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Lock-in and change: Distributed generation in Denmark in a long-term perspective

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Abstract

There is a renewed attention for distributed generation (DG) in European electricity sectors, but implementing DG is often problematic. This article studies the current relative success of DG in Denmark. We take into account not only recent drivers of change such as energy policy and green activism, but also long-term stability and change in the electricity supply sector. In particular we analyse the lock-in on centralized electricity supply, that still frustrates DG development elsewhere. We discuss three successive national electricity regimes, analysing regime lock-in and change in terms of technologies, actors, institutions and the position of DG. Our analysis shows that Danish energy policy as well as innovative activity by key actors indeed were crucial to the recent DG revival in Denmark. On the other hand, our long-term perspective shows that Danish energy policy and actor strategies were tuned to specifically Danish opportunities and barriers created during earlier regimes. These include experience with wind turbines and CHP as well as urban municipal and rural cooperative involvement. Copying the Danish energy policy model to other countries, regardless of national specific opportunities and barriers, will therefore not guarantee a similar outcome.

Keywords: Distributed generation; Denmark; Lock-in; Wind turbines; CHP; Regime shift

1. Introduction

Recent developments in European electricity sectors have spurred a renewed attention for distributed generation (DG) as an alternative to large-scale, centralized production. DG (or decentralized production) refers to a variety of technologies, but the main options considered are decentralized combined heat and power plants (CHP) and renewable technologies such as wind turbines. DG holds the promise of improved environmental performance of energy sectors due to higher efficiencies (using waste heat) and the use of carbon-low (natural gas) or carbon-free fuels (renewables). DG also promises a lower need for investments in expensive transport and distribution infrastructures and the postponement of investment decisions on large centralized units (Hoff, 1996; Hoff et al., 1996; Koeppel, 2003).[1]

There are, however, several problems with integrating DG in the current electricity paradigm dominated by large power units. According to Pepermans et al. (2005), these problems include high financial costs, less choice between more costly primary fuels, lack of a level-playing field (non-discriminatory access to the grid), and degradation of power quality (e.g. unstable frequencies). Uyterlinde et al. (2002) mention problems related to authorizations and permitting, grid connection, market access and contracting, financing, and (contextual) issues like uncertainty about policy developments, market power of dominant utilities, and lacking skills of planning and installing a DG plant. Strachan and Dowlatabadi (2002) emphasize problems

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[1]The International Agency (IEA) explains this renewed attention by developments in distributed generation technologies, constraints on the construction of new transmission lines, increased customer demand for highly reliable electricity, the electricity market liberalization, and concerns about climate change (IEA, 2002).

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related to subsidies and institutional factors, such as the difficult cooperation between utilities and new decentralized electricity producers.

Despite these problems, some countries have successfully implemented DG. In Denmark the DG share in the gross electricity production increased from 1% in 1980 to no less than 35% in 2001, made up by decentralized CHP (24%) and wind turbines (11%) (Danish Energy Authority, 2004). An international comparison, using slightly different demarcation criteria, shows Denmark as the European leader in wind turbine and CHP implementation (Figs. 1 and 2).

In this article we investigate this relative success of DG in Denmark. We shall take a long-term perspective. Existing studies have taken a short- or medium-term perspective, looking at the 1990s and sometimes also the 1970s and 1980s. They tend to emphasize the role of policy measures, such as government support for research, development and demonstration, buy-back regulations, and investment subsidies (Meyer, 1995; Meyer and Koefoed, 2003; Boccard, 2004; Szarka, forthcoming). Other explanations highlight the quality of technological learning (Ibenholt, 2002; Kamp et al., 2004) and the distributed rather than centralized nature of innovation (Garud and Karnøe, 2003).

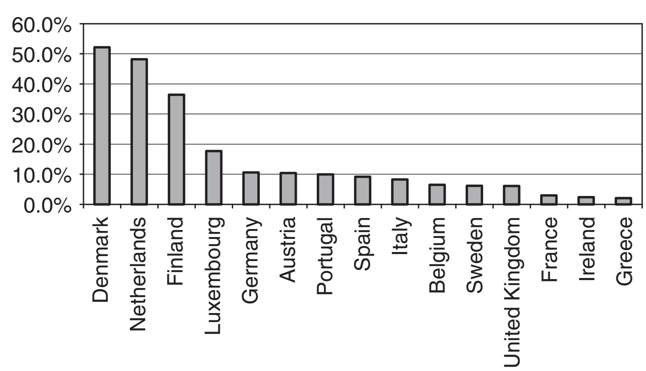

Fig. 1. Share of CHP electricity in total electricity production in EU countries in 2000 (Van Oostvoorn, 2003). Note that these figures include centralized CHP plants; in Denmark, these account for more than half of the total CHP production.

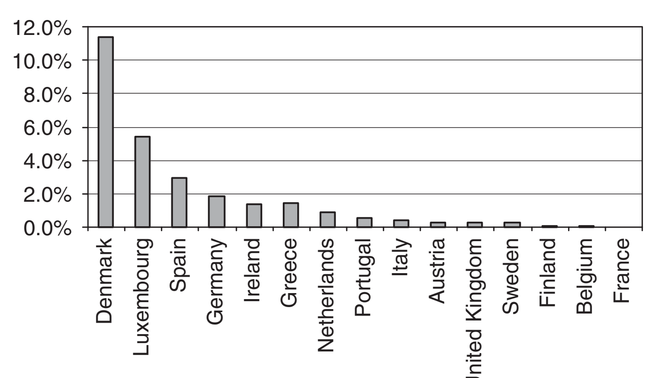

Fig. 2. Share of wind turbine electricity in total electricity production in EU countries in 2000 (IEA, 2003).

While these studies focus on what is new, they hardly address the dynamics of the pre-existing centralized, large-scale electricity supply situation. This situation constituted the point of departure for subsequent DG developments, may have conditioned their relative success in Denmark, and seems to frustrate similar developments elsewhere. Several literatures have conceptualized these systems' historically shaped stability and resistance to change. Historians and sociologists of technology study energy technologies as embedded in 'large technological systems' that acquire 'momentum' and resist radical change. For large-scale electricity supply systems, such momentum may have been considerable as early as the 1920s and 1930s (Hughes, 1983, 1987, 1995; Kaijser et al., 1991; Verbong and Van der Vleuten, 2004).[2] Economists of innovation use concepts of 'path-dependency' and 'lock-in' by historical events, where 'important influences upon the eventual outcome can be exerted by temporally remote events' (David, 1985; Arthur, 1989). A historical lock-in on hydrocarbon-based energy technologies implies a current 'lock-out' of, e.g. renewables (Islas, 1997; Unruh, 2000, 2002). A more recent approach to 'technological transitions' investigates conservative forces on and within 'sociotechnical regimes', such as the hydrocarbon regime, as a challenge for system innovations (Kemp, 1994; Rip and Kemp, 1998; Geels, 2002, 2004; Elzen et al., 2004). These approaches have their differences (Nye, 2004). Yet all emphasize the importance of a historical perspective to uncover technological stability as a precondition for understanding change, and all argue that this stability has technological as well as financial, social, and institutional components.

Our analysis of the recent DG success in Denmark takes into account recent drivers of change as well as long-term stabilities deriving from the past. In other words, we study the DG revival in the context of the long-term development of Danish electricity supply.

To organize the historical data, we use the concept of successive Danish national regimes of electricity supply. Thue (1995) used this concept to address the totality of electricity supply systems in a given country in a given era (compare Kaijser, 1999). Following Douglas C North he reserved the concept for institutional 'rules of the game'. By contrast, we incorporate insights from the above-mentioned theories (Verbong and Van der Vleuten, 2002; Geels, 2004) and define national electricity supply regimes as constellations of several interlocking components that give regimes their temporal stability: (1) on the material level, the dominant design(s) of electricity supply systems; (2) the actors that own and operate these systems, their organizations, and their perceptions and expectations; and (3) the institutional rules, mainly in terms of organizational

[2] The Large Technical Systems literature is reviewed in Van der Vleuten (2004, forthcoming); and Lanthier et al. (2004).

and regulatory frameworks defining the relationships between actors.

Using the scale of power production for primary demarcation, we identify three successive national regimes of electricity supply—and, consequently, two major regime shifts—in Denmark. (1) 1900–1950: small- and large-scale electricity supply systems set up by a variety of actors co-existed in a *regime of co-existence*. In this regime, several key components of the current Danish DG success were first introduced. (2) 1950–1970: electricity production was rapidly centralized in a highly successful *regime of centralization*. DG was marginalized. This regime defined the immediate barriers and opportunities for the subsequent DG revival. (3) The 1970s, 1980s and 1990s: a *hybrid regime* emerged in which centralized systems provided the electricity supply backbone, while DG units were rapidly interconnected. This regime produced today's relative success of DG in Denmark. We shall follow stability and change in the technological configurations, actor playing field, and institutional rules through these regimes and the regime shifts that separate them. Our analysis ends with the late 1990s' attempts to create a liberalized European electricity market, which may ignite yet another regime shift (Meyer and Koefoed, 2003).

Notably, we include the possibility of conflict in periods of regime stability, and dispense with the monolithic or harmonic character of the regime concept (compare Hård, 1993). Technical change is a contested process, and even periods of technological stability can take the (temporarily stable) form of competing actors and designs. This situation may even be institutionalized, as the first and third Danish regime of electricity supply illustrate.

2. Distributed generation in the regime of co-existence

A first Danish electricity supply regime stabilized in the 1920s and lasted to the early 1950s.[3] We call it a regime of co-existence. In this regime, four electricity supply systems existed and expanded next to each other—mostly without making physical contact. These systems include, in order of their first appearance in Denmark: (1) auto-production systems: internal power generation and distribution in e.g., farms or factories; (2) local systems: isolated low voltage, direct current (DC) systems for public power supply with a reach of a few kilometres; (3) district systems: isolated systems for public supply using medium voltage transmission alternating current (AC) with an average reach of some 10–20 km; and (4) 'centralized systems': state-of-the-art large power plants interconnected in a power grid distributing electricity through high-, medium- and low-voltage networks. The latter were introduced in Denmark in the 1910s and 1920s. By 1950 the transmission grids of two centralized systems, mutually unconnected but transnationally linked (to Germany and Sweden, respectively), covered most of the country. Surprisingly, even within the supply areas of these centralized systems, decentralized supply systems did not disappear. On the contrary: they continued to expand their decentralized production capacity. Only in relative terms their market share decreased—from 56% of the domestic electricity output in 1939 to a still highly significant 30% in 1950. By then, the available statistics registered no less than 2100 auto-production systems, 284 local systems, and 44 district systems.

In this regime several actors, rules, and technologies crucial to the later Danish DG story were first introduced.

2.1. The actors: four social group and their visions

Four social groups shaped this particular regime of co-existence (Van der Vleuten, 1996, 1998, 1999): a rather heterogeneous group of auto-producers, and three well-integrated and self-aware groups supplying electricity to the public. These latter groups shared one overall concern with electrification, which clearly differed from concerns in later regimes: to electrify the country as fast as possible.

The group of auto-producers consisted mainly of farms and industries seeking immediate profit from electric lighting or electric drive. This group did not develop organizational or ideological coherence and only incidentally engaged in wider discussions of efforts to electrify the country. Until the 1950s, industries with a constant power demand (like the cement industry) or heat consumption (like the paper industry) clearly preferred autoproduction to electricity purchase (Van der Vleuten, 1996).

In the arena of public electricity supply, the dominant social groups were urban municipal utilities, rural co-operatives, and a heterogeneous but quite self-aware group of the largest utilities. Urban municipalities massively engaged in electricity supply from the turn of the 20th century. Dominant arguments in municipal councils were making electricity publicly available, but even more so the promise of extra income to the municipal treasury. This group was primarily made up by medium and small size market-towns and, incidentally, rural municipalities. Nearly all chose to produce their own electricity in decentralized local or district systems. The coherence of this group was fostered by common associations, journals, and a specialized group of consulting firms serving most of these utilities.[4]

The group of rural utilities drew on the co-operative movement. This movement had been very strong in Denmark since the last decades of the nineteenth century. Co-operative dairies revived Danish agriculture, and the co-operative principle had since been extended into service organizations (wholesale trade, banking) and production

[3]Historical and statistical data for the first and second regime are taken from Van der Vleuten (1998) unless otherwise noticed.

[4]Particularly the P.A. Pedersen firm. There were associations of plant managers, an association of market-towns (*den danske Købstadsforening*) and an association of municipal utilities (*Foreningen af købstadskommunale Elektricitetsværker*, 1925), a strong fraction in the Danish electric utility association DEF (*Danske Elvaerkers Forening*, 1923).

(other types of factories). From the turn of the century, rural inhabitants massively founded jointly owned power systems to improve the competitive position of rural Denmark. Hundreds of very small local systems covered supply areas of only a few kilometres each. Some covered larger rural districts using high-voltage transmission, and a few joined large-scale electricity supply schemes. Also this group of overwhelmingly decentralized actors displayed great coherence in discourse and choices, fostered by specialized consulting engineers and common interest organizations and journals.[5]

Finally, a group of large utilities set up centralized systems. These included the largest municipal utilities, the largest rural co-operatives, and a single privately owned utility. This group aimed for rational, centralized supply of the entire country by a few, very large power plants. It closely followed international state-of-the-art electrotechnical science and ideas and was well-connected to the Danish Association of Engineers, the Electrotechnical Society, and the Polytechnical School in Copenhagen.

This co-existence of systems owned by different actors was accompanied by competing visions on electrification. For three decades this situation remained stable, but it was not a peaceful stability. Proponents of centralized supply passionately pleaded for conversion of decentralized systems to centralized supply. They incessantly mobilized the great advantages of centralized supply as formulated by Georg Klingenberg (1916), the influential head of the German company AEG and professor at the Berlin Polytechnical School: economies of scale, an economic mix of hydro and thermal power, and back-up and load sharing. Decentralized utilities should shut down and purchase their power from the grid.

Municipal and rural utilities and their organizations, however, did not comply. In their vision, Denmark lacked the cheap production sites (large hydropower and lignite fields) that made centralization attractive abroad. The huge costs of interconnections would outweigh any advantages of scale, load sharing and back-up sharing. Municipal electricity production represented a municipal business interest in terms of local value added. Rural utilities added a great distrust of larger utilities and legislators in Copenhagen. Generally it was argued that decentralized production was more reliable and cheaper. Until the 1950s, such claims were mostly backed by positive financial results and by calculations of the national Electricity Council.

2.2. The rules: organizational and legal frameworks

In Sweden, England, France and the US national or state governments or very large utilities took control of the supply field, and built centralized systems in a top-down fashion. By contrast, the players in the Danish electricity supply field negotiated organizational and legal frameworks that allowed them to maintain decentralized systems next to centralized ones.

This situation was reflected in the first legal framework defined by the 1907 Electricity Supply Act. The Danish government chose not to interfere in the supply business. Rather it sought to stimulate the 'free development of electricity supply' (Van der Vleuten, 1998:144) by supportive measures such as safety regulations and land expropriation rules, administered by an Electricity Commission. This government policy did not change until the Electricity Supply Act of 1976.

This liberal legal framework left the technical and organizational shaping of electricity supply to the actors in the field. Propagators of centralization then pulled several strings to achieve their vision. They mobilized the Danish Society of Engineers, which set up a 'centralization committee' (1917) to lobby with municipal, parish and province councils and Members of Parliament to support centralized systems only. They also set up the Danish Association of Utilities DEF (1923) to represent utilities towards the state, and worked closely with the state Electricity Commission to achieve centralization through the legal system.

However, this organizational strategy backfired when opponents publicly questioned key centralization proponents' mobilization of public institutions for electrification schemes that would ultimately benefit their own large utilities. Smaller urban and rural utilities stepped up their own organization and lobby activities and demanded equal representation in key institutions. Plans for state intervention to enforce centralization were rejected. The DEF became an umbrella organization for all groups instead of a voice of the powerful few. Finally the 1935 Electricity Supply Act gave urban and rural utility interest groups formal representation in the Electricity Commission (renamed Electricity Council). The situation of competing utilities and co-existing systems, reserving ample space for DG technologies, had been institutionalized.

2.3. The technology: technology choices in decentralized systems

In this regime of co-existence, large utilities installed ever larger production units and expanded their power grids. Meanwhile smaller utilities developed technologies of decentralized systems. Three of these are of particular importance to the subsequent Danish DG story.

First, CHP production was developed particular by urban municipal utilities. Commercial town heating had been practiced in the US from the 1870s and in Germany from the 1890s. In the 1920s Danish market towns started town heating generally in combination with electricity production. Larger utilities took heat from the steam turbines, smaller ones from diesel engines. Out of some 70 power producing urban utilities, 14 co-produced heat and

[5]There were regional plant managers associations, regional utility associations in Funen (1917), Lolland (1922), Jutland and Zealand (both 1930s), and a national Danish Association of Rural Utilities (*De danske jævnstrømsværker*) (mid 1930s).

power by the mid 1930s and over 30 by 1954. Five of these operated within a centralized supply setting, greatly adding to the overall CHP share in Danish power production, which was remarkably high already half a century ago.

Second, rural local systems proved a fruitful setting for the development of wind turbines. Paul la Cour, known in the Danish press as 'Denmark's Edison' and highly concerned with rural values and competitiveness, built the first DC public supply system using wind electricity in Askov (Jutland) in 1902. A standard design soon powered many very small local systems. Later most systems outgrew windmill capacity and switched to diesel engines. During the Second World War, a number of small utilities returned to wind power, and by the 1950s some 1800 independent electric wind farm systems existed. In the 1960s and 1970s, this early work would be rediscovered and further developed.

Third, decentralized utilities experimented with interconnections to other systems. Importantly, they did not do so to achieve gradual centralization. Instead, they sought to improve the economy of their decentralized systems. In fact they disentangled technologies of interconnection from the ideology of centralization. Some utilities connected to larger ones to postpone expansion of decentralized capacity and temporarily purchase additional power. Others built interconnections for load and back-up sharing between decentralized systems, a scheme termed 'decentralized co-operation'. The Second World War fuel shortages forced most decentralized systems to interconnect to purchase electricity; when fuel again became available, they resumed decentralized generation. The new interconnections were used as additional facilities only.

3. Shaping a centralized regime

In the 1950s and 1960s the regime of co-existence gave way to a regime of centralization. Most decentralized systems disappeared. Whereas Danish electricity supply previously had been extremely decentralized by international standards, by 1970 it had become one of the most centralized. Two centralized systems, covering East Denmark and West Denmark respectively, accounted for 96% of the Danish electricity output. The regime of centralization defined the immediate barriers and opportunities for the subsequent DG revival in the 1970s, 1980s and 1990s.

3.1. The rules: inventing a new organization structure

Several developments intertwined to produce this regime shift. First, while the regulatory framework remained unaltered, an organizational innovation changed the relationships between small and large utilities.

In the highly profiled East-Danish model of centralized supply, technical centralization was facilitated by an organizational model, in which independent large players negotiated mutual contracts. Smaller urban and rural utilities were not welcomed in this scheme except as electricity buyers. This model was challenged in West Denmark. Even more than in East Denmark, West-Danish utilities refused to become mere buyers in a centralized electrification scheme. In this context four urban utilities in South-Eastern Jutland discussed their needs to expand production capacity. They had interconnected their decentralized plants in the 1930s, and later interconnected to their larger neighbours. Instead of purchasing power from these neighbours, they decided to pool resources and build a joint power plant of their own. This way they would fully control electricity prices and the municipal profits. They founded a production partnership, which supplied power to the partners at cost price. The system went into operation with the completion of the new power station in 1951.

This combination of centralized production and decentralized ownership rapidly caught on. It was interpreted as a variation on the popular co-operative idea, which made it acceptable for small utilities. Also large utilities embraced the partnership model as 'a magnificent association, completely in line with the spirit of co-operation'.[6] Similar production partnerships were established all over West-Denmark. Small as well as large utilities joined in and became partners instead of competitors. In 1956 these partnerships jointly founded ELSAM, a 'partnership of partnerships' for the entire West-Danish region, to co-ordinate the construction of a new 150 kV power grid.

The association of municipal utilities also pushed the co-ownership principle of large power stations in East Denmark, resulting in the integration of smaller utilities in the East-Danish centralized system. Also the Eastern Danish partners founded a common partnership, originally to distribute Swedish hydropower imports and preside over the new East-Danish power grid (Kraftimport 1954, renamed Elkraft in 1978).

3.2. The actors: changing views on DG

The production partnership innovation enabled the regime shift, but did not cause it single handedly. Rather, it intertwined with changing views on electricity supply of the owners of decentralized systems. Within almost a single decade, a perception of economic and technical superiority of decentralized supply was replaced by an overwhelming support for centralized supply.

Two major, external historical events inspired urban and rural utilities to re-examine their position. First, the post-war reconstruction resulted in the shaping of a welfare and consumer society, and the electricity demand exploded. Utilities had an immediate lack of production capacity. Second, the war itself had triggered the interconnection of most supply systems. Although initially regarded as a temporary measure, the existence of interconnections

[6] Professor Henriksen of the Polytechnical School, cited in Van der Vleuten (1998,p. 257).

implied that the centralized supply option seemed less outrageously expensive.

In this context, consulting engineers advised urban municipal utilities to re-examine their supply options. The idea of joint large power plants was developed to solve two problems at once: capacity expansion could be pooled, and municipalities still controlled their local profit margins. When the partnership model caught on, urban municipal utility spokesmen and organization almost unanimously supported it, and thereby the centralization option.

Rural utility spokesmen made a similar shift. The rapidly increasing post-war electricity demand strained many very small local systems to the point of breakdown. Investments in dynamo's and distribution networks could hardly keep up. Utilities and consulting engineers acknowledged that their previously very reliable systems started to falter. With regard to economic feasibility, they too recognized that centralized production systems had improved their competitive position in the post-war era. Furthermore, as the rest of the world increasingly used AC systems, AC equipment and appliances rapidly became cheaper than DC equipment and appliances. Provided that electricity prices were low and rural inhabitants became co-owners of the means of production, concentration of production became an acceptable alternative. Notably, even then centralized supply was not inherently economically superior. In many cases, even very small utilities found it profitable to convert only after larger utilities offered significant subsidies.

3.3. The technology: implications for decentralized generation

With the new organizational framework and stakeholder perceptions, the physical electricity supply structure changed rapidly. The focus was on the establishment of very large thermal power plants interconnected in 150/120 kV power grids. Most decentralized production plants were shut down. This was part of the negotiation process. If large power plants were to be profitable, decentralized plants would have to be shut down so as to achieve the largest possible turnover. In the new organizational setting most small utilities accepted this.

Decentralized production did not vanish entirely though. In the margins of the story, several urban municipalities found ways to maintain decentralized CHP plants. Some negotiated permission to decentrally produce electricity following their town heating demand. Others transferred their CHP plant to local heat utilities, which henceforward sold small amounts of electricity to the municipal electric utility. Such plants disappeared from the electricity supply statistics (they were now labelled 'autoproducers'). They became invisible but continued to exist.

Finally, also wind turbine technology was further improved. In 1950 the national government asked the DEF to investigate if wind power was a future national energy supply option. A new Windpower Committee and the large SEAS utility supported the development work of Johannes Juul: by the late 1960s, Juul had developed his now famous grid-connected wind turbine. Despite cheap and reliable performance, the project was stopped in view of decreasing fuel prices. Still, another precondition for the subsequent wind turbine success now was in place (Hvidtfelt Nielsen, 1999, 2002).

4. Creating a hybrid regime

Although the centralized regime seemed successful and stable, the 1970s triggered a new regime shift. Gradually a hybrid regime (Heymann, 1999) emerged, which ultimately produced the current position of DG in Denmark. By the 1990s the base load was still carried by the two centralized systems. Simultaneously, decentralized systems—in particular wind turbines and decentralized CHP plants—revived and were connected to the power grid. Again this regime shift was characterized by interrelated changes in the institutional framework, the actor playing field and actor concerns, and the physical electricity supply structure.[7]

4.1. The rules: a new legal framework

In the 1950s a change in the organizational framework had softened the lock-in on co-existence; in the 1970s it was a regulatory framework change that undermined the lock-in on centralized supply. The Danish government reacted to the oil crises of 1973 and 1979 with state intervention. In earlier regimes the government might have let the supply industry deal with major problems internally; indeed the utilities acted quickly, cutting their oil use by 40% within 2 years (Van Est, 1999). Yet the social democratic minority government in power in 1973 embraced central planning. Arguing that energy had become a political weapon, it negotiated a parliamentary majority for state coordination of the oil, electricity and heat sectors and the state-led construction of a natural gas sector.

In international comparison the form of intervention was not particularly harsh but quite consistent in time (McGowan and Thomas, 1992; Rieder, 1998). The first component of the new regulatory structure was the Electricity Act of 1976. The Act ended the era of self-regulation by the electricity supply industry. Henceforward the utilities needed a government concession for plants over 25 MW and approval of plant construction and expansion. Second, prices were to be set according to cost and to be evaluated by an Electricity Price Committee. Third, the Act empowered the government to order changes in utility generating machinery (e.g. in fuels or efficiencies). The Act did not specify how power plants were to be changed. This was to be negotiated in Energy Plans.

These Energy Plans were part of a broader energy policy package. Later in 1976 the Danish Energy

[7]The following draws its data mainly from Wistoft, et al. (1992), Rieder (1998) and Van Est (1999).

Authority (*Energistyrelsen*) was established to co-ordinate Danish energy policy. The Authority served under various ministries and developed Energy Plans, which subsequently were to be approved by Parliament. Their content reflected parliamentary majorities negotiated by minority governments that characterize Danish politics since 1972. The lack of strong majority governments also implied that energy policy was comparatively little affected by government changes during this regime.

In 1979 the package was completed with two more Acts. A Natural Gas Act enabled the construction of a state-owned natural gas supply system connecting North Sea platforms to individual users. Finally, a Heat Act introduced central government planning for the heating market, reducing oil dependency by promoting natural gas and CHP production.

4.2. The actors: negotiating visions in the new regime

In the new regulatory framework, Energy Plan negotiations became the major arena for formulating visions on electricity supply. Rieder (1998) distinguishes between three alliances in these negotiations. First, electric utilities teamed up with the Liberal Party into a 'liberal alliance'. Second, the Danish Energy Authority, the Trade Ministry and the Social Democratic Party formed a 'state alliance' keen on government coordination, but quite open to innovation; for, unlike in many other countries, the Danish state did not have an ownership stake in centralized supply. Third, new environmental grassroots organizations became important players, teaming up with some smaller political parties into a 'green alliance.' Most important was the Organisation for Information on Atomic power OOA (1973), founded in response to ELSAM's publication of potential nuclear power plant sites. OOA became a broad anti-atomic power lobby with immense popular backup. It co-founded the Organisation for Sustainable Energy OVE (1975), supporting individuals and cooperatives setting up wind turbines and small rural CHP plants (Wistoft et al., 1992; Petersen, 1996).

The overall concern in the first two national Energy Plans of 1976 and 1981 was reducing oil dependency. The first plan painted a future energy vision including a state-owned natural gas network, brought in by the state alliance, and nuclear power, brought in by the liberal alliance. This vision also included renewables and CHP. In the short term it called for a transition from oil to coal in power plants, which utilities accomplished voluntarily.

The green alliance, however, contested the nuclear power component and published an Alternative Plan (Blegaa et al., 1976). Their vision contrasted a centralized 'plutonium society' with a decentralized, more 'human' 'solar society'. Decentralized CHP plants fuelled by natural gas and renewables would produce 'a more robust and secure energy system, fewer limitations on physical planning, higher savings of foreign currency, and more Danish jobs' (cited in Van Est, 1999). The green alliance organized massive popular opposition to nuclear power and was ultimately successful. The second Energy Plan tuned down nuclear power (which was finally rejected in 1985) and stepped up the renewables component with a concrete target of 60.000 wind turbines covering 8.5% of the electricity demand by 2000.

After the oil price collapse of 1985 and the Brundtland report of 1987, environmental concerns replaced oil dependency as lead motive in Danish energy visions. The centre-right governments of 1982–1993 went along; the establishment of a nuclear industry had failed, but it could now support the booming wind turbine industry, which became a major export success and employment factor. The third Energy Plan of 1990 heralded environmental values and forced upon the utilities targets of CO_2 (20%), SO_2 (60%) and NO_X (50%) emission reduction.

The fourth Energy Plan of 1996 foreshadowed another regime shift. Maintaining earlier CO_2 goals, it was highly concerned with a transition to a competitive, market-based energy sector in a European common market (Danish Energy Authority, 1999). Once more, the utilities felt bypassed in the political process.

4.3. The technology: reviving wind turbines and CHP plants

In many countries, similar visions and targets proved paperwork only. In Denmark, however, the electricity supply reality converged. Gradually a hybrid system emerged, combining a centralized supply system with a rebirth of grid-connected DG.

The DG technologies of choice, for Danish energy policy as well as innovative actors in the field, were those for which a basis had been developed in earlier regimes: wind turbines and decentralized CHP plants. The wind turbine revival built on the 1960s' experiments with grid-connected turbines and even on the early 1900s' idea of small rural cooperatives, leading to the founding of many so-called wind turbine associations in the 70s and 80s. Also the revival of decentralized CHP used existing capabilities; in 1970, a number of large electric utilities and a few smaller ones supplied waste heat as district heating. In addition, many small- and medium-sized municipalities ran district-heating systems from local heating stations, which could relatively easily be converted to CHP plans. Urban municipalities had experience with this technology from earlier regimes.

In the new regulatory regime, national energy visions supported these technologies and were backed by solid policy measures. Some measures undermined the possibilities for electric utilities to lock-out new wind turbine and CHP owners. Concerning wind turbines, media and parliamentary pressures on DEF resulted in a rather beneficial agreement for grid connection: the utilities should pay 35% of the connection costs and buy surplus power at 85% of the consumer price from wind turbine owners in their supply area. These favourable conditions made wind parks profitable investment projects also for municipal utilities. In addition, the 1976 Energy Plan initiated financing of renewable energy research and in 1979 Parliament introduced a 30% subsidy for private investment in renewable energy production. The 1981 and 1990 plans continued substantial subsidies.

Similarly, decentralized CHP received massive government support through legislation and subsidies. The most interventionist measure was introduced with the 1990 Energy Plan: district heating plants in range of the natural gas network were obliged to convert to gas-fired CHP production. By 1999 this was largely achieved. District heating companies outside the natural gas supply areas should change to biomass-based CHP production if technically and economically feasible (Danish Energy Authority, 1999). Furthermore, construction and production of CHP plants was encouraged and subsidized. With these measures, many industries and also municipal utilities (re)embarked on decentralized CHP production. In addition, new rural cooperatives established some 100 natural gas-fired mini-CHP plants supplying typically 200 houses each. In 1997 there was 390 MW industrial CHP, 70 MW mini CHP, and 1300 MW municipal decentralized CHP (Danish Energy Authority, 1999).

Besides undermining the possibilities of electric utilities to lock out new DG actors, policy measures drew the utilities themselves into the new hybrid regime as major investors in wind turbines and CHP. We mentioned already municipal utilities setting up CHP plants and wind parks. Moreover, when ELSAM applied for the construction of two coal-fired power plants in the mid-1980s, the three alliances negotiated a deal obliging utilities in return to install 600 MW wind power by 2000 and 450 MW CHP by 1995.

The results of all this were impressive. The wind energy targets of the 1981 Energy Plan were actually met. By 2001 wind turbines produced 11% of the gross electricity production, decentralized CHP plants even 24% (Danish Energy Authority, 2004).

We emphasize, again, that such successful regime change is not necessarily monolithic or harmonic. Conflict characterized many institutionalized quarrels between electric utilities on one hand, and national politicians and several DG producers on the other. Another example is what the Danish media called the mini-CHP scandal: according to the media, rural villagers were lured into the CHP adventure by the Danish Energy Authority and natural gas suppliers with optimistic prognoses of gas prices. By the late 1990s their economy proved disastrous and consumers' heat and power bills rose unacceptably high, necessitating Parliament to issue emergency financial aid packages (Ørskov, 1998a, b).

5. Conclusions

Our long-term study of DG in Danish electricity supply allows several conclusions on the relative success of DG in Denmark today:

1. An explanation of this success should include factors of change as well as factors of long-term stability. This requires a long-term perspective. We analysed the constitution of the centralized regime prior to the 1970s. Like in many other countries, DG was marginalized. However, the particular Danish centralized regime included several opportunities for future change. First, next to large utilities, smaller urban municipalities and rural cooperatives became system owners. Their position in the centralized regime derived from their successful engagement in electricity supply already in the first decades of the 20th century, as well as successful negotiations during the regime shift towards centralized supply. Second, it is important to note that the state chose not to have an ownership stake in centralized supply prior to the 1970s. Third, Danish stakeholders built up experience with specific DG technologies as wind-electric and decentralized CHP generation from the early 20th century. These technologies became less visible in the centralization regime, but capabilities remained latently present nevertheless.
2. Against this background we studied change in the DG situation in the 1970s, 1980s and 1990s. Our analysis confirms studies highlighting the importance of energy policy measures as well as innovative strategies by new actors for the DG revival. Yet our long-term perspective brings into vogue why these policies and strategies were effective: they were well tuned to opportunities and barriers created in previous electricity supply regimes. Thus, (1) the outsider position of the state allowed it to take serious DG options without cutting into vested interests of its own. Only with the natural gas system it would gain an ownership stake and become biased. (2) The subsequent energy policy measures and green actor strategies effectively cashed in on the opportunities created in earlier regimes. They revived existing capabilities on wind turbine and decentralized CHP technologies as well as municipal and cooperative ownership forms. (3) Danish energy policy effectively undermined the electric utilities' capacity for DG lock-out by luring the utilities themselves onto the path of hybridization. Municipalities and rural cooperatives, co-owners of the centralized system but historically experienced with DG and engaged in district heating, were forced back into decentralized generation. Even big players as ELSAM were convinced to engage in wind turbine and CHP development.
3. As the relative success of Danish energy policy was based upon specific policy measures but also upon historically grown characteristics of Danish electricity supply, merely copying Danish policy measures will not guarantee DG success in other countries. For instance, attempts to copy the co-operative idea from Danish biogas plants to the Dutch context failed, partly due to a lack of trust from the participating farmers and energy companies (Raven, 2005). Further (comparative) research is necessary to test our hypothesis that

successful policy measures capitalize on existing national capabilities.

Our case study also allows some theoretical conclusions that may inform the literatures on system change and regime shifts:

4. Our analysis of regimes and regime shifts in terms of technologies, actor perceptions and institutional rules shows that stability and change are two sides of the same coin. In both regime shifts studied, some elements of the old regime were vigorously rejected, while others were carried along into the new regime. Thus, both in a negative and in a positive way new regimes were built on top of their predecessors.
5. Technological change as well as technological stability should be analysed as potentially contested processes. Hård (1993) criticized the sociotechnical system concept for its harmonic character: functional interactions between components are emphasized, while elements and voices of conflict and dysfunctionality are silenced. Similarly, we broke with the monolithic character of the sociotechnical regime concept. This helped us to bring into vogue successive national electricity regimes in Denmark, which might be characterized by dominant actors and a dominant technological design (centralization regime), but also by temporally stable, institutionalized competition between actors and several dominant designs (regimes of coexistence and hybridization).

Notably, Danish energy policy itself has recently changed direction. The model that produced the Danish relative DG success is dissolved. In line with a shift towards a liberalized electricity regime, direct support for DG is replaced by market-coordinated sustainability. It is currently uncertain if DG developments will continue; CHP levels have been stable for some years (Meyer and Koefoed, 2003; Danish Energy Authority, 2004; Jørgensen, 2005).

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