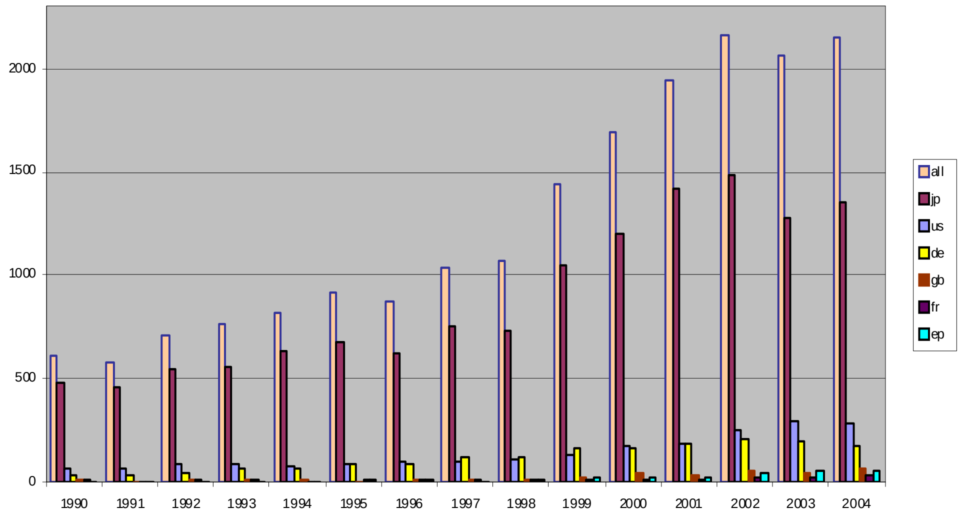


Figure 5: Global patent applications in photovoltaics



public support that goes beyond the initial rather limited 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 faced new challenges over the last years. These challenges originated in 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) each of them apparently hard to cope with by the dominant regime of the sector. PV as an innovative decentralized small technology, which could be connected to the grid without severe difficulties and compatibility problems successfully, exploited the emerging opportunity. PV could rely on existing scientific knowledge in this area and the expertise of suppliers (e.g. machine building industry).

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 *Länder*. 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 proved 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, and it was supported by an advocacy coalition comprising scientists, politicians, environmentalists and increasingly economic actors.

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

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