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The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology

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Abstract

To arrest climate change, a transition to a low-carbon economy must take place quite rapidly, within a century at most. Thus, the rate of diffusion of new technologies such as those for the generation of electricity from renewable energy sources becomes a central issue. This article explores the reasons for the particularly rapid spread of two such technologies in Germany, wind turbines and solar cells. We trace this diffusion to the nature of the policy instruments employed and to the political process which led to the adoption of these instruments. The analysis demonstrates how the regulatory framework is formed in a 'battle over institutions' where the German parliament, informed and supported by an advocacy coalition of growing strength, backed support policies for renewables sourced electricity against often reluctant governments and the opposition from nuclear and coal interests. It also demonstrates that this major political and environmental achievement carries a modest price if we consider total costs to society, i.e. including both subsidies to coal and the negative external economies of coal.

Keywords: Renewable energy; Regulatory framework; Market creation

1. Introduction[1]

Fossil fuels constitute the dominant source of energy in the world, contributing about 80% (91,000 TWh) of total primary energy supply and 64% (9400 TWh) of electricity generation in 1999. This dominance is associated with clear environmental and climate challenges. A wider use of renewable energy technology is seen as one way of meeting these challenges. For instance, the European Union aims at increasing the share of renewable energy of the supply of electricity from about 14% in 1997 to 22% by 2010 (Lauber, 2002). To obtain this target (reduced to 21% as a result of Eastern European enlargement), and go beyond it later on, a range of renewable energy technologies need to be diffused.

Many of these technologies are available in an early form after several decades of experimentation, but their impact on the energy system is hitherto marginal. If these, and their successors, are to have a substantial impact on the climate issue, powerful government policies must promote their diffusion and further development over several decades to come.

While many governments claim to support the diffusion of renewables, the actual rate of diffusion of new technologies in the energy system varies considerably between countries. Drawing on the literature in 'economics of innovation' or related fields, it is possible to 'explain' differences in rates of diffusion by, inter alia,

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[1]This paper is a joint product of the two authors. The input made by Jacobsson comes from a large project pursued together with Anna Bergek, Lennart Bångens and Björn Sandén (formerly Andersson). Jacobbsson's input thus draws extensively from three of the papers written in that project. Key references are Bergek and Jacobsson (2003), Jacobsson et al. (2002). We are grateful to those three colleagues as well as two anonymous references and the Editor, who gave valuable comments on an early draft.

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the nature of policies pursued. Immediately, the next question follows: Why do then some countries choose policies which apparently are superior in terms of inducing transformation whereas other countries choose policies which work less well? On this issue, 'economics of innovation' has little to add, as much of the discussion on policy takes a 'rationalistic' approach attempting to pinpoint the 'best' way.

Policy-making is, however, not a 'rational' technocratic process but rather one that appears to be based on such things as visions and values, the relative strengths of various pressure groups, perhaps on beliefs of 'how things work' and on deeper historical and cultural influences. What then are the political (in a broad sense) determinants and 'boundaries' of policy making and, therefore, of the rate at which the energy sector is transformed?

In this paper, we combine an 'economics of innovation' analysis (linking diffusion patterns to actual policies) with a 'politics of policy' analysis (explaining the choice of policies in the larger political context). In our first attempt to do so, we will focus on the case of Germany. Germany is one of the leading countries in terms of both the supply and use of two key renewable energy technologies: wind turbines and solar cells. Our objective is to explain the high rate of diffusion of wind turbines and solar cells in Germany not only by the particular features of the German regulatory framework in the energy sector but also by the ideas and processes which led various political bodies to adopt that framework. In the European debate, much emphasis is given to the costs of implementing key features of that framework, in particular the Feed-in Law of 1990 and its successor, the Renewable Energy Sources Act of 2000. We will therefore also make a preliminary assessment of both the financial flows and the social costs associated with various energy technologies in Germany.

The paper is structured in the following way. Section 2 contains a brief introduction to the technologies studied as well as some elements of an analytical framework for studying relatively early phases of diffusion and transformation processes. In Section 3, we outline German politics and policies on renewables and how they have impacted on the diffusion process for wind and solar power. Section 4 contains a discussion of the financial flows and social costs of these policies. Our main conclusions are given in Section 5.

2. Elements of an analytical framework[2]

Large-scale hydropower and combustion of different types of biomass currently provide the bulk of the energy supplied by renewable energy sources. In 1999, these supplied roughly 2600 and 160 TWh of electricity, respectively, worldwide (UNDP, 2000;[3] IEA, 2001). In addition to these, the 'new' renewables—e.g. wind turbines and solar cells—are now diffusing at a quite rapid rate.[4]

Figs. 1 and 2 show the global diffusion of wind turbines and solar cells. After an extensive period of experimentation, dating back decades[5] and lasting throughout the 1980s, the global stock of *wind turbines* grew very rapidly during the period 1990–2002 and reached a capacity of 32,037 MW. The stock of *solar cells* also grew at a high rate but the stock was more limited, 2 407 MW in 2002. For both technologies, the bulk of the stock was installed in the period 1995–2002. In other words, we have been witnessing what may be the beginnings of a take-off period in the long-term diffusion of these technologies.

Whereas the share of these technologies in the global energy supply is marginal at present—less than 0.5% of the 15,000 TWh of electricity generated in the world (Jacobsson and Bergek, 2003)—there are visions of wind power accounting for ten per cent of the world's electricity supply and of solar cells supplying 1% by 2020 (EWEA, 1999; Greenpeace and EPIA, 2001). The real issue is no longer the technical potential of these (and other) renewable energy technologies, but how this potential can be realised and substantially contribute to a transformation of the energy sector.

Yet, a large-scale transformation process of this kind requires far-reaching changes, many of which date back several decades and involve political and policy support in various forms in pioneering countries. Drawing on a rich and very broad literature, we will outline elements of an analytical framework[6] that captures some key features of early phases of such transformation processes.

Some characteristics of such phases may be found in the literature on industry life cycles (e.g. Afuah and Utterback, 1997; Utterback and Abernathy, 1975; Van de Ven and Garud, 1989; Utterback, 1994; Klepper, 1997; Bonaccorsi and Giuri, 2000). It emphasises the existence of a range of competing designs, small markets, many entrants and high uncertainty in terms of technologies, markets and regulation. We need,

[2]The section draws a great deal on Jacobsson and Bergek (2003).

[3]This data is for 1998.

[4]Whereas we focus on these two technologies, we are aware of a larger range of renewables that include e.g. wave power, new ways of using biomass (e.g. gasified biomass—see Bergek, 2002) and solar thermal.

[5]Already in the 1930s, experiments with large (several hundred kW) wind turbines for electricity generation were undertaken Germany, and the first solar cell was produced in 1954 by Bell laboratories (Heymann, 1995; Wolf, 1974, cited in Jacobsson et al., 2002).

[6]For reasons of space limitations, the discussion has had to be held brief. A longer discussion is found in Jacobsson and Bergek (2003) and in Carlsson and Jacobsson (2004).

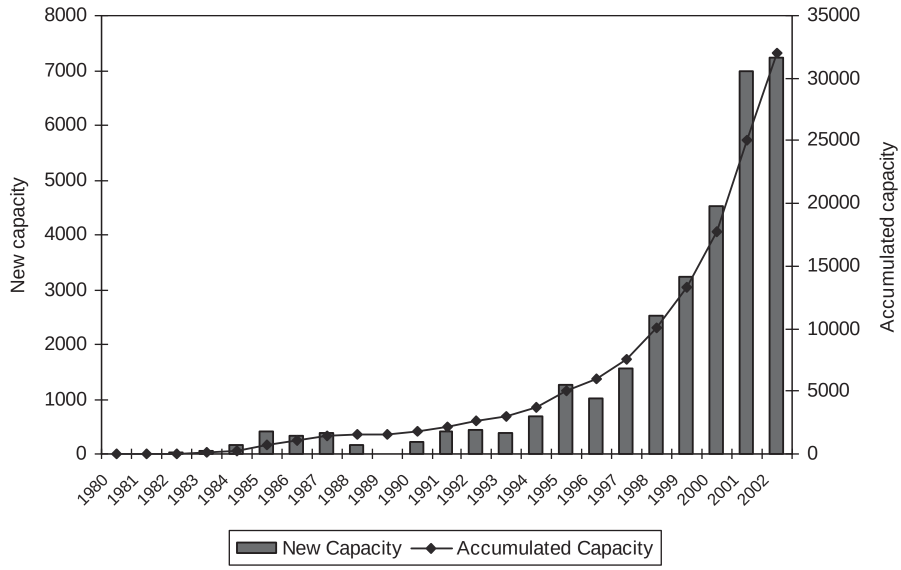

Fig. 1. The global diffusion of wind turbines, 1980–2002. *Sources*: Johnson and Jacobsson, 2001; Bundesverband Windenergie, 2003a; Windpower Monthly, 2003.

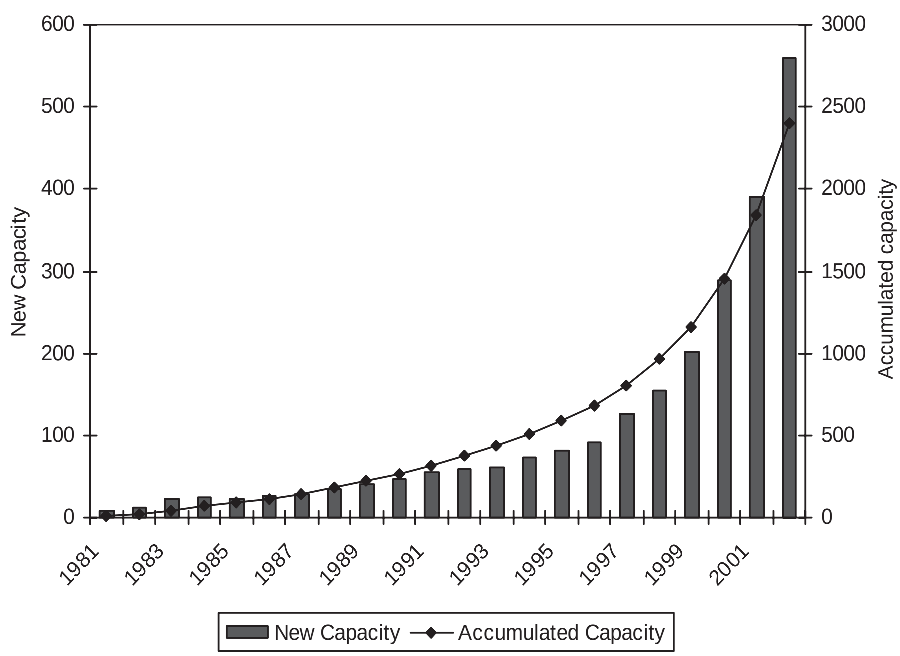

Fig. 2. The global production of solar cells, 1981–2002, MW. *Source*: Jacobsson et al., 2002; Schmela and Michael, 2003.

however, to understand the conditions under which this formative stage, with all its uncertainties, emerges in a specific country. We will outline four key conditions, or features, of early parts of such processes. These are institutional changes, market formation, the formation of technology-specific advocacy coalitions, and the entry of firms and other organisations.

First, as emphasised in the literature on 'economics of innovation' *institutional change* is at the heart of the process (Freeman and Louca, 2002). It includes alterations in science, technology and educational policies. For instance, in order to generate a range of competing designs, a prior investment in knowledge formation must take place and this usually involves a redirection of science and technology policy well in advance of the emergence of markets. Institutional alignment is also about the value base (as it influences demand patterns), market regulations, tax policies as well as much more detailed practices which are of a more immediate concern to specific firms, as discussed, for instance, by

Maskell (2001). The specific nature of the institutional framework influences access to resources, availability of markets as well as the legitimacy of a new technology and its associated actors. As argued in the literature of both 'innovation systems' (e.g. Carlsson and Jacobsson, 1997a) and 'transition management' (Rotmans et al., 2001), the nature of the institutional framework may therefore act as one of many mechanisms that obstruct the emergence of a formative stage and its evolution into a growth phase. Firms, therefore, compete not only in the market for goods and services but also to gain influence over the institutional framework (Van de Ven and Garud, 1989; Davies, 1996).

Second, institutional change is often required to *generate markets* for the new technology. The change may, for instance, involve the formation of standards, such as the Nordic telecommunication operators' decision to share a common standard (NMT) for mobile telecommunications. In the formative phase, *market formation* normally involves exploring niche markets, markets where the new technology is superior in some dimension. These markets may be commercial and involve unusual selection criteria (Levinthal, 1998) and/or involve a government subsidy. A 'protected space' for the new technology may serve as a 'nursing market' (Ericsson and Maitland, 1989) where learning processes can take place and the price/performance of the technology improve (see also Porter, 1998). Nursing markets may, through a demonstration effect, also influence preferences among potential customers. Additionally, they may induce firms to enter, provide opportunities for the development of user–supplier relations and other networks, and, in general, generate a 'space' for a new industry to evolve in.

The importance of early markets for learning processes is not only emphasised in management literature but also in the policy oriented literature on 'Strategic Niche Management'. A particularly clear statement of this is found in Kemp et al. (1998, p. 184):

> Without the presence of a niche, system builders would get nowhere… Apart from demonstrating the viability of a new technology and providing financial means for further development, niches help building a constituency behind a new technology, and set in motion interactive learning processes and institutional adaptation…that are all-important for the wider diffusion and development of the new technology.

Third, whereas individual firms, and related industry associations, may play a role in competition over institutions (Feldman and Schreuder, 1996; Porter, 1998), such actors may be but one part of a broader constituency behind a specific technology. The build up of a constituency involves the 'entry' of other organisations than firms. It may involve universities but also non-commercial organisations (e.g. Greenpeace). Unruh (2000, p. 823) underlines the existence of a range of such organisations and the multitude of roles they play.

> …users and professionals operating within a growing technological system can, over time, come to recognize collective interests and needs that can be fulfilled through establishment of technical… and professional organisations…These institutions create non-market forces…through coalition building, voluntary associations and the emergence of societal norms and customs. Beyond their influence on expectations and confidence, they can further create powerful political forces to lobby on behalf of a given technological system.

The centrality of the formation of constituencies is well recognised in the political science literature, in particular in the literature on networks (Marsh and Smith, 2000; Rhodes, 2001). Thus, Sabatier (1998) and Smith (2000) argue that *advocacy coalitions,* made up of a range of actors sharing a set of beliefs, compete in influencing policy. For a new technology to gain ground, *technology-specific coalitions* need to be formed and to engage in wider political debates in order to gain influence over institutions and secure institutional alignment. As part of this process, advocates of a specific technology need to build support among broader advocacy coalitions to advance the perception that a particular technology, e.g. solar cells or gas turbines, answers wider policy concerns. Development of joint visions of the role of that particular technology is therefore a key feature of that process. Hence, the formation of "political networks" sharing a certain vision and the objective of shaping the institutional set-up is an inherent part of this formative stage.

Fourth, *entry of new firms* is central to the transformation process. Each new entrant brings knowledge, capital and other resources into the industry. New entrants experiment with new combinations, fill 'gaps' (e.g. become a specialist supplier) or meet novel demands (e.g. develop new applications). A division of labour is formed and further knowledge formation is stimulated by specialisation and accumulated experience (e.g. Smith, 1776; Young, 1928; Stigler, 1951; Rosenberg, 1976). Finally, early entrants raise the returns for subsequent entrants in a number of ways, i.e. positive external economies emerge (Marshall, 1920; Scitovsky, 1954). In addition to the conventionally related sources of external economies (e.g. build up of an experienced labour force and specialised suppliers of inputs) early entrants strengthen the 'political' *power* of a technology-specific advocacy coalition and provide an enlarged opportunity to influence the institutional set-up. Early entrants also drive the process of *legitimation* of a new field, improving access to markets, resources, etc. for subsequent entrants (Carrol (1997) and resolve under-

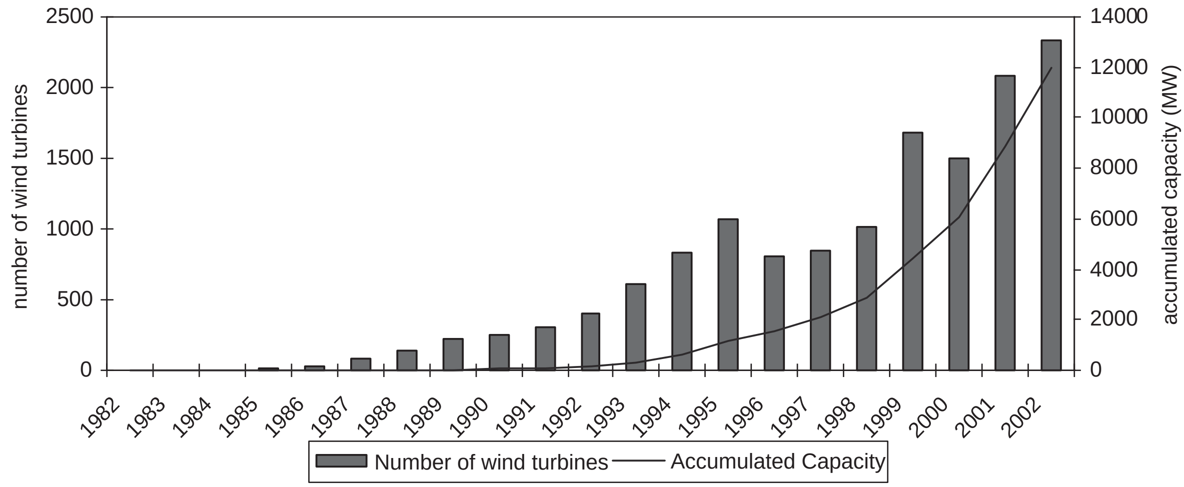

Fig. 3. The diffusion of wind turbines in Germany, 1982–2002 (annually installed numbers and accumulated capacity). *Sources*: Bergek and Jacobsson, 2003; Bundesverband Windenergie, 2003a.

lying technical and market uncertainties (Lieberman and Montgomery, 1988).

The time span involved in an early phase where these four features emerge may be very long. This is, for instance, underlined in a recent study of Israel's 'Silicon Wadis,' which began a rapid period of growth in the 1990s after a history starting in the 1970s (De Fontenay and Carmell, 2001). Other examples are given in Geels (2002) and in Carlsson and Jacobsson (1997b).

A *'take-off'* into a rapid growth phase may occur when investments have generated a large enough, and complete enough, system for it to be able to 'change gear' and begin to develop in a self-sustaining way (Carlsson and Jacobsson, 1997a; Porter, 1998). As it does so, a chain reaction of powerful *positive feedback loops* may materialise, setting in motion a process of cumulative causation. Indeed, as pointed out long ago by Myrdal (1957), these virtuous circles are central to a development process—as these circles are formed, the diffusion process becomes increasingly self-sustained and characterised by autonomous dynamics (Rotmans et al., 2001), often quite unpredictable in its outcome. All the four features of the formative phase are involved in such dynamics. For instance, the emergence of a new segment may induce entry by new firms, strengthening the political power of the advocacy coalition and enabling further alignment of the institutional framework (which, in turn, may open up more markets and induce further entry, etc.).

Under what conditions a 'take-off' takes place seems to be extremely difficult to predict. A necessary condition is, however, that larger markets are formed—there must be an underlying wave of technological and market opportunities. Some ICT clusters have become successful by linking up to the US market (Breshanan et al., 2001) whilst the Nordic technological systems in mobile telephony grew into a second phase with the European GSM standard. As we shall see below, it has been alterations in the *regulatory frameworks* that triggered a set of actions and reactions and propelled the diffusion process in the cases of wind power and solar cells in Germany. At the heart of the story that is to be told lies a 'battle over institutions'.

3. Wind energy and solar cells in Germany: politics, policies and their impact on diffusion

This section will deal with basic values and beliefs as well as processes leading up to policy-making, the attendant policies, the impact of these policies on technology diffusion and subsequent feed-back loops to policy making. Although we are analysing what with hindsight is an early phase in the diffusion process, we shall divide this into three sub-phases. 1974 to the late 1980s was a formative phase for both wind and solar cells. Important decisions in favour of market creation were taken beginning in 1988, and this policy was implemented during subsequent years. 1990 brought a first take-off for wind while continuing the formative phase for solar cells. 1998 reinforced the take-off for wind and began a take-off period for solar cells. These three sub-phases are clearly seen in Figs. 3 and 4, which portray the diffusion of these technologies in Germany. Whereas Germany accounted for a less than 1% share of the global stock of these technologies in 1985 and 1990, respectively, it came to play a prominent role in the global diffusion from the early 1990s. Indeed, at the end of 2002, Germany had more than one-third of the global stock of wind turbines—12.001 out of 32.037 MW of installed capacity—and about one-ninth

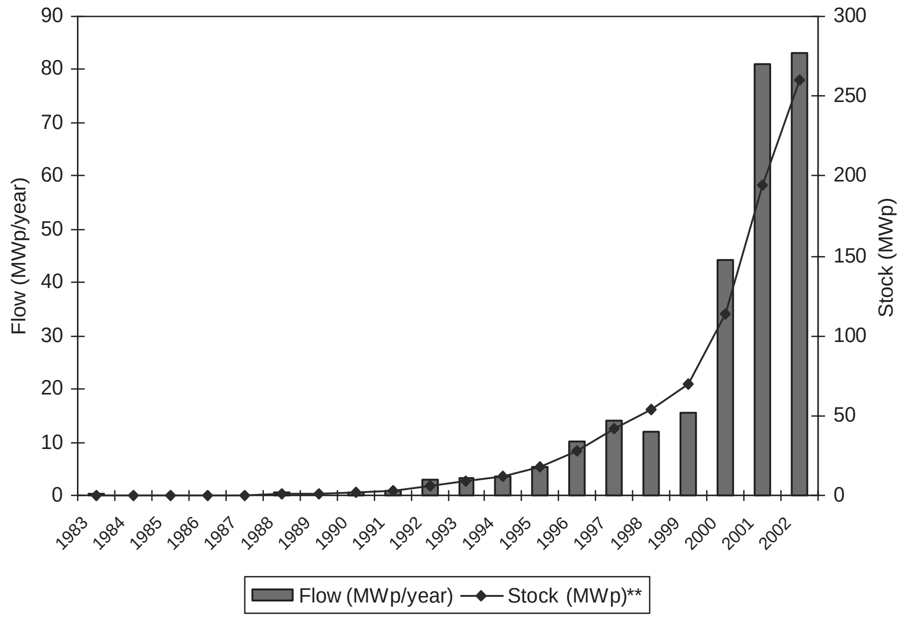

Fig. 4. The diffusion of solar cells in Germany, 1983–2002. 2002: without off-grid PV applications. *Source*: Jacobsson et al., 2002; IEA, 2003b; and http://www.iea-pvps.org.

of the stock of solar cells, approximately 275 MW_p out of 2.403 MW_p (See Figs. 1–4).

3.1. 1974 to 1988—a formative phase of wind and solar power

The energy crises of the 1970s produced major rethinking in Germany as in many other countries. The main emphasis there was to increase government support for hard coal and nuclear power use (Schmitt, 1983; Kitschelt, 1980). From the mid-1970s, however, nuclear power became increasingly controversial with the public; its rapid expansion led to many bitter confrontations and a policy of repression until the end of the decade. Many believed that the government should instead bank on energy efficiency and renewable energy. A first Enquete Commission[7] of the German parliament in 1980 recommended effficiency and renewables as first priority but also the maintenance of the nuclear option (Meyer-Abich and Schefold, 1986). In 1981, the Federal Ministry of Research and Technology commissioned a 5-year study, which drew a strong echo in the media when it was published around the time of the Chernobyl accident. It concluded that only reliance on renewables and efficiency would be compatible with the basic values of a free society, and that this would be less expensive than the development of a plutonium-based electricity supply as envisioned at that time (Meyer-Abich and Schefold, 1986). Against this background of strong pressure from public opinion, R&D for renewable energy sources was raised to a significant level—not as significant per capita as in other countries such as Sweden, Denmark and the Netherlands, but larger in total amount. In 1974, annual spending started with about DM 20 million. It reached a peak of DM 300 million in 1982—the year when the government passed from the social democratic/liberal to a conservative/liberal coalition under chancellor Kohl—and declined thereafter to a low point of 164 million in 1986 (the year of the Chernobyl accident). Further decline had been scheduled but was reversed at that point (Sandtner et al., 1997). Much publicly financed R&D was intended for developing off-grid renewable energy technologies for export to the Third World, not for the domestic market (Schulz, 2000).

Until the end of the 1980s and in fact beyond, renewable energy faced a political–economic electricity supply structure that was largely hostile. The electricity supply system was dominated by very large utilities relying on coal and nuclear generation. These utilities were opposed to all small and decentralised forms of generation, which they deemed uneconomic and foreign to the system. The two key ministries—Economic Affairs on one hand, Research and Technology on the other—offered only limited help. The Ministry of Economic Affairs was (and still is) in charge of utilities and, in fact, their chief ally. Both the Social Democratic-Liberal (before 1982) and the Conservative-Liberal[8] governments (1982–1998) strongly supported nuclear

[7]Committee of the Bundestag (lower house) composed half of MPs, half of experts who also have the right to vote. Enquete commissions are set up irregularly to deal with major new policy issues turning very substantially on scientific expertise.

[8]Conservative is used as synonymous with Christian Democratic.

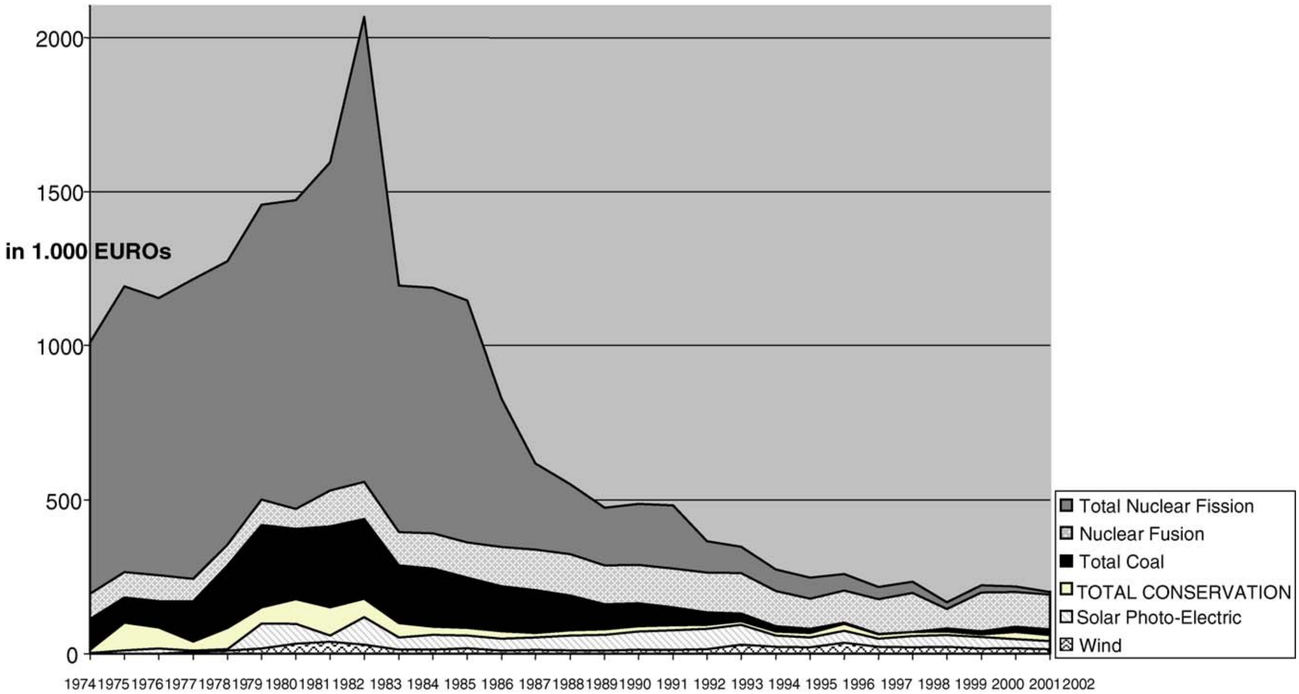

Fig. 5. Energy R&D in Germany 1974–2002 (in 2002 prices). *Source*: IEA, 2003a.

and coal. This is clearly seen in the allocation of R&D funds, where R&D funding to nuclear power and fossil fuels dwarfed that of renewable energy technology (Fig. 5).

Moreover, during the oil crisis, the government created powerful incentives for utilities to use otherwise non-competitive domestic hard coal. These incentives were paid out of a government fund financed by a surcharge or special tax on final customers' electricity prices. This surcharge varied between 3.24% of that price in 1975–1976 and 8.5% in 1989 (Bundesverfassungsgericht, 1994). At the same time, the Ministry of Economic Affairs—normally in charge of market creation programs—did little for renewable energy sources. It only made use of the general competition law to oblige the utilities (then operating as territorial monopolies) to purchase electricity from renewable energy sources produced in their area of supply at avoided costs. However, the large utilities interpreted this so narrowly (as avoided fuel costs only) that the obligation had little effect.[9] The ministry resisted all demands for market formation with the slogan that energy technologies had to prove themselves in the market and that it was not prepared to subsidise technologies that were not mature.

At the same time, the Ministry of Research—the former Ministry of Nuclear Affairs renamed in 1962, whose tasks now came to include renewables—viewed its responsibility as one of only supporting research and development, and to a smaller extent demonstration. It was more generous in funding nuclear demonstration projects. By 1980, it had spent about DM 13 billion on nuclear RD&D (Kitschelt, 1980; Zängl, 1989). Under the prevailing distribution of responsibilities—which was jealously enforced by the much more powerful Ministry of Economic Affairs (Ristau, 1998)—it was allowed to support renewable energy technologies only in pre-market phases. There was little opportunity or willingness to bridge the gap between research prototypes and market-competitive products.

Yet, in this largely unfavourable political context, institutional changes occurred which began to open up a space for wind and solar power; a space which proved to be of critical importance for the future diffusion of these renewables. This institutional change largely related to the formation of government funded R&D programme for these technologies.

These 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. Some programmes may have pursued ambivalent goals; thus one of the purposes of the GROWIAN project of a large (several MW) wind turbine was allegedly to demonstrate that wind power was not viable (Heymann, 1999). However, the wind power R&D programme was large enough to finance most projects applied for and flexible enough to finance most types of projects (Windheim, 2000a). In the period 1977–1989, about 40

[9]Only some local utilities—Stadtwerke, i.e. municipal utilities—took a different course.

R&D projects were granted to a range of industrial firms and academic organisations for the development or testing of small (e.g. 10 kW) to medium-sized (e.g. 200–400 kW) turbines (elaboration on Windheim, 2000b).[10]

Much the same applied to R&D in solar cells. In the period 1977–1989, as many as 18 universities, 39 firms and 12 research institutes received federal funding (Jacobsson et al., 2002).[11] Although the major part of the research funding was directed towards cell and module development and the prime focus was on crystalline silicon cells, funds were also given to research on several thin-film technologies.[12] In addition, R&D funds were allocated to the exploration of a whole range of issues connected to the application of solar cells, such as the development of inverters. As a consequence, and in spite of the fringe status of that R&D, a broad academic cum industrial knowledge base began to be built up about 25 years ago for both wind turbines and solar cells.

In the 1980s, a set of demonstration programmes became part of the R&D policy. Investments in wind turbines were subsidised by several programmes (Hemmelskamp, 1998). At least 14 German suppliers of turbines received funding for 124 turbines in the period 1983–1991 (elaboration on Windheim, 2000b).[13] This programme constituted an important part of the very small national market in the 1980s—total installed power was just 20 MW by the end of 1989 (Durstewitz, 2000a). An early niche market was also found in 'green' demand from some utilities—reflecting the strength of the green movement (Reeker, 1999)—and from environmentally concerned farmers (Schult and Bargel, 2000; Tacke, 2000).

In solar cells, the first German demonstration project took place in 1983. This was wholly financed by the federal government and had an effect of 300 kW_p, which was the largest in Europe at that time. In 1986, it was followed by a demonstration programme, which by the mid-1990s had contributed to building more than 70 larger installations for different applications. Yet, by 1990, the accumulated stock amounted to only 1.5 MW_p (see Fig. 4). Although the demonstration programme had only a minor effect in terms of creating a 'protected space', it was effective as a means of enhancing the knowledge base with respect to application knowledge. Hence, by that time, learning had taken place not only among four firms which actually had entered into solar cell production (e.g. AEG, MBB and Siemens) but also to some extent 'downstream' in the value chain.

In sum, this formative phase was dominated by institutional change in the form of an R&D policy that began to include, at the fringe, R&D in renewables. Although small in relation to R&D in nuclear and other energy technologies, it allowed for a small space to be opened for wind and solar power in which a range of firms and academic departments began a process of experimentation and learning. Small niche markets were formed and a set of firms were induced to enter.

In addition to these firms and universities, a range of other organisations were set up, organisations which later were to become key actors in advocacy coalitions for wind and solar power. These included conventional industry associations such as the German Solar Energy Industries Association, which was founded in 1978 (Bundesverband Solarindustrie, 2000). As importantly, environmental organisations that were independent of industry grew up to provide expertise and visions of the future. For instance, in 1977, at the height of the anti-nuclear power controversy, actors of the green movement set up the Institute of Ecology (*Öko-Institut*) for Freiburg to provide counter-expertise for their struggle with governments and utilities. This institute became very important for coming up with proposals for the development of renewable energy policies later on. In a similar vein, Förderverein Solarenergie, started in 1986, in 1989 developed the concept of 'cost covering payment' for electricity generated by renewable energy technology, a concept which was later applied in various Feed-in Laws at federal and local levels. A third type of association is Eurosolar, founded in 1988, which is an organisation for campaigning *within* the political structure for support of renewables and which is independent of political parties, commercial enterprises and interest groups, yet counts several dozen members of the German parliament in its ranks (not only from red–green).

3.2. 1988–1998—take-off for wind power but not for solar power

The accident in Chernobyl in 1986 had a deep impact in Germany. Public opinion had been divided about evenly on the question of nuclear power between 1976 and 1985. This changed dramatically in 1986. Within 2 years, opposition to nuclear power increased to over 70%, while support barely exceeded 10% (Jahn, 1992). The social democrats committed themselves to phasing out nuclear power; the Greens demanded an immediate shutdown of all plants.

Also in 1986, a report by the German Physical Society warning of an impending climate catastrophe received much attention, and in March 1987 chancellor Kohl

[10]The numbers exclude funding given for the purpose of demonstration wind turbines. In addition, there was support for projects that could benefit all sizes of turbines.

[11]These are estimates based on elaboration of data from Jahresbericht Energieforschung und Energietechnologien, various issues, Bundesministerium für Wirtschaft und Technologie.

[12]These were: amorphous silicon (aSi), copper sulphide, cadmium selenide, cadmium telluride and copper indium diselenide (CIS).

[13]According to Hemmelskamp (1998), 214 turbines were supported.

declared that the climate issue represented the most important environmental problem (Huber, 1997). A special parliamentary commission was set up to study this matter—the *Enquetekommission* on climate. The commission worked very effectively in a spirit of excellent co-operation between the parliamentary groups of both government and opposition parties. There was general agreement that energy use had to be profoundly changed. The matter was given increased urgency by the fact that the price of oil had declined again, so that further increases of fossil fuel consumption had to be expected unless serious measures were taken; at the same time, the price gap between renewable energy technologies and conventional generation grew larger (Kords, 1996; Ganseforth, 1996).

A series of proposals for institutional change were formulated which included an electricity feed-in law for generation from renewables (Schafhausen, 1996). Pressure from parliament on the government to take substantial steps in favour of renewables increased, as evidenced by a variety of members' bills (Deutscher Bundestag, 1987, 1988a, b, 1989, 1990a, b). This was obviously reflecting a high level of public concern with this issue at that time. The Ministry of Economic Affairs tried to counteract these efforts (“no subsidisation of technologies unfit for the market”) but failed to persuade all the deputies of the government coalition. Nor was it able to induce the utilities to create framework conditions more favourable for the expansion of renewables on a voluntary basis.

Eventually the government more or less reluctantly—support came only from the Research and the Environment Ministries—adopted several important measures. In 1988, the Ministry of Research launched two large demonstration cum market formation programmes. A first was directed at wind power and initiated in 1989. Initially, it aimed at installing 100 MW of wind power—a huge figure compared to the stock of 20 MW in 1989. Later, it was expanded to 250 MW. The programme mainly involved a guaranteed payment of €0.04/kWh for electricity produced, later reduced to 0.03.[14] The second demonstration cum market formation measure was the 1.000 roofs programme for solar cells. Furthermore, the legal framework for electricity tariffs was modified in such a way as to allow compensation to generators of renewables sourced electricity above the level of avoided costs. Finally, the Electricity Feed-in Law was adopted, which was originally conceived mainly for a few hundred MW of small hydropower (Bechberger, 2000).

Remarkably, the Feed-in Law—the most important measure since it was conceived for a longer term—was adopted in an all-party consensus (though social democrats and greens wanted to go further in the support of renewables sourced electricity).[15] As mentioned above, the basic concept of the Feed-in Law was put forward by several associations—Förderverein Solarenergie (SFV), Eurosolar and an association organising some 3.500 owners of small hydro power plants, many of whose members were politically conservative and able to effectively campaign for the new law in a larger association organising small and medium-sized firms. It seems that passing the law did not require a large political effort, despite the opposition of the utilities which were not entitled to receive any benefits under this law if they invested themselves in the new technologies (Ahmels, 1999; von Fabeck, 2001; Scheer, 2001). But then a few hundred MW hydropower was hardly a serious matter, and in addition the big utilities were at that time absorbed in taking over the electricity sector of East Germany in the process of reunification (Richter, 1998).

The Feed-in Law required utilities to connect generators of electricity from renewable energy technology to the grid and to buy the electricity at a rate which for wind and solar cells amounted to 90% of the average tariff for final customers, i.e. about DM 0.17.[16] Together with the 100/250 MW programme and subsidies from various state programmes (DEWI, 1998), the Feed-in Law gave very considerable financial incentives to investors, although less for solar power since its costs were still very high compared to the feed-in rates. One of the declared purposes of the law was to ‘level the playing field’ for renewables sourced electricity by setting feed-in rates at levels that took account of the external costs of conventional power generation. In this context, the chief member of parliament supporting the feed-in bill on behalf of the Christian Democrats in the Bundestag mentioned external costs of about 3–5 Eurocents per kWh for coal-based electricity (Deutscher Bundestag, 1990c).

These incentives stimulated the formation of markets and had three effects. First, it resulted in an ‘unimaginable’[17] market expansion from about 20 MW in 1989 to close on 490 MW in 1995 (BWE, 2000).[18] Second, it led to the emergence of learning networks which developed primarily between wind turbine suppliers and local

[14]In addition, private operators, e.g. farmers, had the possibility to obtain an investment subsidy (Durstewitz, 2000a).

[15]In the early 1990s, the Ministry of Economic Affairs actually demanded a very large support programme for renewable energies (about €0.75billion) but could not secure the necessary political support (Hemmelskamp, 1999).

[16]Generators were not required to negotiate contracts, participate in bidding procedures or obtain complicated permits; this simplicity was certainly essential for the success of this act (von Fabeck, 1998).

[17]This was the word used by a central person in the evolution of the German wind turbine industry and market.

[18]The bulk of the sales within the 100/250 MW programme took place 1990–1995 and the programme accounted for most of the nearly 60 MW that were installed in the years 1990–1992 (ISET, 1999, Table 3).

components suppliers due to the need of adapting the turbine components to the particular needs of each turbine producer.The benefits of learning also spilled over to new entrants (induced by market growth), since these could rely on a more complete infrastructure. Third, it resulted in a growth in the 'political' strength of the industry association organising suppliers and owners of wind turbines who were now able to add economic arguments to environmental ones in favour of wind energy.

However, when the Feed-in Law began to have an impact on the diffusion of wind turbines, the big utilities started to attack it both politically and in the court system (basically on constitutional grounds)—unsuccessfully, as it were. This reflected more than just opposition to small and decentralised generation. First, no provision had been made to spread the burden of the law evenly in geographical terms; this came only in 2000. Second, the utilities were by this time marked by the experience of politically dictated subsidies for hard coal used in electricity generation. These subsidies had grown from €0.4 billion in 1975, the year the 'coal penny' was introduced, to more than €4 billion annually in the early 1990s (see Section 3.1 above). Two-thirds of this was covered by a special levy on electricity, one third had to be paid by the utilities directly but was also passed on to the consumers.[19]

Political efforts to change the law seemed at first more promising. In 1996, utilities association VDEW lodged a complaint with DG Competition (the subdivision of the European Commission which looks after fair competition) invoking violation of state-aid rules. The Ministry of Economic Affairs then proposed to reduce rates on the occasion of an upcoming amendment (the law had to be changed in any case in order to spread the burden of feed-in payments more evenly in geographical terms, and also because of liberalisation), a measure supported by DG Competition. Even though the notification of the Feed-in Law to the European Commission had not drawn an adverse reaction right after its adoption, DG Competition now argued that feed-in rates should come down substantially along with costs, addressing particularly wind power (Salje, 1998; Hustedt, 1998; Advocate General Jacobs, 2000). The Ministry of Economic Affairs was happy enough with this support; its official line was that renewable energies were only "complementary" and could not pretend to replace coal and nuclear generation.

All this led to insecurity for investors and stagnating markets for wind turbines from 1996 to 1998. Indeed, climate policy had suffered a general setback at the governmental level due to the financial and other problems resulting from German reunification (Huber, 1997). However, the issue was still strong with public opinion. Thus, a survey conducted in 1993 in 24 countries showed that concern over global warming was greatest in Germany (Brechin, 2003).

In any event, the big utilities' political challenge to the Feed-in Law failed in parliament (Ahmels, 1999; Molly, 1999; Scheer, 2001). In 1997, the government proposal to reduce feed-in rates mentioned above led to a massive demonstration bringing together metalworkers, farmer groups and church groups along with environmental, solar and wind associations; the Association of Investment Goods Industry VDMA gave a supportive press conference (Hustedt, 1997, 1998). The government failed to persuade even its own MPs. In a committee vote, the government proposal lost out by a narrow vote of 8–7, and it seems that as many as 20 CDU/CSU members were determined to vote against the new rates in the plenary (Scheer, 2001). Clearly, the new technology had by now acquired substantial legitimacy. As one CDU member and executive of the wind turbine industry put it: "In this matter we collaborate with both the Greens and the Communists" (Tacke, 2000). The Feed-in Law was now incorporated in the Act on the Reform of the Energy Sector of 1997, which transposed the EU directive on the internal market for electricity.

When it became clear that the feed-in rates would remain unchanged, this removal of uncertainty resulted not only in a further expansion in the market for wind turbines (see Fig. 3), but also in the entry of larger firms into the wind turbine industry as well as into the business of financing, building and operating wind farms, strengthening the advocacy coalition yet again.

The second market introduction cum demonstration programme of the research ministry was focused on small solar cell installations, the 1.000 roofs programme, for which it provided an investment aid of 60–70%. Eventually, the programme led to the installation of more than 2.200 grid-connected, roof-mounted installations with an effect of 5.3 MW_p by 1993 (IEA, 1999; Staiss and Räuber, 2002). Whereas the 1.000 roof programme was successful, the market formation that it induced was not large enough to justify investments in new production facilities for the solar cell industry, in particular as the industry was running with large losses (Hoffmann, 2001). The industry now expected that there would be a follow-up to the 1.000 roof programme, but no substantial programme emerged (Brauch, 1997). In 1993, Eurosolar proposed a 100.000 roof programme that in the subsequent year was taken up by the Social Democrats (Hermann Scheer, the first president of Eurosolar, is himself a Social Democratic MP). This proposal was, however, not supported by the party groups of the (Conservative/Liberal) government coalition (Scheer, 2001). If the industry was to survive, market creation had to come from other quarters. This led to intensified efforts to mobilise other resources, a

[19] In 1994, the Kohlenpfenning (coal penny) was held unconstitutional (Bundesverfassungsgericht, 1994; Wachendorf, 1994).

process which demonstrated the high level of legitimacy that solar PV enjoyed in German society.

The most important help came from municipal utilities. In 1989, the federal framework regulation on electricity tariffs—the tariffs themselves are set at the *Länder* level—was modified in such a way as to permit utilities to conclude cost-covering contracts with suppliers of electricity using renewable energy technologies, even if these full cost rates exceeded the long-term avoided costs of the utilities concerned. On this basis, local activists petitioned local governments to enforce such contracts on the utilities. After much effort, most *Länder* expressly allowed such contracts, and several dozen cities opted for this model, including Bonn and Nuremberg. As the process first started in Aachen, this is known as the Aachen model (Solarenergie-Förderverein, 2002; Staiss and Räuber, 2002).[20] It was carried by many activist groups and to some extent co-ordinated by some of the new associations such as Eurosolar or SFV (Solarenergie-Förderverein, 2002).

Additional help came from some of the Länder, which had their own market introduction programmes, the most active being North Rhine-Westphalia. Some states acted through their utilities, which would subsidise solar cells for special purposes, e.g. schools (Bayernwerk in Bavaria, or BEWAG in Berlin). Some offered "cost-oriented rates" which however remained below the level of full cost rates (thus HEW in Hamburg). Finally, in a major effort, Greenpeace gathered several thousand orders for solar cell rooftop "Cyrus installations" (Ristau, 1998). Owing to these initiatives, the market did not disappear at the end of the 1.000 roofs programme but continued to grow (see Fig. 4).

Even though the size of the market was quite limited, these initiatives had two significant effects. First, they induced a number of new, often small firms to enter into and enlarge the industry. 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. Second, the large number of cities with local Feed-in Laws and a proliferation of green pricing schemes revealed a wide public interest in increasing the rate of diffusion—the legitimacy of solar power was apparent. Various organisations could point to this interest when they lobbied for a programme to develop yet larger markets for solar cells. As mentioned above, Eurosolar proposed a programme to cover 100.000 roofs in 1993 and, since 1996, the German Solar Energy Industries Association had worked towards the realisation of such a programme (Bundesverband Solarindustrie, 2000).[21]

Lobbying by the German solar cell industry also intensified. Siemens had at this time already started its production in the US and a second producer, ASE, had the opportunity of doing so with an acquisition of Mobil Solar. To continue production in Germany without any prospects of a large home market would clearly be questionable from a firm's point of view. ASE threatened at this time to move abroad if a market expansion did not take place (Hoffmann, 2001). A promise of a forthcoming programme was then given and ASE decided to invest in a new plant in Germany, manufacturing cells from wafers produced with a technology acquired from Mobil Solar. Production started in mid-1998 (ASE Press Release, 1998) in a plant with a capacity of 20 MW (Hoffmann, 2001).

The decision to locate production in Germany implied a dramatic increase in the German industry's solar cell production. A second major investment was Shell's entry into the German solar cell industry through its investment in a new plant in Gelsenkirchen in 1998 (9.5 MW, Stryi-Hipp 2001). Here too, a dialogue with policy makers preceded the investment (Zijlstra, 2001). Hence, in 1998, two major investments were made which greatly expanded capacity in the German solar cell industry.

In sum, the initial 'space' given to wind and solar power in the 1970s and 1980s was now enlarged. In part, this was due to external changes (Chernobyl and the climate change debate) mediated by public awareness and the acceptance of the necessity to change the energy system. But it was also a result of the initial investments in the first formative period. Out of those investments came not only an initial knowledge base, but also an embryonic advocacy coalition consisting of industry associations, an infant industry and various interest organisations. A positive feed-back from those early investments resulting in an ability of this coalition to shape further institutional change can be discerned (1990 Feed-in Law). Further feed-back loops from market formation, through entry of various organisations, to an enhanced political power of the coalition and an ability to defend favourable institutions (which then led to further market formation, entries, etc.) was a key feature of the subsequent diffusion process for wind power in the 1990s. For solar photovoltaics, the process of market formation was made more difficult by the high cost of solar power but through an intensive work by the advocacy coalition, where the interest

[20]In the same year, Bayernwerk introduced the first 'green pricing' scheme, which involved investment in a 50 kW_p plant. Shares were sold to about 100 people who paid a premium rate for this electricity (Schiebelsberger, 2001). Many such schemes followed, for instance by RWE in 1996. About 15,000 subscribers eventually paid an eco-tariff (twice the normal tariff) for electricity generated by solar cells, hydropower and wind (Mades, 2001).

[21]The late 1980s and the 1990s saw a veritable proliferation of renewable energy associations. For instance, an association for biogas (1992), one for biomass (1998) and yet another solar energy association (UVS, 1998). Most of these engage in lobbying and educational activities, sometimes also in exchange of information and experience.

organisations Eurosolar and Förderverein Solarenergie plus Greenpeace played a key role, local market formation programmes were initiated and these were to become precursors to larger, federal programmes in the subsequent phase.

3.3. 1998 to 2003—take-off for solar power, continued growth for wind power and new political challenges

In 1998, the Social Democratic/Green coalition, which replaced the Conservative-Liberal government committed itself to a market formation programme for solar cells as called for by the PV industry and earlier on by Eurosolar and other organisations. The coalition agreement contained commitments to the introduction of an eco-tax on energy, to legislation improving the status of renewable energy, a 100.000 roof programme for solar cells and a negotiated phase-out of nuclear power; all these goals were realised by 2001 (Staiss, 2003). By January 1999, the 100.000 roofs programme (for about 350 MW) was started, providing subsidies in the form of low interest loans to investors. For the sake of speed, the programme did not take the form of a law but of a decree enacted by the Ministry of Economic Affairs. This ministry maximised bureaucratic obstacles at first, but relented after strong protests by parliamentary groups of the coalition (Witt, 1999b, c). In 1999, 3.500 such loans were granted for installations amounting to a mere 9 MW_p. It was clear that everyone was waiting for a revision of the Feed-in Law, which however took some time to prepare.

Later in 1999, the reform of the Feed-in Law was started. After launching the trial balloon of a renewable energy levy that the utilities would be able to institute voluntarily (Witt, 1999a), the Minister of Economic Affairs—in charge of this subject-matter—leaned in favour of a quota system. When it became clear that the minister was not prepared to respect agreements with the parliamentary party groups of the coalition, these groups seized the initiative and submitted a members' bill which the ministry then tried to dilute and delay without much success, and which was finally adopted as the Renewable Energy Sources Act in March 2000 (Mez, 2003a).

The deputies, particularly the Greens, were inspired by the local Feed-in Laws for solar power and wanted to move this approach to the federal level. For that purpose they organised a process involving a very large, partly technology-specific advocacy coalition—various environmental groups, the two solar industry associations, the association of the machinery and equipment producers VDMA, the metalworkers trade union IG Metall, three solar cell producers and politicians from some *Länder*, e.g. North Rhine-Westphalia (Pfeiffer, 2001). The unorthodox coalition even included a major utility (Preussen Elektra, which testified in favour of the new mechanism equalising the burden of the law on the national level although overall it would have preferred a quota system); as a result the big utilities were not united in their opposition. From these organisations and individuals, the Greens received help in terms of both information and support in influencing members of parliament.

The Social Democrats for their part had a strong industrial policy interest in re-writing the Feed-in Law (Eichert, 2001). They feared that the 1998 liberalisation of the energy market would lead to a long-term decline in employment in the energy sector and in the associated capital goods industry which has always been a point of strength of German industry. At this time, the German wind turbine industry had grown to be the second largest in the world and exhibited great dynamism (Bergek and Jacobsson, 2003). With liberalisation, the price of electricity dropped, and with it, the remuneration for wind turbine owners. It was then feared that the incentive for further diffusion would be lost and that a less dynamic home market would hurt the German wind turbine industry. Strong renewables legislation, these deputies argued, would put German industrial structure and employment on a more sustainable basis both environmentally and economically.

While the Federation of German Industries strongly opposed the law, key industrial association VDMA (Equipment and Machinery Producers, counting about 3000 member firms with approximately 1 million employees) joined the ranks of its supporters—again demonstrating the increasingly broad legitimacy of renewables. The opposition parties (conservative CDU/CSU and the Liberals) were internally divided on many issues and unable to come up with a coherent alternative, though on the whole they argued for more competition and sometimes for state subsidies instead of passing on costs to final customers (Bechberger, 2000; Deutscher Bundestag, 2000a, b). They also argued that the new law was bound to draw a state aid challenge from DG Competition, a point echoed by the Ministry of Economic Affairs. In fact, a special effort was made by the red–green members of parliament to ward off this possibility (rates declining over time; exclusion of state-owned utilities from the beneficiaries). After adoption of the law, DG Competition questioned its compatibility with EU rules; it withdrew its objection only in May 2002, even though the European Court in March 2001 had rejected a similar challenge in the case of *PreussenElektra v. Schleswag* (Lauber, 2001).

The Renewable Energy Sources Act repeated the Feed-in Law's implicit commitment to take external costs into account. In fact, it provided three reasons for the special feed-in rates. First, it referred to the polluter pays principle with regard to external costs. The explanatory memorandum attached to the law explains that

> most of the social and ecological follow-up costs associated with conventional electricity generation are currently not borne by the operators of such installations but by the general public, the taxpayers and future generations. The Renewable Energy Sources Act merely reduces this competitive advantage...

Second, the memorandum stresses that "conventional energy sources still benefit from substantial government subsidies which keep their prices artificially low". Third, the act purports to break the vicious circle of high unit costs and low production volumes typical of technologies for the generation of renewables sourced electricity (Federal Ministry for the Environment, 2000).

Under the new law, the rates of the tariff scheme were guaranteed to investors for 20 years (under the old Feed-in Law no such guarantee had existed). With regard to wind, rates varied with site quality. For at least 5 years from an installation date in 2000 or 2001 (9 years for offshore), the rate was to amount to €0.091/kWh, and longer depending on how far a turbine remained below the performance of a reference facility. For the first years of operation this meant an improvement of more than 10% over the rate applicable under the previous system in 1998 and 1999 (Hirschl et al., 2002). This was compensated to various degrees by the later decline to €0.062/kWh. For turbines installed in 2002, these rates would be about 1.5% lower, with the decline continuing at that annual rate (always for new installations only) for subsequent years, reinforced by inflation since rates are not adjusted to take it into account (Staiss, 2003). Overall this meant greater security for investors, particularly due to the 20-year guarantee mentioned above (Bönning, 2000). As a result, the diffusion of wind turbines was greatly stimulated (see Fig. 3).

With regard to solar, the improvement in incentives was much more dramatic. For 2000 and 2001, the new rates amounted to €0.506/kWh for solar cell facilities mounted on buildings, with a size of up to 5 MW_p, and for other facilities up to 100 kWp. This rate was guaranteed until a cumulative capacity of 350 MW_p was reached. All this would probably not have been obtained without the very considerable interest in paying for solar electricity as revealed by the numerous local Feed-in Laws (Scheer, 2001) as well as by survey data (Solarenergie-Förderverein, 1996). Here too the rate of compensation was set to decline every year for new installations, so that a solar cell unit installed in 2003 would receive €0.457/kWh for 20 years. The annual decline was to be about 5% (Staiss, 2002).

In combination with the 100.000 roofs programme, the revised Feed-in Law meant that solar cells became an interesting investment option for the first time. As is evident in Fig. 4, diffusion took off. A booming market attracted additional entrants that enlarged the industry further.[22] For instance, in 2000, there were ten firms showing roof integrated solar cells at an exhibition (Neuner, 2001), and Germany is seen as the world leader in roof integrated solar cells (Maycock, 2000). Also, the number of solar cell manufacturers rose from two in 1996 to six in 2000 and, as importantly, ASE announced that it would increase its capacity from 20 to 80 MW (Schmela, 2001).[23] Eventually, it raised capacity to 50 MW by the end of 2002 (under the name of RWE-Schott Solar).

Within less than 3 years—in mid-2003—the 350 MW_p ceiling was reached (150 MW were allocated just in the first 6 months of 2003 under the 100.000 roof programme; with this the programme ran out). Even though the ceiling for solar cell installations receiving the special Renewable Energy Sources Act rates was raised in 2002 to the figure of 1.000 MW_p, investment decisions slowed down greatly in the second-half of 2003 as these rates proved insufficient without the low-cost loans of the 100.000 roofs programme. By that time, another amendment to the Renewable Energy Sources Act, to be adopted some time in 2004, was on its way. To secure the continuous growth of the photovoltaics industry, an advance law—a stopgap measure passed in anticipation of a more thorough reform—was adopted by parliament just before 2003 ran out.

The Federation of German Industry (BDI) criticised the Renewable Energy Sources Act 2000 for creating exorbitant burdens, damaging German competitiveness and driving up electricity prices; the Utilities Association (VDEW) pointed to extra costs resulting from the law to justify considerable price increases to final customers, increases which more likely resulted from a decline of competition. Nonetheless pressure on renewables built up, amplified by the Ministry of Economic Affairs. Yet at the same time that ministry lost ground in terms of control over this policy area. In the parliamentary elections of 2002, the Greens had improved their support while the Social Democrats had declined; thus the Greens could claim a stronger position in government, and effectively secured the transfer of the competency for renewable energy from the Ministry of Economic Affairs (held by the social democrats) to the

[22]Some firms also entered a few years earlier in response to the market formation following the local Feed-in Laws.

[23]In 1998, domestic module production had covered less than one quarter of a domestic demand of 12 MW. Beginning in 1999 (demand 15 MW, production 4.3 MW), these figures increased steeply: 40% of a demand of 66.5 MW was covered in 2001. Estimates stand at around 70% for 2002 and 2003. A survey of the industry carried out in 2003 listed four wafer manufacturers, eight cell producers and 21 manufacturers of modules, some of them highly specialised (Hirschl et al., 2002; Solarthemen 170, 2003).

Environment Ministry (held by a Green). This also meant a shift in the parliamentary committee dealing with renewable energy, from the economic affairs committee to the environment committee.

Although no longer in charge of this policy matter, Economic Affairs minister Wolfgang Clement from coal state North Rhine Westphalia joined the critics of the Renewable Energy Sources Act, and in summer 2003 a hardship clause was adopted supposedly to reduce the burden for those firms which could prove that their competitive standing was seriously affected. Only 40 firms were able to successfully invoke that clause by the end of 2003 (Witt, 2003; Windpower Monthly, 2003; Deutscher Bundestag, 2004). Usually, the utilities supplying industrial customers—for whom competition is intense—shift the burden to household and small business clients, whose burden is increased as a result (Bröer, 2003).

By summer/fall 2003, Clement also questioned the very principle of feed-in tariffs, apparently with the motive to secure a package deal for the protection of coal interests. Some Conservative and Liberal leaders—in particular conservative leader Angela Merkel—also attacked the Renewable Energy Sources Act because its ‘‘subsidies’’ supposedly represent a burden for the budget (when in fact, since they are paid for by consumers, they do not even show up there). Coal and nuclear interests are thus fighting the law with new vigour—probably because there is now a real possibility that they might be displaced, with no growth expected in electricity demand, over the coming decades with renewable energy. Undoubtedly they also view the ratification crisis of the Kyoto protocol (after Bush's rejection and Russia's delays) as an opportunity to question its whole philosophy. However, German public opinion seems still strongly committed to climate policy and renewable energy (Brechin, 2003; Solarenergieförderverein, 2003). More importantly perhaps, the conflicts over the Renewable Energy Sources Act in 2003 produced two new members of the renewables coalition: the German Confederation of Small and Medium-Sized Enterprises (BVMW)—representing about two-thirds of all employment—and service workers union ver.di.

In sum, the red–green coalition which came to power in 1998 not only adopted the ‘old’ proposal of 100.000 roofs programme early on but, drawing on a broad and increasingly strong advocacy coalition which now included VDMA, it also rewrote the Feed-in Law in a manner which was advantageous to wind and solar power. The diffusion of wind turbines took off again and that of solar cells soared. A clear feed-back loop from early diffusion to subsequent ability to influence the political process shaping the regulatory framework can be discerned. Yet, the very success of that framework led to an intensified efforts of coal and nuclear interest to change it—the ‘battle’ over the nature of institutions now moves into its third decade.

4. Financial flows and social costs: orders of magnitude

The current renewable energy policy must be seen in a wider context. For the Conservative-Liberal government, renewable energy was ‘‘complementary’’ energy rather than an alternative. For most of the red–green coalition, it is imperative that these energy sources replace other sources in the course of the 21st century. This is part of a climate strategy, which in 2020 should reduce CO_2 emissions by about 40%, and by 80% in 2050 (Jänicke, 2002; Bundesministerium für Umwelt and Naturschutz und Reaktorsicherheit, 2003). As repeated in April 2003, the current German government—though somewhat divided on the issue—and especially its parliamentary party groups want renewables sourced electricity to grow, from 6.25% in 2000, to 12.5% in 2010. By 2050, renewable energy (including imports) is envisioned to contribute above 60% of total electricity demand (Bundesregierung 2002a, b). In this scenario, electricity from renewable energy sources is expected to require regulatory support until about 2020. After 2030 or 2035, it is expected to become cheaper than conventional generation, with a payback date some time before 2050 (Nitsch, 2002).

These visions, emanating mostly from the environment ministry, have led to important controversies. Not surprisingly, the Ministry of Economic Affairs—traditionally the advocate of conventional energy sources—arrives at cost estimates for an energy transition to renewables which are up to ten times higher, though most of these costs are seen to occur in the transportation sector (Fischedick et al., 2002). Criticism also comes from parts of the Conservative-Liberal opposition.[24] It is interesting therefore to look at the financial flows as well as the social costs connected with the different forms of electricity generation. We will argue that the social (i.e., society's) price tag for conventional power generation is much higher than the private (i.e. the consumers' electricity bills); that the support given to renewables is but a fraction of that given to ‘conventional technologies’ and, finally, that the remuneration under current support policy is broadly equal to avoided social costs and, therefore, involves no or very small extra costs for society.

The social cost of power generation based on coal is much higher than the private. In calculating social costs,

[24]In early 2004, CDU/CSU MPs were willing to support the government amendment to the Renewable Energy Sources Act on condition that a ceiling be introduced to limit feed-in payments in total volume, not in terms of extra cost; this ceiling was likely to be reached by 2010 or earlier (Solarthemen 176, 2004).

we need to consider both subsidies and external costs. In terms of 2003 Euros, *subsidies* to hard coal for electricity generation can be estimated very roughly at about €80–100 billion for the period 1975–2002[25]; another 16 billion are scheduled for the period 2005–2012 (Bundesverfassungsgericht 1994; Wachendorf, 1994; IEA, 2002; *Solarzeitalter* 4/2003). During the same time period, hard coal and lignite together caused *external costs* in the range of €400 billion or more, probably substantially more as external costs were considerable higher before the widespread use of flue gas cleaning (European Commission, 2003).[26] Total government funded R&D for coal amounts to €2.9 billion for 1974–2002 (IEA, 2003a).

Nuclear fission in Germany cost taxpayers some €14 billion in R&D funds since 1974 (IEA, 2003a; see also Fig. 5). This amount was spent "to establish an internationally competitive industry", a goal which in the view of the government was not to be hindered by "a premature and overstressed bias towards economic aspects" on the part of the utilities. It is true that most of these funds went to the development of "advanced reactors" such as the high-temperature gas-cooled reactor or the fast breeder reactor (Keck, 1980, p. 316). However, at that time it was thought that advanced reactors relying on plutonium represented the future of nuclear power, since the uranium used in light water reactors would sooner or later become scarce (Meyer-Abich and Schefold, 1986). For the purposes of the advanced reactor programme, the concept of "R&D" was interpreted quite generously; "in order to facilitate financial support by the Federal Government, the programme was framed as an experimental development programme rather than a programme aimed at early commercialisation" (Keck, 1980, p. 323).[27] Finally, participation in the international nuclear fusion programme so far caused Germany R&D expenses of slightly more than €3 billion (IEA, 2003a), but this contribution will have to be multiplied many times over before fusion may actually generate electricity, estimated to occur not before 2050.

How does wind and photovoltaic power compare to all this? From 1975 to 2002, in terms of government R&D funds, wind received €0.47 billion, and solar cells €1.15billion (IEA, 2003a; Sandtner et al., 1997; Räuber, 2002; Deutscher Bundestag, 2003; see also Fig. 5). The red–green coalition so far has not modified energy research priorities substantially, even though Scheer and Fell—the parliamentary leaders of the coalition parties on renewable energy sources—are asking for an increase of R&D on those sources by a factor of ten (Eurosolar, 2003a; Frey, 2003; Siemer, 2003). There is also a cost resulting form market creation programmes. The 250 MW wind programme caused cumulative costs of €0.15 billion from 1989 to 2001 (Staiss, 2003, II–27); to this the costs of the *Länder* programmes must here be added, e.g. of Schleswig-Holstein and Lower Saxony (Paul, 2003). Most expensive so far is the 100.000 roofs programme; its cost was estimated at €0.1 billion for 2001 only (Fischedick et al., 2002). Although this cost varies according to the prevailing interest rates (Genennig, 2002), it is safe to assume that annual cost in future is likely to be several times this amount, for a period of almost 20 years. Yet, we are speaking in terms of very small figures in the context of the energy sector. As to external costs, they were estimated in the ExternE study to amount to 0.05 Eurocents per kWh for wind power and to 0.6 Eurocents for solar PV[28] (European Commission, 2003).

The largest flow of funds connected to renewables is in connection with compensation under the Renewable Energy Sources Act. In 2002, this amounted to €2.2 billion (Deutscher Bundestag, 2003) for 24 TWh (Umwelt 5/2003), which means an average feed-in rate of 9.1 Eurocents/kWh. Compensation under this act will certainly grow for some time, and a 50% increase of total compensation under the Renewable Energy Sources Act is expected between 2002 and 2005 (Deutscher Bundestag, 2003).

The difference between this compensation and that of the private cost of conventional power generation was about €1.45 billion in 2002. However, the relevant measure to consider is the social cost of that power. In other words, we need to relate the compensation under the Renewable Energy Sources Act to the social cost of generation power with conventional, coal-based technologies. For 2002, the cost of electricity generated from hard coal can be estimated at 9.9–12.5 Eurocents/kWh. This includes 3.4–3.8 cents direct generation costs (Staiss 2003, I–248), 2–4.2 cents from coal subsidies (estimated on the basis of IEA, 2002; Statistik der Kohlenwirtschaft, 2003; for the higher figure see Janzing,

[25]The actual figures may be higher as these figures do not seem to be adjusted for inflation.

[26]A tax exemption for coal-generated electricity also needs to be mentioned here.

[27]Tax breaks on undistributed profits for power plant decommissioning cost another €18 billion by 1998 (Mez, 2003b), and more since then. Extra costs to electricity consumers resulting from defective nuclear technology or simply expensive entrepreneurial decisions in this context were usually hidden in the electric rates allowed by sympathetic regulators in the days of territorial monopolies with privileged political connections (before 1998) and are therefore harder to identify (Mez and Piening, 1999). For the sake of perspective, it should also be added that total research spending on nuclear energy in OECD countries is estimated at about €150 billion, supplemented by about €300 billion in cross-subsidies from electricity tariffs, not counting damages or the cost of returning nuclear sites to their former state (Rechsteiner, 2003). There is also low insurance coverage for nuclear accidents.

[28]The figures for solar PV in Germany are about 10 years old and therefore problematic (Nickel, 2004).

2004) and 4.5 cents[29] in external costs (European Commission, 2003). For electricity from soft coal, the respective figure is 7.9–8.3 cents.[30] The 9.1 cents resulting from the Renewable Energy Sources Act mix of tariffs (see preceding paragraph), augmented by slightly more than 0.05 cents of external costs, are in between hard and soft coal generated electricity. As to wind power from turbines installed in 2002, the average rate over the 20 year period is somewhere near 7.5 cents including external costs (9 cents for the first 5 years or longer, coming down to 6.1 cents afterwards). There are two implications of this. First, if social costs are taken seriously—and this was one of the declared goals of both the Feed-in Law and of the Renewable Energy Sources Act—most renewables sourced electricity (though not solar cells) would be in the competitive range right now. Second, the remuneration under this act roughly equals the avoided social costs of coal-generated electricity, which means that in social terms, the extra cost to society appears to be negligible.

In short, taking into account all costs including subsidies and external costs, to increase the share of electricity covered by the Renewable Energy Sources Act appears as a well-founded choice for German society to take even in financial terms. And there are additional considerations in favour of such a choice. Security of supply is one of them. Being a technology leader also confers ‘‘early mover’’ advantages, and the advocates of the German climate strategy view renewables sourced electricity as an area of strong export potential. Already renewable energy sources have created about 120.000–150.000 jobs; a further increase can be expected in the future. Also, the annual private cost per capita–about €18 in 2002—seems far from exorbitant.[31]

5. Conclusions

It might come as a surprise to see Germany among the leaders in the transformation of the energy system (here with regard to electricity). In the 20th century, Germany was one of the few large industrial states without oil resources and no large oil corporation of its own (Karlsch and Stokes, 2003). Partly for this reason, it came to rely with particular intensity on domestic coal, and later on nuclear energy. This was reinforced by the energy crises of the 1970s, where such a choice was imposed in a rather authoritarian fashion by chancellor Helmut Schmidt, and was continued by his successor Helmut Kohl after 1982. But then, this choice led to intense controversies and the rise of a strong anti-nuclear movement in the 1970s, a strong environmental movement in the 1980s (especially over acid rain, largely from coal) and the first big Green party in Europe. Early on, renewable energy sources caught public attention as an alternative to the nuclear path towards a plutonium economy. Under pressure from a movement in favour of renewables, the above governments with some reluctance also supported the development of renewable energy sources, though not for domestic use at first.

Even this limited and ambivalent support fell on fertile ground, as there was a broad range of people just waiting to play an active role in developing the new technologies—as researchers, farmers, technicians, entrepreneurs, customers etc. For this reason even modest support was enough to create a space for wind and solar power to start out on a formative period. All four features of such periods were present: institutional change in the form of a changed energy R&D policy (although only on the margin), the formation of markets (although very small) in the form of protected niches, entry of firms and establishment of some of the elements of an advocacy coalition. Hence, all the four features were there, if only in an embryonic form while the existing structure remained intact. Yet, the value of this very first phase did not lie in the rate at which the new technology was diffused, or in whether or not existing structures (e.g. regulatory regime) were altered, but in the opportunities for experimentation, learning and the formation of visions of a future where renewables would play a prominent role in electricity generation.

In the second-half of the 1980s, Chernobyl, forest die-back due to acid rain and the emergence of climate change as a political issue led to strong demands for change from the public. These demands were mediated creatively not by the government, but by the parliamentary groups of the political parties who on these issues were unusually co-operative. They also learned to pressure and if necessary to bypass the government; in that sense Germany—like Denmark from the early 1980s to the early 1990s (Andersen, 1997)—also had its ‘‘green majority’’ in parliament prepared to bypass governments which were considerably less ‘‘green’’, except that in the German case this majority, although somewhat thinned by now, has held up for a decade and a half so far on the energy issue.

These demands led to the first important measures of market formation in the late 1980s. Large-scale demonstration programmes were initiated (250 MW and 1000 roofs) which involved a very significant upscaling of the

[29] This figure is in the middle of a range 3–6 cents.

[30] These figures will go up as old coal plants need to be replaced, whereas the cost of generation per kWh of renewables sourced electricity will decline from now on if—as intended—solar cells will be introduced at a moderate rhythm.

[31] As to a more rapid introduction of competitive mechanisms, their impact in Europe is quite limited so far (Lauber, 2004) and does not always point into the direction expected. Thus, prices for wind power seem to be considerably higher at present under Britain's Renewable Obligation system than in Germany, despite a more ‘‘competitive’’ mechanism and much better wind conditions (Knight, 2003).

initial protected market space. The 1990 Feed-in Law gave additional and powerful financial incentives to investors in renewables. A first feed-back loop from the investments in the formative phase to an emerging advocacy coalition capable of influencing the institutional framework can here be discerned. Indeed, with hindsight, the Feed-in-Law may well be seen as the first sign of a breach into an old structure.

With such a dramatic change in the institutional framework, wind power was able to move into a take-off phase characterised by very rapid diffusion.[32] Firms were induced to enter into the buoyant industry, learning networks evolved and the advocacy coalition was strengthened. Thus, virtuous circles, which involved all the four features, began to operate. The 'unimaginable' growth also led to an adjustment in beliefs. While Liberals and most Conservatives continued to see renewables as a 'complementary' source of energy, the parliamentary group of SPD developed visions of a transition to renewables which came close to that of the Greens. The legitimacy of renewables gained additional strength in the political arena.

When the established actor network (utilities with the help of the Ministry of Economic Affairs and DG Competition) attempted a rollback of the Feed-in Law in the mid-1990s, they met with opposition from a coalition which had been strengthened by a rapid diffusion of wind turbines and was powerful enough to maintain regulatory continuity—one of the key criteria of success in this area (Haas et al., 2004). Thus, the advocacy coalition had gained enough strength to win battles over the shape of the regulatory framework—a second feed-back loop from diffusion to the process of policy making is here highly visible.[33]

Meanwhile, for solar power, a set of local initiatives provided enough protected market spaces for the industry to survive. Although small, these markets induced further entry of firms and revealed a strong legitimacy for solar power, which later helped the Greens and SPD to alter the regulatory framework to the benefit of solar power.

When the red–green coalition took over in 1998, its parliamentary party groups—once more against the opposition of the Ministry of Economic Affairs—soon took measures to vastly increase the protected market space for solar power (100,000 roofs), to further improve the conditions for investors in wind power (in particular by further reducing uncertainty) and to give investors in solar cells adequate financial incentives. In order to achieve this, the coalition drew in yet new actors into this policy network, coming partly from the renewable energy sector (equipment producers, owners and operators of installations and their associations), partly from "conventional" associations such as investment goods industry association VDMA or the metalworkers union, which had joined the coalition during the preceding years.

This institutional change accelerated wind power installation and brought an early take-off phase for solar cells as well. A virtuous circle was set in motion for solar power where the enlarged market induced yet more firms to enter and strengthened the coalition further. Indeed, in 2003/2004, the coalition—supplemented by new allies such as the union of service workers and the confederation of small- and medium-sized enterprises (Eurosolar, 2003b)—is trying to repeat this feat against a renewed opposition from the nuclear and coal interests. In this, they may well be successful, as the new regulatory regime has gained widespread support. The revision of the Feed-in law in 2000 was even supported by one of the largest utilities and in late 2003, the CDU/CSU members of parliament supported the advance law for solar cells.

This suggests not only a wider acceptance of the regulatory regime but also that these CDU/CSU members may now share a vision where solar cells will have a substantial role to play within a few decades. Legitimacy of a new technology and visions of its role in future electricity generation are therefore not only a prerequisite for the initiation of a development and diffusion process but also a result of that very same process. Legitimacy and visions are shaped in a process of cumulative causation where institutional change, market formation, entry of firms (and other organisations) and the formation and strengthening of advocacy coalitions are the constituent parts. At the heart of that process lies the battle over the regulatory framework.

However, to be successful, the diffusion must be defensible also on economic grounds. The comparison with other available sources shows that in terms of overall cost to society, renewables sourced electricity is likely to be a perfectly reasonable choice, and one that will be amortised within a time span that is not unusual for major infrastructure investments. It is clearly somewhat ironic that a major political struggle was required merely to 'get prices right' (and to correct a choice of technology which was inferior from a social perspective) often against an opposition which appears to be playing that very same tune. Even so, and despite the exceptionally high degree of legitimacy of renewable energy sources in German society, it may be difficult to maintain a supportive policy for the time period required, i.e. another two decades, against established actors which are still well-connected, particularly in a policy environment marked by liberalisation and privileging considerations of short term profitability over

[32] Those measures were well designed in terms of regulatory design and impact, in particular the Feed-in Law. Bureaucratic entanglements and complex procedures were largely avoided.

[33] Whereas Denmark in 1999 gave in under EU pressure and accepted liberalisation of renewables sourced electricity as unavoidable, the German parliament stuck to its guns.

long-term strategies. Perhaps successful exports of the wind and photovoltaics industry will contribute a momentum of their own. But as the Danish turnaround on renewable energy after the 2001 elections shows, such processes of diffusion are not deterministic but unpredictable, not only carefully orchestrated but also influenced by many chance events.

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