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Conference Paper

Entrepreneurial Opportunity and the Formation of the Photovoltaic Industry in Eastern Germany

50th Congress of the European Regional Science Association: "Sustainable Regional Growth and Development in the Creative Knowledge Economy", 19-23 August 2010, Jönköping, Sweden

Provided in Cooperation with:

European Regional Science Association (ERSA)

Suggested Citation: Brachert, Matthias; Hornych, Christoph (2010) : Entrepreneurial Opportunity and the Formation of the Photovoltaic Industry in Eastern Germany, 50th Congress of the European Regional Science Association: "Sustainable Regional Growth and Development in the Creative Knowledge Economy", 19-23 August 2010, Jönköping, Sweden, European Regional Science Association (ERSA), Louvain-la-Neuve

This Version is available at:

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Entrepreneurial opportunity and the formation of photovoltaic clusters in Eastern Germany

Matthias Brachert, Christoph Hornych

1 Introduction

Research on the spatial distribution of economic activity has focused mainly on identifying conditions that sustain industrial clusters, as these are perceived to be the locus of regional economic growth (Braunerhjelm and Feldman, 2006; Lee and Sine, 2007). However, very little is known about the factors that facilitate the emergence of spatial structures in new industries or its performance implications. To achieve deeper insights into these formation processes, ‘theory must explain how information and resources for entrepreneurial activities come to be disproportionately massed in some places and some times’ (Romanelli and Schoonhoven, 2001). Within this context, recent developments in institutional economic geography underline the contribution of social movements to institutional change and government action, thus affecting entrepreneurship and entrepreneurial opportunity (Sine and David, 2003; Lee and Sine, 2007). As government actions have a spatial dimension, they can induce windows of locational opportunity (WLO) supporting the evolution of spatial patterns of new industries (Storper and Walker, 1989; Boschma, 1997; Boschma and van der Knaap, 1999).

To date, there has been little research into the role of institutional change and government action in the evolution of new industries or entrepreneurial opportunity (Lounsbury *et al.*, 2003; Sine and David, 2003). With regard to the energy sector, the importance of institutional change seems to hold for the effects of environmental movements, as they were able to give an increased awareness of pre-existing technological solutions (see, in particular regarding alternative sources of energy, Lee and Sine, 2007). Changes within this field – in the past as reactions to oil crises – can nowadays be seen as reactions in response to climate change caused by emissions of CO₂. This calls for a rapid rate of diffusion of CO₂-neutral energy technologies, so that the shift towards renewable energies results in a series of technological discontinuities in the energy field (Anderson and Jacobsson, 2000).

The aim of this paper is to explain the evolution of the spatial structures of one particular type of renewable energy in Germany – the photovoltaic (PV) industry. We first demonstrate how environmental movements have contributed to institutional change and government action, leading to changes in the legal and regulative structure in Germany. We describe how these changes opened up a window of locational opportunity, thus combining the WLO concept with the entrepreneurial opportunity concept. As market entries occurred mainly in Eastern Germany, the paper also explores the factors leading to a concentration of economic activity related to the new PV industry in this part of the country. Based on the WLO concept, we combine this framework with the industrial dynamics literature by Klepper (2007) to describe the role of routines in the spatial evolution of the PV industry.

The paper is structured as follows. After a brief introduction to the theory of entrepreneurial opportunity and social movements, the paper discusses the WLO

concept and factors explaining the evolution of geographic structures in new industries. The empirical part begins with the illustration of the role of environmental movements in the evolution of schemes supporting renewable energy in Germany. The following section explains how these developments resulted in a window of locational opportunity for the PV industry in Eastern Germany, and describes the evolution of spatial patterns in this industry. The final section of the paper explores the factors promoting the spatial patterns of the PV industry, and concludes with a discussion of the results.

2 Entrepreneurial opportunities and the formation of clusters

When new industries emerge, initial locations are scattered spatially, but not all of these are able to attract or generate concentrations of economic activity that lead to potential industrial clusters in later stages of the industry growth cycle (Storper and Walker, 1989). Given this knowledge, theories have been put forward to explain how the spatial patterns of these new industries evolve, and which factors translate industry growth into geographical industrialization (Storper and Walker, 1989; Krugman, 1991; Arthur, 1994; Brenner, 2004). These theories have in common, that they cite ‘historical accidents’ or ‘chance events’ as main factors explaining the development of new industries in certain locations. When looked at more closely, it is evident that there are processes behind these ‘historical accidents’ and ‘chance events’ that explain why industries evolve in certain places. Therefore notions such as ‘chance events’ should not be taken as given (Menzel, 2008), and research should focus on these as a central theme when examining the emergence of the constituent components of new industrial clusters.

2.1 Entrepreneurship and entrepreneurial opportunity

There is a growing body of work highlighting entrepreneurship, entrepreneurial opportunity and spin-offs as constituent elements in the formation of spatial structures in new industries (Bathelt 2001; Brenner, 2003; Dahl *et al.*, 2003; Sternberg, 2003; Henn, 2008). Feldman (2001) argues that ‘Entrepreneurs appear to be a critical element in the formation and vibrancy of clusters of technology intensive firms.’ Entrepreneurship is defined as the discovery, evaluation and exploitation of future goods and services (Venkataraman, 1997), so regions must first offer opportunities to induce entrepreneurship (Shane and Venkataraman, 2000). Such opportunities are characterized as ‘situations in which new goods, services, raw materials, and organizing methods can be introduced and sold at greater than their production costs’ (Shane and Venkataraman, 2000). Literature presents three different ways of categorizing emerging entrepreneurial opportunities (Eckhardt and Shane, 2003):

- by their locus of change;
- by the initiator of change; and
- by the source of opportunities.

The locus of change suggests five different loci, following Schumpeterian types of innovation. These include opportunities emerging from the creation of new products or

services, the discovery of new markets, entrepreneurial opportunities arising from innovations in new raw materials, new methods of production, or new ways of organizing (Schumpeter, 1934). The initiators of change can vary, as non-commercial entities such as governments or universities are as likely to generate opportunity-creating changes as are commercial entities such as existing companies, their suppliers or customers, independent entrepreneurs or diversifying entrants (Klevorick *et al.*, 1995). Opportunities may also differ depending on their sources. Exogenous shifts in information in response to government actions, demographic changes or new knowledge influence the variety and number of entrepreneurial opportunities. Additionally, information asymmetries between different market participants, supply- or demand-side changes and rent-seeking behaviour may act as additional sources of entrepreneurial opportunities (Eckhardt and Shane, 2003).

2.2 Social movements, the transformation of regulatory regimes and entrepreneurial opportunity in the energy sector

As noted above, government action is one source of entrepreneurial opportunity. Recently, literature on the consequences of social movements has begun to stress the relationship between environmental movements, government action and the creation of entrepreneurial opportunities (Sine and David, 2003; Lee and Sine, 2007; Sine and Lee, 2009). Examples of the successful impact of social movements on entrepreneurial opportunity and sector emergence can be found in different fields such as green building, recycling, organic food supply or renewable energy. This body of work highlights that new firms, industries or technologies do not emerge in isolation (Lee and Sine, 2007). Social movements are able to ‘prompt search processes that erode the taken-for-granted nature of institutions, resulting in the re-evaluation of the costs and benefits of existing institutional structures and the creation of new entrepreneurial opportunities’ (Sine and David, 2003). By contesting existing institutions, they are able to ‘construct a cognitive framework, values, norms and *regulatory environments* which shape the extent to which potential entrepreneurs view particular types of technologies and characteristics of the material-resource environment as valuable elements of an entrepreneurial opportunity’ (Sine and Lee, 2009, emphasis added).

We focus here on the ability of social movements to stimulate government action and influence the design of legal structures. If social movements result in legal amendments, ‘[The] Law can ... function in such a manner that ... the prevailing norms controlling the operation of the coercive apparatus have such a structure as to induce, in their turn, the emergence of a certain economic relations’ (Weber, 1978, cited in Lee and Sine, 2007). Thus law and legal structure can influence the creation and expansion of new markets and therefore encourage entrepreneurial opportunity (Lee and Sine, 2007). Furthermore, as the impact of laws and legal structure are spatially bounded, and regulations can differ by region, these variations can induce changes in opportunities for new industries to emerge in particular regions. This spatial dimension allows the bringing together of social movements, the idea of entrepreneurial opportunity and the WLO concept (Storper and Walker, 1989; Boschma, 1997; Boschma and van der Knaap, 1999). By linking these two concepts we are able to explain how institutional

change can influence the emergence of the spatial structures of new industries in certain regions.

2.3 The WLO concept

The WLO concept was introduced by Scott and Storper (1987) and later applied to a phase model of geographical industrialization by Storper and Walker (1989) (see Figure 1). The starting points of the WLO concept are ‘historical accidents’ leading to the localization of fast-growing industries (Storper and Walker, 1989).

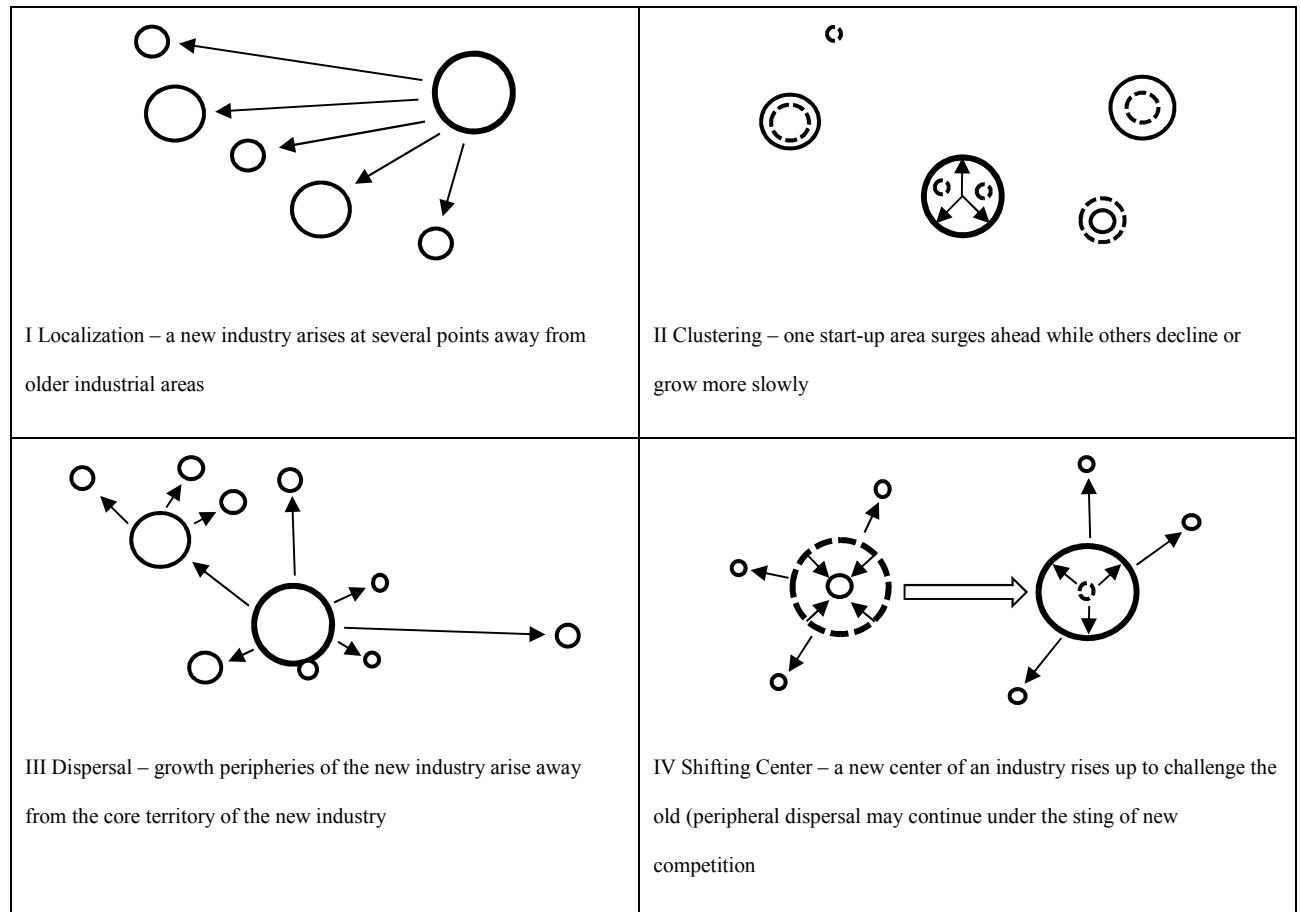


Figure 1 The four basic patterns of geographical industrialization (schematic)

Source: Storper and Walker (1989), p. 71.

In the Storper and Walker (1989) model, these emerging industries present new opportunities for all regions, as they denote a fundamental break with the past, offering relative locational freedom. New industries can be distinguished from older ones by two facts: first, their high returns on investment tend to free them from locational constraints; and second, fast-growing industries possess a locational capability to meet their specific requirements (Boschma, 1997). In contrast to traditional location theory, Storper and Walker (1989) suggest that, via above-normal profits, ‘industries are capable of generating their own conditions of growth in place by making factors of production come to them or causing factor supplies to come into being where they did not exist before’. As a result of the newness of the industry they cannot rely on

favourable institutional conditions in the early stages and have to develop new institutional structures (Boschma, 2007). These conditions result in a lack of location-specific constraints (in relation to labour, institutions or inter-industrial linkages), leading to substantial freedom to develop the area where the industry originated (Storper and Walker, 1989). This situation opens a WLO in the early stages of development. Following this location phase, as the industry life cycle proceeds, the WLO begins to close as the industry reaches regional critical mass. Causes of this closure can be seen in the emergence of Marshallian agglomeration economies, supportive local environments and supporting institutions (Boschma and Ledder, 2009), which together lead to the clustering phase of the industry.

Despite Storper and Walker (1989) presenting a coherent approach to explaining the evolution of patterns of geographical industrialization at the industry level, their model is not able to explain the processes behind the initial concentration and the structure of economic activity (Henn, 2008). Later adjustments of the WLO concept reject the assumption that space is not important (historical accidents) in the evolution of new industries. Boschma (1997) cites generic resources – ‘skills and knowledge that are not yet specific to support the new industry, but may still favour their development’ (Boschma and Ledder, 2009) – as sources of regional advantage in attracting or generating production capacities of new industries. While they point out that generic resources may act as necessary conditions, the regional appearance of these is by no means a sufficient condition for the growth of a new industry (Boschma, 2007). A better regional endowment with these generic resources might only increase the probability of developing as a location for the new industry.

Furthermore, Boschma and Frenken (2009) argue that ‘apart from basic institutions, it is hard to think of territories that are well endowed with very favourable institutions before a new industry starts to develop, because existing institutions generally do not fit with the specific features of a new industry’. This argument may hold for traditional industries evolving in previous centuries, but it may not for institutional change and governments reacting to recent environmental movements within the power sector. We, however, agree with Storper and Walker (1989), as they mention that there are possibly existing industry-specific conditions under which initial innovations arise, including cultural, technological and institutional conditions for entrepreneurship. This view is supported by entrepreneurial opportunity and technological systems literature, which claims that institutions and institutional change are not only important for adopting specific technological paths but also for the growth of new industrial clusters (Carlsson and Stankiewicz, 1991; Edquist and Johnson, 1997; Jacobsson and Bergek, 2004). Our paper therefore argues that institutional change and government action can be seen as alternative sources of generic resources within the WLO concept. As institutional change is able to induce government action, this can result in the emergence of certain economic relations and entrepreneurial opportunities. Additionally, within a spatial context, this institutional change can contribute to regional variations in the evolutionary processes of growth, reflected by entrepreneurial opportunities, spin-off dynamics and the build-up of agglomeration economies.

2.4 Determinants of the evolution of geographical structures in new industries

Having focused on the deeper understanding of institutions affecting entrepreneurial opportunity in the initial stages of the evolution of geographical structures of new industries, we now consider the factors leading to concentrations of economic activity in emerging industries (see Phase II in Figure 1). Recent literature has begun to link the WLO concept with industrial dynamics (Boschma and Ledder, 2009). As industry growth results in the selective process of clustering in the WLO concept, factors behind this process need to be examined more deeply. While Storper and Walker (1989) hold that different locational capabilities for generation agglomeration economies are responsible for differences in development, the literature on industrial dynamics supposes that spin-off dynamics act as transmission channels through which knowledge and routines are created and diffused among a growing number of firms within a region (Boschma and Ledder, 2009). Agglomeration economies in the Storper and Walker (1989) model result from the regional division of labour, a specializing labour market, reduced transaction costs through the positive effects of spatial proximity, and the development of local supportive institutions. The role of spin-offs¹ was highlighted by Klepper (2007). As spin-offs are expected to locate close to the incumbent firms, they can act as important factors in the explanation of spatial clustering. The spin-off process can induce agglomerations around successful firms and can magnify an early cluster of leading firms into an extraordinary agglomeration.

Nevertheless, there might be no clear distinction between agglomerations and the spin-off process being solely responsible for the process of spatial clustering of a new industry. Agglomeration economies and spin-offs may in fact act as complementary processes at different stages of the industry life cycle (Boschma and Wenting, 2007). In section 5 we shall analyse the importance of the part played by agglomeration economies and spin-off dynamics in the emergence of the photovoltaic sector in Eastern Germany between 1991 and 2008.

3 Environmental movements and the evolution of a legal supporting scheme for the photovoltaic (PV) industry in Germany

Fossil fuels constitute the major source of energy in the world. As these sources are associated with environmental and climate challenges, the shift towards a low-carbon economy is seen as a major response to climate change (Jacobsson and Bergek, 2004). In Germany, the share of renewable energy as a proportion of total electricity generation has increased from 1.07 per cent in 1998 to 15.68 per cent in 2007 (see EEG Quota in Figure 2). While this is still far from being a sustainable electricity supply, no other country has seen a comparable growth of renewable energy production capacity (Wüstenhagen and Bilharz, 2006). Taking a deeper look into the share of specific sources of renewable energy, the wind sector in particular contributes 59 per cent (2007) of the renewable electricity generation. But, when looking at annual growth rates since 2001, despite starting from a low absolute level, solar energy is the most dynamic driver of growing capacity in the renewable energy sector.

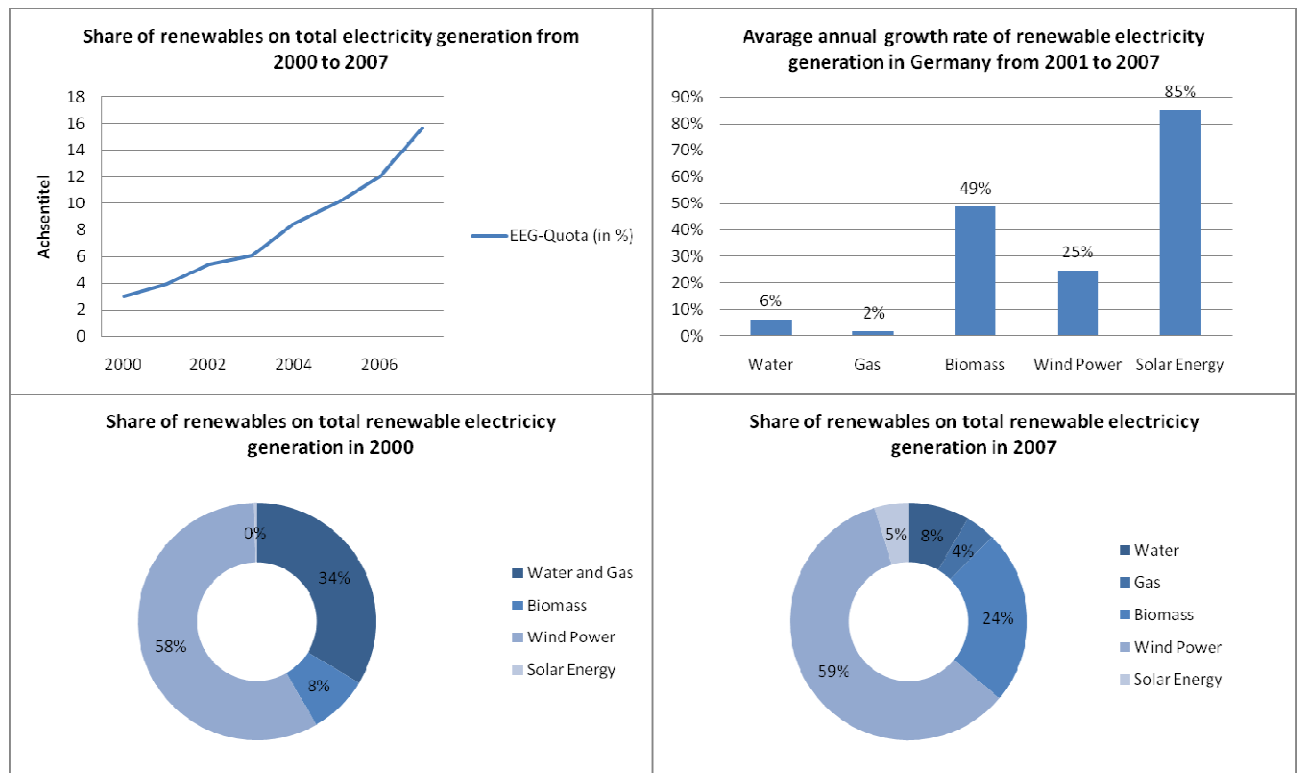


Figure 2 The development of renewable energy in Germany since 2000

Source: BDEW (various years).

These developments indicate significant changes in the energy sector in Germany. To understand the conditions behind this development, one needs to look at the historical background. The literature recognizes three phases of renewable energy emergence in Germany (Jacobsson and Lauber, 2006).

3.1 1974–88 – social movements and the formation of a renewable energy framework

The discussion about renewable energies contributing significantly to the German mix of energy consumption began in 1973. The first oil crisis demonstrated German dependence on oil imports, and demands arose for different sources of energy (Wüstenhagen and Bilharz, 2006). The initial reaction was a shift in energy policy to the promotion of nuclear power and coal, but the German government also began to promote research into renewable energy sources. Public demand for the transformation of the energy system increased after the mid-1970s, as the use of nuclear power became increasingly controversial. Civil society organizations began to campaign against the rapid expansion of nuclear power stations, leading to many violent confrontations until the end of the decade (Kitschelt, 1986; Jacobsson and Lauber, 2006). Out of this controversy there emerged a green or anti-nuclear movement, which saw neither nuclear power nor oil as suitable long-term energy sources. The movement promoted ideas of energy efficiency and renewable energy sourcing (Jacobsson *et al.*, 2004). With no major political party adopting a clear anti-nuclear position during the debate, established channels of political articulation offered very few possibilities for organized protest.

This resulted in more confrontation, and anti-nuclear movements began to push for institutional change and government action with the help of a new ecological party founded at the end of the 1970s (Kitschelt, 1986). Their views were supported by the first Enquete Commission of the German Parliament in 1980, which recommended the adoption of renewable energy and energy efficiency as the first priority, but also the maintenance of the nuclear option (Lauber and Mez, 2004).

Largely related to the issue of government-funded research and development (R&D) programmes for renewable energy technologies, universities, institutes and firms began research in various directions (Jacobson and Lauber, 2006), building a second strand of emerging photovoltaic (PV) interest. Despite the political-economic electricity supply structure being in favour of coal and nuclear power generation at this time, research funds were allocated across the entire field of solar-powered systems manufacture, developing a broad academic and industrial knowledge base. Related to institutional change and public pressure, this contributed to the opening of a space for renewable energies through R&D efforts. The supply of public R&D funds encouraged the growth of knowledge and guided the development efforts of the firms entering the PV market (Jacobsson *et al.*, 2004). Additionally, public debate on environmental protection promoted the initiation of a more stable market development policy. As a result, a set of demonstration programmes were integrated in German R&D policy (Staiß, 2000).

Overall, the formative stage of the renewable energy framework can be characterized in terms of institutional change in the form of increased public support for renewable energy. This change created the first niche markets and encouraged the learning process, thus strengthening the marketability of solar power. Moreover, different forms of supportive actors for renewable energy in general, and PV technology in particular, developed from the environmental movement: new political parties, industry and environmental associations, specialized research institutes (in particular, the Institute of Ecology), and solar energy development associations (Wüstenhagen and Bilharz, 2006). The aim of these organizations was to promote solar energy diffusion via the generation of institutional change – by shaping government action in favour of solar energy (Jacobsson *et al.*, 2004).

3.2 1988–98 – the struggling performance of solar power

The disastrous accident at Chernobyl nuclear power station in 1986 led to a recurring attention on the nuclear debate. Between 1976 and 1985, public opinion had been divided fairly equally on the question of nuclear energy, but within two years of the Chernobyl accident, opposition to nuclear power had risen to more than 70 per cent (Lauber and Mez, 2004). In this context, the strong pressure from public opinion led to the flow of considerable amounts into R&D budgets for renewable energy sources – not per capita but in absolute amounts (Jacobsson and Lauber, 2006). Accompanied by increasing concern about the ozone problem and climate change resulting from emissions of CO₂, there was general agreement that changes in energy use were needed. With the help of the installation of an Enquete Commission on climate change, the discussion was introduced into the political-parliamentary space. This resulted in a series of actions and proposals for institutional change, including different support

programmes for PV energy, reflecting the considerable public concern about this issue (Schafhausen, 1996).

The first major government action of importance for the PV industry was the 1,000 roof programme (1991–1995), the world's largest demonstration and market formation programme for the PV industry at this time. Despite being successful, with the installation of more than 2,000 photovoltaic systems with a cumulative capacity of 4MW_p (megawatt peak), the termination of the programme was not followed by subsequent promotions, leading to market exits and migration of the biggest solar manufacturers in Germany (Bechberger and Reiche, 2004). As the solar industry did not profit from the Energy Feed-in Law (StrEG) of 1991, because compensations did not cover production costs, German solar cell production was almost non-existent by 1994 (Bechberger and Reiche, 2004).

After production fell, the most important help towards mobilizing market development in PV technology came from a further important development: the amendment of the federal framework on electricity tariffs. The legal framework in Germany was modified in such a way that local utilities were able to sign cost-covering contracts with suppliers of renewable energy. With the help of this amendment, local support groups for renewable energy were able to request local governments to adopt these models of energy supply in their regions (Jacobsson and Lauber, 2006). With additional aid from the federal states, many of the dispersed federal, regional and local support programmes for PV energy were able to sustain the market after the end of the 1,000 roof programme (Wüstenhagen and Bilharz, 2006). The large number of cities adopting local feed-in laws and green pricing schemes revealed that demand for solar power still existed and was still growing. Accompanied by intensified lobbying efforts, solar industry and solar development associations began to demand support for a large home market to emerge (Jacobsson *et al.*, 2004).

In sum, the second period of PV energy emergence has come about through external events (mainly Chernobyl and the emerging climate change discussion). These events led to shift in public awareness towards changes in the established energy systems, and articulated demands for changes in favour of renewable energies. The green movement in particular was able to contribute significantly to this discussion. Supported by growing industrial and scientific knowledge about the ability of solar energy to contribute to the German energy supply, a broad set of institutional actors developed, supporting solar energy. These led to government action in PV market development and the introduction of legal amendments supporting the diffusion of PV technology.

However, the high cost of solar energy generation still limited market diffusion, and government action was not able to introduce stable market development prospects, which led to a lack of entrepreneurial opportunities. The majority of the firms involved in PV technology therefore decided to leave the market and only local solar initiative were able to contribute to the maintenance of the market. Thus an increasing proportion of PV development was now in the hands of policy-makers – backed by strong majority of the population – taking the lead in the policy process (Wüstenhagen and Bilharz, 2006).

3.3 1998 onwards – the opening window for solar power

The change to a Social Democratic–Green federal government in 1998 encouraged renewable energy development. Within the coalition agreement, some arrangements were made that were dedicated to renewable energy. Building on proposals from different solar development associations, these included the origination of a 100,000 roof programme for solar market formation and a reform of the Feed-in Law to promote the diffusion of solar energy (Staiß, 2000).

Under the initial Feed-in Law (StrEG) of 1991, compensation for renewable energy producers was linked to avoided costs. By taking the average utility revenues per kWh, the government attempted to introduce a fair value payment for renewable energy generation. In this type of system, feed-in tariffs vary according to general electricity tariffs, exposing the producer to changes in these tariffs (Mitchell *et al.*, 2006). For wind energy in particular, this compensation was high enough to induce market growth. Considering PV energy, an income of 16.52 Pf/kWh (~8.5 ct/kWh) compared to costs of DM 1.50 (~76.7 ct/kWh) for 1 kWh generated was not sufficient to encourage market development (Bechberger and Reiche, 2004). When electricity prices began to decrease in 1999 as a result of power market deregulation in Germany, producers of renewable energy came under pressure. Fearing the loss of incentives for market diffusion of renewable energy, market liberalization created a window of opportunity in political space (Wüstenhagen and Bilharz, 2006).

The temporary price reduction left some room for fixed payments for renewable energy. Inspired by local feed-in laws for solar power, the introduction of fixed tariffs in the Renewable Energy Law (EEG) in 2000 was largely a response to this (Mitchell *et al.*, 2006). The key elements of the Renewable Energy Law were (Wüstenhagen and Bilharz, 2006):

- a purchase obligation for the local grid obligator;
- guaranteed minimum prices for twenty years; and
- a nationwide cost settlement system to balance out regional disparities.

Accompanied by the launch of the 100,000 roof programme (subsidies in the form of low interest loans to investors) the improvements in incentives for solar energy production were dramatic. New compensation rates for solar energy increased to 50.6 ct/kWh for systems installed in 2000 and 2001, followed by an annual decline of the compensation rate of 5 per cent. This combined with the 100,000 roof programme led to a situation where solar energy became an interesting investment option for the first time (Jacobsson and Lauber, 2006). Development was encouraged further by an amendment to the Energy Feed-in Law in 2004. The initial Feed-in Law of 2000 included a cap, limiting photovoltaic system installations to 350MW_p a year. By 2003, market volume had already reached this point. As investment decisions slowed down, a subsequent law passed through parliament removing this cap and enabling further market growth. While some firms had entered the PV market a few years earlier in response to the market formation initiatives at the local level, these new conditions of solar energy promotion attracted further entries, and the WLO opened up for PV companies.

Summing up, the Social Democratic–Green federal government introduced key elements which influenced the diffusion of renewable energies in general, and solar power in particular. The 100,000 roof programme – in response to the earlier proposals of solar development agencies, and the Energy Feed-in Law of 2000 – inspired by several local feed-in laws in different German regions, provided strong incentives to invest in solar power. But they were also showing a clear feedback loop from early diffusion to the subsequent ability to influence public political processes by shaping the regulatory framework in favour of renewable energy (Jacobsson and Lauber, 2006). These government actions brought about very favourable conditions for an expansion in solar generation production capacity, thus increasing dramatically entrepreneurial opportunities in this field. The next section explains in more detail the impact of the Renewable Energy Law on entrepreneurial opportunities.

4 Entrepreneurial opportunities and incentives resulting from the German feed-in law

In contrast to organic food or other ‘green’ products, consumers of ‘green power’ do not demand a physically differentiated product. Within a feed-in tariff system, the difference between energy sources lies in the monetary flows a generator achieves for renewable energy production (Wüstenhagen and Bilharz, 2006). With the introduction of a fixed feed-in tariff system in 2000 (and its further amendment in 2004) government action created a situation in which solar energy could be introduced and sold at a price greater than the production cost. This exogenous shift ensured that a solar energy producer received a fee above the market price, reflecting the fact that solar energy was not yet competitive. Furthermore, the design of the Renewable Energy Law supported entrepreneurial opportunities by reducing risks for renewable energy producers, making investments highly attractive and pushing demand. These risks can be divided into three sources (Mitchell *et al.*, 2006):

- price risks;
- volume risks; and
- balancing risks.

Looking at price risks, a feed-in tariff removes these, since the fee is not dependent on the market price. Additionally, solar energy producers do not face any price volatility leading to a price reliability. Because the volume produced builds a second constraint on producers’ revenues, the purchase obligation for the local grid obligators mitigates the individual producers’ risk that their energy will not be purchased (Mitchell *et al.*, 2006). With regard to the balancing risk in a feed-in tariff system, generators can bypass the need to supply a certain load profile. As the production of energy from solar sources leads to an unreliable amount of power being generated, the purchase obligation does not punish time-varying load profiles.

Overall, this situation has created a number of advantages for renewable forms of energy in general and solar energy in particular. The reduction of risk gives the renewable energy producers an increased ability to finance their projects with the help of the capital market, and this also enables smaller firms to undertake projects. This

situation has had a strong impact on market growth, enabling firms to tackle the construction of large solar parks, which has led to major increases in the demand for PV systems. Government action has therefore influenced the number of entrepreneurial opportunities, and possibilities for new entrants have arisen through the creation of uncapped markets in the PV sector. They can sell their products, if they are able to produce at prices below those set by feed-in tariffs, up to their production capacity limit without major entrepreneurial risk. This situation has provided a WLO for the PV industry in Germany.

5 Evolution of the spatial structure of the Eastern German photovoltaic industry

5.1 Data description

Information about firms in the PV industry was obtained from a unique database, collected within an ongoing research project, including the total number of firms (about 400) in the German PV manufacture and supply industry. The segment related to the trade in photovoltaic products, and the installation and operation of solar parks are not included in this database. The database focuses on information about the companies in the value-adding production chain in the PV industry: location, date established, market entry, products, employment and company turnover. The value-adding production chain includes silicon, ingot, wafer, cells and module manufacturers, thin-film companies and specialized suppliers having at least one business division in PV technology. For a detailed description of the value-adding production chain, see Staiß *et al.* (2007). Regarding the entry of new firms, the study defines a market entry as follows. For firms in the value-added chain of the PV industry, the founding date of the enterprise corresponds to market entry. The market entry of the suppliers is defined as the point of first-time production of specific photovoltaic products. The supplier industry comprises, among others, plant engineering and construction for the PV industry.

5.2 The localization stage

Regarding the emergence of entrepreneurial opportunities, these cannot be exploited by optimizing, because the set of alternatives is unknown when introducing new products (Baumol, 1993). Given this uncertainty, the resulting spatial structure is unlikely to be optimal in the initial stages of development, leading to the evolution of different physical locations in the early stages. As government action opened a WLO for the PV industry at the end of the 1990s, the first wave of market entry by PV producers in Germany can be observed.

The majority of the new companies were founded in Eastern Germany – a result of different factors affecting the localization stage of the PV industry. Eastern Germany was less dominated by established industries than western Germany, so openness to new industries was higher in these regions. The general policy of promoting economic development in Eastern Germany (in particular, extensive investment incentives) may also have had a stronger influence on the localization decisions in the (investment-intensive) PV industry than in other branches of industry. These conditions mainly favoured market entries in the eastern part of the country. We therefore focus our

analysis of the evolution of the spatial structure of the photovoltaic industry on Eastern Germany (see Figure 3).

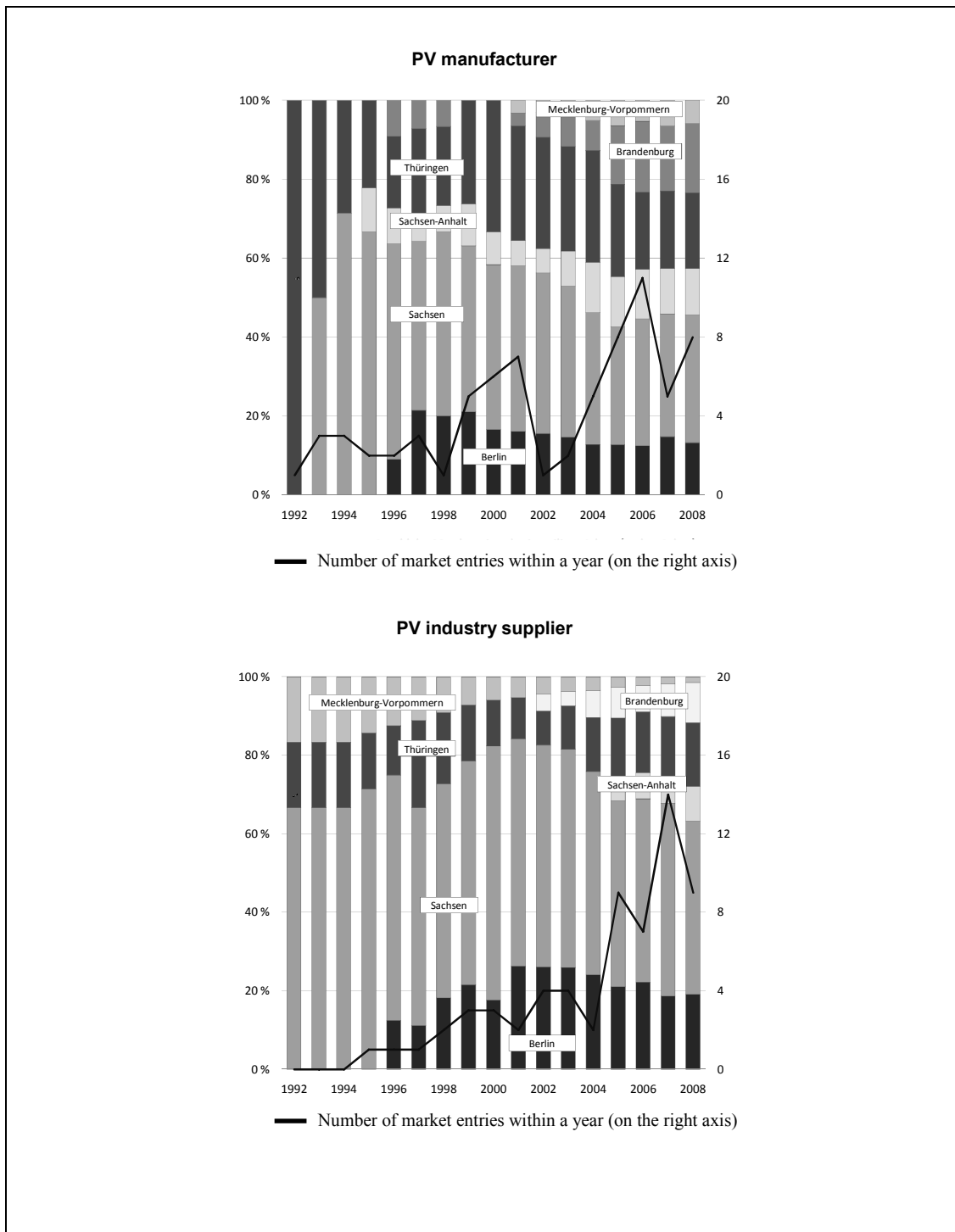


Figure 3 Number of entries and spatial distribution of companies in the PV industry in eastern Germany, 1992–2008

Source: Brachert and Hornych (2009).

The first entries in the localization stage (see Figure 4) focused on the federal states of Saxony (for example, Solarwatt in Dresden, SolarWorld in Freiberg), Thuringia (Ersol in Erfurt), and on Berlin (Solon, SolarWerk). While entrepreneurial opportunities were encouraged by government action, the choice of location was

influenced by the above mentioned generic resources, which played a decisive role in the regional allocation of production facilities. Freiberg, as the site of the former VEB Spurenmateriale (a former GDR state-owned company with experience in silicon production – the raw material for PV systems), and Dresden and Erfurt as centres of microelectronics, were well endowed with basically favourable conditions (for example, experience in dealing with silicon, available skilled labour in relation to PVs, specialized infrastructure) for the formation of new firms or the takeover of existing firms (for example, of the Freiburger Elektronikwerkstoffe GmbH by Bayer Solar) (Willecke and Räuber, 2003). However, companies were also formed that did not rely on existing generic factors in the region, in this case being the result of administrative intelligence on location policy in the respective regions (for example, Q-Cells in Bitterfeld-Wolfen). Consequently, the localization stage led to a dispersed location pattern of the PV industry in Eastern Germany (see Figure 4).

Production capacity of the plants at that time was characterized as being relatively low. The limited market volume and minor turnover of the whole photovoltaic industry restricted the formation of a specific supply industry. The first market entrants to this field emerged from co-operation projects around the year 2000 (see Figure 3). This development was pursued by existing engineering companies who diversified into the production of solar equipment, especially in Saxony. In particular, the existence of linked branches, such as the semi-conductor industry, favoured the formation of a supplier industry in this region.

5.3 The clustering stage

As a result of the strong market growth² and the emergence of new technological solutions (in particular, thin-film technology), a second wave of market entries by new companies occurred after 2003 (see Figure 3). Caused by differing business strategies, there were specific developments at various industrial locations.

Firms pursuing a strategy of vertical integration established spin-offs or joint ventures with existing PV companies, covering additional parts of the value chain (for example, SolarWorld in Freiberg). Such vertical integration offers the advantage of a comprehensive approach to cost reduction in PV systems and allows the internalization of profit margins throughout the value chain (Conkling and Rogol, 2007).

Competing technology paths are the reason behind a second pattern of development in the clustering stage. The PV industry today is characterized by a wide variety of technological solutions, in the different stages of commercialization (Ruhl *et al.*, 2008). It is not clear which technology in the respective market segments will be competitive in the future. A dominant design is still to come. As a result, some firms have chosen a strategy of technological diversification, leading to a second type of firm formation. These developments in firm strategy have been achieved mainly by successful incumbents in the PV sector, demonstrating their great importance for the development of regional industry concentrations, especially in Freiberg, Bitterfeld-Wolfen and Erfurt. As Klepper (2007) observed in studies on the emergence of the spatial structures of other industries, spin-offs or joint ventures seek to locate in geographical proximity to the incumbent firm. This is the same for the PV industry. Incumbent firms are important sources of competencies and entrepreneurial opportunities. The spatial proximity of

spin-offs developing out of these allows increased interaction along the value chain (vertical integration) or exchange of production knowledge and experience between PV technologies, so that, from a theoretical perspective, increases in both productivity and innovation are expected (Feldman, 1999).

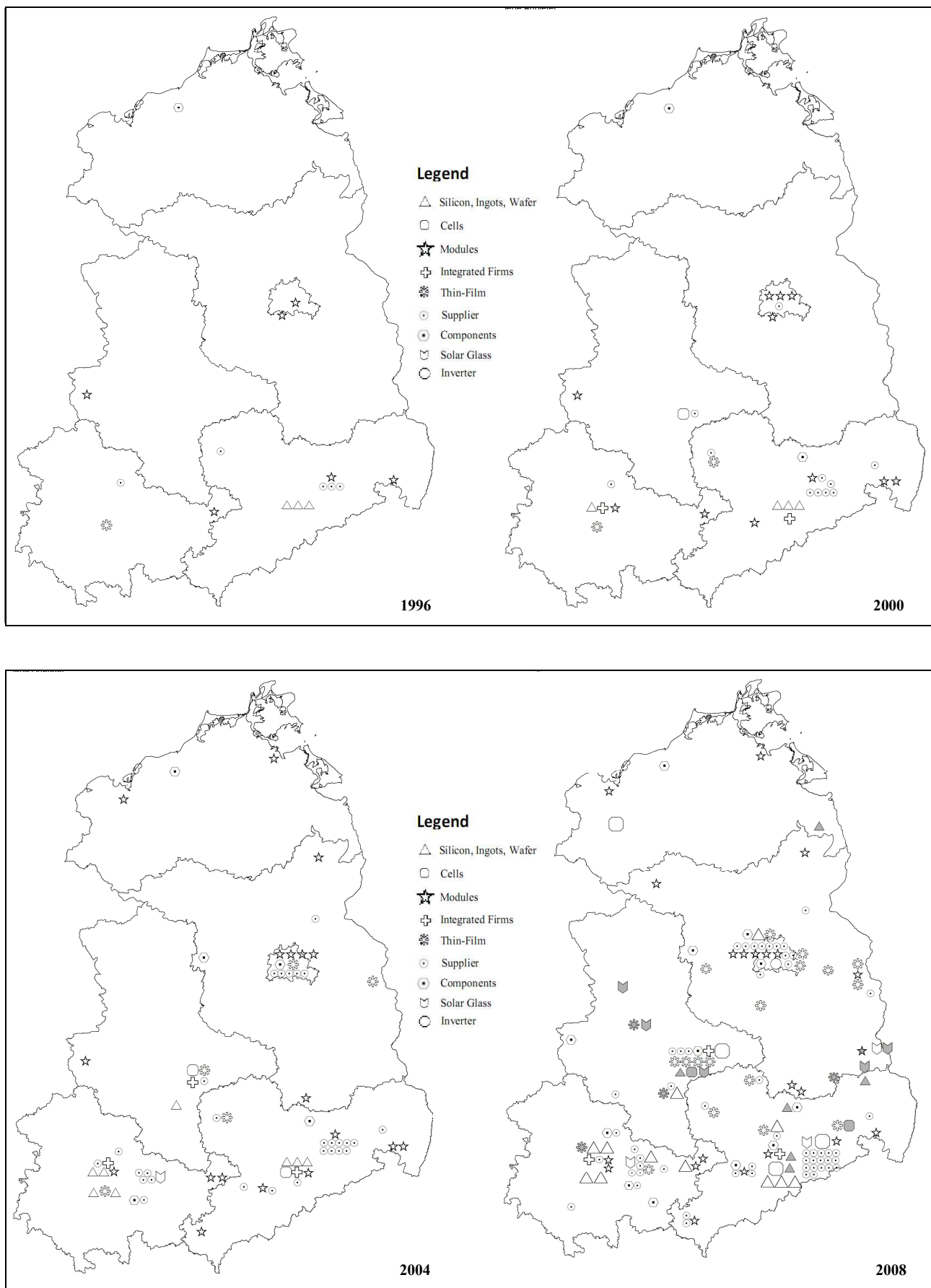


Figure 4 Locations of the PV industry, Eastern Germany, 1996–2008

Source: Brachert and Hornych (2009).

5.4. The role of incumbent firms: the case of Bitterfeld-Wolfen

Taking a closer look at the emergence of spatial structures in the PV industry in Bitterfeld-Wolfen, the firm Q-Cells demonstrates the role of leading incumbents in the evolution of the region's concentrations of new industries. The case of this city illustrates how an early-entrant company can stimulate major agglomerations in new industries.

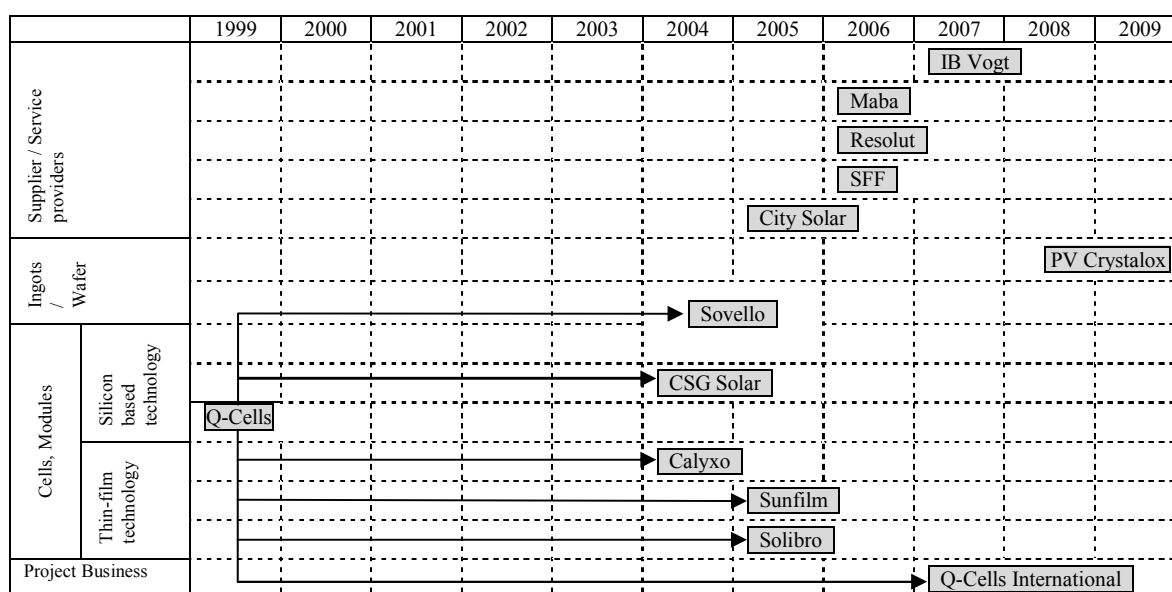
Bitterfeld-Wolfen, a small town located in central Germany, 35km north-east of Leipzig, was one of the leading centres of the chemical industry in the time of the GDR. In the last decade of the GDR in particular, Bitterfeld-Wolfen had become a symbol of fatal pollution of the environment, through the use of obsolete production technologies and an absence of environmental regulations. After German reunification in 1990, the city faced far-reaching structural changes. Despite the shut-down of numerous plants and the loss of employment, Bitterfeld-Wolfen remained a location for the chemical industry. As the window of locational opportunity for the PV industry opened at the end of the 1990s, Bitterfeld-Wolfen was not seen initially as having favourable location conditions for the new industry.

The city's history as a location for the PV industry began in 1999, with the founding of the Q-Cells company. Despite the company preferring Berlin as a location, regional administrative intelligence was able to convince the founders of the benefits of Bitterfeld-Wolfen by offering rapid administrative procedures, available property and support from public venture capital companies. Entering the market in 1999, the firm can be characterized as an early entrant. The four founders of Q-Cells already had experience in the photovoltaic industry – they were formerly employed at Solon, a company producing solar modules, located in Berlin, which had been established in 1996. Moreover, the founder team also included an expert with broad management competencies (Kuehnle and von der Osten, 2008). Q-Cells started with a workforce of only nineteen people. In 2001, the production of silicon-based solar cells began. After some years of high production and employment growth in a strongly expanding market, Q-Cells became in 2007 the single largest producer of solar cells worldwide. The development of the city of Bitterfeld-Wolfen as a location for the PV industry is strongly linked to the diversification strategy of Q-Cells. As well as being the leader in silicon-based technology, different approaches to generating solar power were also explored. To monitor advances in these fields, Q-Cells established a number of subsidiaries, each of them working with an alternative technology. Sovello was founded in 2004 under the name EverQ, as a joint venture with two other firms in the PV industry. The aim of Sovello was to produce solar cells and modules using String Ribbon technology. CSG Solar, founded in 2004, applies a technology to crystalline silicon on glass. Q-Cells also pursued different approaches in thin-film technology. Calyxo (founded in 2005) specializes in cadmium-tellurid technology; Sunfilm (founded in 2006 as Sontor) in a technology using amorphous silicon; and Solibro (founded in 2006) in CIGS technology. Finally, in 2007, Q-Cells International was founded, an active project business developing solar parks. As all these companies are located in direct spatial proximity to the incumbent firm, Bitterfeld-Wolfen became one

of the leading locations of the PV industry in Eastern Germany. As Klepper (2007) states, incumbent companies can be a source of agglomeration and cluster development. This observation is epitomized by Q-Cells in Bitterfeld-Wolfen.

In fact, the spatial concentration of these firms led to decisions to establish additional firms in Bitterfeld-Wolfen. As well as the subsidiaries of Q-Cells, City Solar, a research and development service provider, has been located in the area since 2005. PV Crystalox, a producer of ingots and wafers, moved to Bitterfeld-Wolfen in 2009, and several firms from the supply industry are located in spatial proximity to the production firms. Thus the local firms profited from joint R&D projects leading to buyer/supplier relations (MABA, Resolut), while other firms located there because the demand for Q-Cells was combined with a demand for service locations in close proximity (IB Vogt, SSF). The growth of Q-Cells therefore led to the development of one of the leading sites of the PV industry in Eastern Germany. With approximately 3,500 employees, more than 25 per cent of the total employment of the Eastern German PV industry is located in the town (Brachert and Hornyk, 2009). Figure 5 illustrates the evolution of the spatial structure of the PV industry in Bitterfeld-Wolfen.

Figure 5: The emergence of the PV cluster in Bitterfeld-Wolfen.



Returning to whole industry development, as well as the regional impact of incumbents, competing technologies were responsible for the creation of new photovoltaic companies in Eastern Germany. In particular, thin-film technology has seen twenty-two entrants since 2001, as well as enormous market and employment growth. Besides this concentration of the industry in Saxony-Anhalt, firms working with thin-film technology are also concentrated in the Berlin-Brandenburg region. In addition, Eastern Germany has become attractive for foreign investors. Generally, the investors have set up their manufacturing facilities in geographical proximity to the already established centres of the industry (for example, Signet Solar in Mochau, or

Masdar PV in Erfurt) or in regions with a high number of generic factors (for example, First Solar in Frankfurt (Oder)).

As consequence of increasing market volume, the clustering stages have led to the entry of numerous suppliers, strengthening the vertical dimension of emerging spatial structures (Bathelt *et al.*, 2004). Since 2005 in particular, an increased number of entries to the supplier segment can be seen (see Figure 4 and Stryi-Hipp, 2005). As photovoltaic systems are increasingly standardized products, production efficiency gains result from the connection with different cross-sectional technologies such as optics, engineering, nanotechnology and so on. Therefore regions with concentrations in related industries – such as Saxony with its strong concentration in the semiconductor industry, for example – have been able to profit from entries in the supply field. This situation reflects the importance of knowledge shared among related industries that enables them to profit from new sector emergence.

Alongside the activities of the expanding companies, agglomeration economies were appearing as a result of institutional arrangements accompanying the process of clustering. One element of the formation of clusters was the emergence of regional inter-firm networks. The intensity of collaboration within the industry has risen sharply (Richter *et al.*, 2008). Examples of research co-operation are ‘SiThin Solar’ and the ‘INNOCIS’ network. Another aspect of the clustering process itself is the potential of the new industry to create supportive institutional structures. This is especially apparent in the establishment of training and education facilities to meet the growing regional demand for a qualified workforce. Almost all the regions in Eastern Germany are willing to build such capacity (Franz, 2008). There are, for example, PV courses of study planned at the TU Bergakademie Freiberg, the TU Ilmenau, the Technical University of Berlin, the University of Jena and the University of Applied Sciences Anhalt; the establishment of several endowed professorships – for example, at the MLU Halle-Wittenberg and the Technical University Ilmenau; various training programmes; and the establishment of specialized public research institutes (for example, the Fraunhofer Center for Silicon Photovoltaics CSP in Halle).

As a consequence of the clustering stage, some leading centres of the photovoltaic industry have developed in Eastern Germany. Two-thirds of the approximately 14,000 employees working in the PV industry in 2008 are located in Bitterfeld-Wolfen, Freiberg, Dresden and Erfurt/Arnstadt. Regarding these concentrations, we agree with the observations made by Klepper (2007). As noted above, incumbents can be seen as one of the major structure-forming components in the regions. This not only holds for Bitterfeld-Wolfen, but also for locations such as Freiberg and Erfurt/Arnstadt. They are able to produce major agglomerations of the new PV industry with the help of spin-offs, and act as a source of knowledge for regional firms in related industries engaging in buyer/supplier relationships. Know-how from related industries leads to further entries to the PV market, influenced in particular by locations such as Saxony that have experience in supplying the semiconductor industry. These developments, accompanied by the emergence of agglomeration economies, have become an important location factor for the PV industry. These include, in particular, a strengthening of the institutional support for the PV industry through the establishment of specialized educational programmes (endowed professorships, degree courses in PV

technology at universities, and vocational training schools). According to Walker and Storper (1989), these developments indicate the closing of the WLO. While in the localization phase, location was of minor importance for the company, but later the participation in agglomeration economies become an important location factor for the PV industry.

6 Conclusions

In the creation of the PV industry in Eastern Germany we can distinguish two different stages of development: the localization stage and the clustering stage. The evolution of spatial structures in the localization stage was influenced by entrepreneurial opportunities arising through government action, which in turn was stimulated by social movements making demands for institutional change in the energy systems. This pressure from the social movements encouraged the government to introduce market development programmes. Despite it taking more than two decades for solar energy to become popular, it was the Renewable Energy Law that led to solar energy becoming established and sold at greater than its production costs. The design of the Renewable Energy Law also increased the number of entrepreneurial opportunities through uncapped markets with fixed prices and obligations to buy.

Seen from an *ex-post* perspective, this situation opened up a WLO for the spatial evolution of the PV industry in Eastern Germany. The emergence of new locations for the PV industry in the localization stage was influenced strongly by the generic factors of the regions. In particular, the old industrial areas with experience in microelectronics were able to profit from market entries. But there were also other locations, such as Bitterfeld-Wolfen, which developed into leading sites for the new industries, despite offering no favourable conditions in terms of generic resources.

Following the work of Storper and Walker (1989), the current stage of development of the PV industry is characterized by the development of clusters at leading locations, while the secondary sites are losing relevance. This development pattern can currently be seen in Eastern Germany. In contrast to Storper and Walker, who suggest agglomeration economies as the sole factor explaining selective clustering, we have found that spin-offs of leading PV firms and the entry of firms with know-how in related industries are the main drivers in the process of cluster formation. These processes result from the strategy of vertical integration as well as from strategies of technological diversification. The results therefore agree with the observations made by Klepper (2007). Agglomeration economies may act as complementary effects, especially in the institutional support for the PV industry.

The design of the Renewable Energy Law introduced further entrepreneurial opportunities for other regions to engage in PV production. In Germany, a strong domestic market is accompanied by a sizeable production capacity, indicating profits from the early establishment of lead markets. However, looked at from a global perspective, this link is not visible. For example, while Spain has been one of the biggest PV markets in recent years, its domestic industry has only a small production capacity (Salas and Olias, 2009), and China has become one of the leading producers of solar cells and modules despite an almost non-existent PV market (Meersohn and Hansen, 2010). China has also developed different spatial patterns in its PV industry,

and has not shown concentrations of production comparable to those found in Eastern Germany. Against this background, the significance of proximity between producers and purchasers in the PV industry remains unclear. Further research is needed to examine the geography of upstream and downstream players in the PV industry.

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¹ In this study we define spin-off as the splitting off of a part of a firm, which remains linked to or controlled by the incumbent firm (see also Kudla and McInish, 1988; Daley *et al.*, 1997).

² The emergence of spatially concentrated industry structures in the WLO model (clustering stage) is related to the strong market growth processes of the industry (Storper and Walker, 1989). This assumption holds in the case of the PV industry. The turnover of the industry increased from €201 million in the year 2000 to €5,741 billion in 2007 (Bundesverband Solarwirtschaft, 2008).