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The Evolution of the Danish Smart Grid Sector - Industrial Composition and Interaction Patterns

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Abstract

The aim of this study is to analyse the evolution of the smart grid sector in Denmark, focusing particularly on actors as catalysts for system transformation.

The transition of the electricity sector reached a stage, in which the industrial and academic focus gradually shifts from single technologies of sustainable energy production towards a more systemic perspective. Literature emphasizes that in order to address the challenge of climate change, depleting natural resources and growing energy demand worldwide, far-reaching transformation of energy systems have to happen. These would include a shift towards sustainable low-carbon energy production, but also the development of a new transmission and energy storage infrastructure, and intensive changes related to energy efficiency.

The energy sector is often conceptualized as a large technical system (Hughes, 1987), with a tendency for developing and sustaining path dependencies and rigidities to change, stabilised by a variety of lock-in mechanisms (Unruh, 2000). Broader frameworks describe the energy sector as a socio-technical system, which additionally develops rigidities in institutional, policy- and market dimensions (Geels, 2004). Such a structure generates high entry barriers for innovative technologies and entrepreneurial ventures, what necessarily hampers the creation of variety. Yet, it is the capacity of the system to create and sustain variety, what drives innovation (Nelson and Winter, 1982). In order to advance the understanding of sectoral change, it is important to focus on technologies or events, which have the potential to facilitate variety creation.

One central technical challenge is the integration of intermittent and decentralized energy sources into the power grids. A smarter grid infrastructure is considered to become the key technology for dealing with the issue. These ?intelligent? energy grids are not only expected to accommodate a variety of renewable energy sources in the system, but also to permit new patterns of energy consumption, such as the use of electric vehicles.

To allow for such applications, the traditional electricity grid has to be upgraded. In addition to the hardware components of today?s energy grids, smart grids require a sophisticated communication and regulation structure, connecting all components of the system. A significant amount of ICT technology (both soft- and hardware) will need to be introduced.

The hypothesis of this paper is that increasing the number of potential applications, while incorporating a large share of decentralized energy generation is expected to make the energy sector more dynamic in at least two ways. Firstly, new features are likely to create niches, what might ease entry of new actors, while lowering selection pressure. Secondly, large-scale renewables integration into one system might facilitate the interaction between different actors, what is regarded as an important antecedent of learning and innovation.

Industry data and data on Danish smart grid test projects is used to map the industrial dynamics in the sector, identifying the characteristics and competence bases of actors. To understand the interplay between the meso and micro levels, the contribution is complemented by case studies of two smart grid projects, looking at the interaction between incumbents and new entrants.
The Danish grid industry is promising as an empirical example because of at least three (interrelated) reasons. 22 per cent - the highest national share - of all European smart grid research and deployment projects are carried out in Denmark. Throughout the past three decades, Danish firms accumulated strong competences in the field of large-scale integration of wind power. Traditionally, (e.g. during the development of wind power technologies or the first mobile telecommunication standard NMT) Danish actors showed an extraordinary level of interaction and collaboration, including small actors and new technologies.

If the hypothesis is confirmed than this study can contribute to guide industrial policies, which would facilitate further entry and establishment of new actors within the industry, in order to accelerate the transformation of the energy sector.

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The Evolution of the Danish Smart Grid Sector

Industrial Composition and Interaction Patterns

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Abstract

In order to address the challenge of climate change, depleting natural resources and growing energy demand worldwide, far-reaching transformation of energy systems have to happen. A smarter grid infrastructure is considered to become the key enabling technology. Yet, it is unclear, how the development of this technology is reflected in the composition of the energy sector and which interaction dynamics it might cause. Industry data and data on Danish smart grid test projects is used to map the industrial dynamics in the sector, identifying the characteristics and competence bases of actors, and thereby analysing the transformative capacity of the smart grid technology. Results show that, while many new players entered the Danish *smart grid sector* in the past decade, only very few of those acted as producers of innovative technology. Most of the firms are entrants from ICT industries and seem to complement large incumbent firms as suppliers of software and communication technology. Successful stabilization mechanisms of the current energy system, such as overall technology lock-in, market power of the incumbents, strong regulations, several types of network externalities and the uncertainty about alternative technology solutions, inhibit radical change of the existing grid technologies.

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1 Introduction

Recent developments in the global process of energy system transition, a tactic to cope with the environmental, industrial and developing challenges in the beginning of the 21st century, reached a phase in which systemic issues start to play an increasingly significant role. Taking a systemic perspective is important, as the energy infrastructure over time has developed into a complex system with extremely interwoven technical, economic, institutional and administrative structures (e.g. Hughes, 1987). These influence the processes of change and are in the same time affected, as the overall energy system changes (e.g. Markard, 2011). The earlier academic focus on innovation in particular fields of renewable energy generation such as wind, solar or biomass provided important insights, but it has occasionally come at the expense of attention on the development in the energy transmission- and distribution area. Yet, it is this part of the energy system, which is critical to the ability of the whole system to integrate renewables (Farhangi, 2010). Hence, in order to address climate change and depleting natural resources - while facing globally growing energy demands - the transformation of the energy sector not only requires a radical decarbonisation of energy production and intensified energy efficiency management, but also a renewal of the grid infrastructure.

This upgraded energy grid will have to handle numerous challenges resulting from the transformation of the overall energy system. On the energy generation side it will have to incorporate and balance a variety of decentralized and potentially unstable renewable energy sources. On the traditional consumption side, it will have to allow for new energy usage patterns including electric mobility and prosumption. These features are commonly ascribed to the smart grid, which is essentially seen as the target of the on-going change in the grid development.

Increasing the number of potential applications, while incorporating a large share of decentralized energy generation is expected to make the energy sector more dynamic in at least two ways: Firstly, new features are likely to create niches, what might ease entry of new actors, while lowering selection pressure. Secondly, large-scale renewables integration into one system might facilitate the interaction between different actors, what is regarded as an important antecedent of learning and innovation.

There are, nonetheless, several problems with transforming the existing energy grid into a new generation intelligent grid, most of which originate from the technological stability of the current energy system. Studies of technological change conceptualise and study energy technologies as rooted in large technological systems (Hughes, 1987). Once these systems gain momentum, they also develop effective resistance mechanisms against radical change (Van der Vleuten, E. and Raven, R., 2006). While in the case of the latter conceptualization, rigidities are linked to technological standardisation, newer frameworks understand conservative technologies as sociotechnical regimes, thereby extending the sphere of activity of stabilising mechanisms from the merely technological into the broader social domain (Geels, 2002, 2004).
Drawing on the aforementioned and similar theoretical concepts, academic studies came up with various approaches and research frameworks to identify patterns of innovative change in technological systems.

Different versions of the innovation system approach such as the sectoral system of innovation and production (Breschi and Malerba, 1997; Malerba, 2002) or the technological innocation system (e.g. Bergek et al., 2008) emphasize knowledge creation through learning and interaction as a driving force of innovation. The multi-level perspective (Geels, 2002, 2004) stresses the role of landscape pressures on the macro level and the importance of niches as protected micro level biotopes for the development of radical innovations within rigid systems. On the meso level the sectoral-specific transformative capacity of new technologies (Dolata, 2009) in its interplay with the adaptability of structures and institutions is seen as a determinant of technological change.

This paper aims at understanding the sectoral transformability of the smart grid technology by analysing the development of the industrial composition and the interaction of companies in the sector. Although, theoretically, and according to policy ambitions (DI Energibranchen, 2012), the upgrading of the grid infrastructure should open up the sector for entry by new innovative firms, several stabilisation mechanisms seem to have a major restraining effect.

As empirical example the paper takes the development of the grid infrastructure in Denmark. This seems promising, since the small country pursues very ambitious targets of renewable energy integration (Ministry of Climate, Energy and Building, 2012), its energy sector accumulated knowledge about large-scale integration of wind power over the past three decades (Lund et al., 2012) and finally because Denmark, with 22 per cent, hosts the highest share of European smart grid test and demonstration projects.

The paper is organised as follows: The next section describes the technological aspects of the grid reconstruction and general policy aspirations related to the process and its outcomes. It is followed by a section explaining the relevant theoretical concepts, which are used to frame the research. Section four addresses the methodology. Section five then presents results of the investigation into the development towards a smarter grid. Finally, section six concludes the analysis, discusses implications for theory and policy, and outlines potential areas for future research.

2 The Energy Grid Infrastructure- Policy and Technology

3 Theoretical Background

Conceptualizing the current energy grid

The current energy grid is the technological departure point in the construction of a smart grid. In order to advance the understanding of this transition, it is necessary to elaborate a conceptual definition of the energy grid, its components and their characteristics. The energy grid system can be classified as a large technological system (LTS), which contains a number of messy, complex, problem-solving components - both physical and nonphysical (Hughes, 1987). The system includes physical artifacts such as hardware components for the transmission and distribution of electricity. In addition it contains organizations, such as manufacturing firms or utility companies. Other components, which the system definition can entail, are legislative artifacts, for instance regulatory laws and finally there are natural resources that are adapted in order to get utilized in the system. All these components interact with each other, following formal, normative and cognitive rules. Since energy grids are physically connected to energy producers on the one side and users on the other, the aforementioned components also interact with artifacts and agents external to the system. Hughes (1987) argues that LTSs are socially constructed and society shaping.

Path-dependency and lock-ins

Existing LTSs are stabilized by various lock-in mechanisms on technological, financial, social and institutional levels. These stabilization mechanisms are important for the performance, efficiency and security of the system but also a precondition for understanding change (Van der Vleuten, E. and Raven, R., 2006). On technology level large network-like systems tend to develop self-stabilizing network externalities, which eventually lead to path-dependency and lock-ins into certain, occasionally inferior technological solutions [1] (David, 1985; Arthur, 1989). Other stabilization mechanisms are behavioral patterns, sunk investments, vested interests seeking to preserve the status quo, subsidies and regulations fitted to the existing infrastructure (Unruh, 2000). Thus, over time developed path-dependencies and lock-ins generate a 'lock-out' of change and

[1] Historical examples are for instance the QWERTY keyboard or VHS Video.

new technological solutions.

Socio-technical transitions

Changes in such systems not only consist of the introduction of new technology, but also entail changes in markets, policy, user practices and cultural meanings and are therefore labeled 'socio-technical' (Geels, 2004). The construction of the smart grid, an extended update of the existing energy grid, will require extensive changes in different dimensions of the socio-technical system. Firstly and most obviously existing technology artifacts will be replaced by new equipment, which can vary in the degree of its innovativeness. Incumbent producers and utility companies, adapted to the static routines of the regime, might not have the capabilities and interest to develop the required solutions. Theoretically such a situation can create a 'window of opportunity' for new firms to enter the sector.

TIS / MLP and the importance of niches in both approaches
Transition paths (MLP)

The role of niches

Taxonomy of niche-developments in socio-technological transitions: niche-accumulation, technological add-on, hybridization

Technological change in the grid infrastructure

In the case of smart grid, the technology change is, yet, an at least twofold development. On the one hand there is the installation of new grid infrastructure hardware, on the other the symbiotic upgrade, which complements the grid with advanced metering and communication technology. While in the first case technology would potentially replace, existing equipment, the latter change is additive in its nature. Digital communication technology and advanced software solutions are expected to build a superstructure on top of the current grid. Parallels can be drawn in terms of the development of companies' technologic competencies. Incumbent energy technology manufacturers possess experience and capabilities to build grid infrastructure hardware. These competencies will compete with the competencies of potential entrants. Incumbents will try to protect their market shares by stabilizing the current technology regime and using financial and bargaining power. Strategies can include responding to some grid transition requirements by developing incremental innovations on top of the existing technology. Design of technology ecosystems, which provides best compatibility with own technology and standards, and thus would 'lock-out' (radically) new equipment. Taking the leadership in research and demonstration projects to shape technology trajectories. Acquisition of innovative small firms. Incumbent actors are likely to emphasize the importance of proven security and stability of their technology in the long run, in contrast to the uncertainty ascribed to new radically innovative solutions.

Design of advanced measuring and communication technology or software, is usually not a core competence of energy technology manufacturers. ICT firms and energy grid incumbents do not compete in the same markets and differ significantly in the their technology competencies. Entry from these firms is therefore not likely to face significant resistance, as long as introduced ICT technology would integrate into the existing grid architecture.

4 Data and Methods

Company level data from 159 firms and organization affiliated with the smart grid sector

Combined from 3 sources: (1) Smart grid market mapping report by the Copenhagen Cleantech Cluster, (2) Danish energy research database (companies participating in smart grid project) and (3) members of the Danish Intelligent energy alliance.

Expert interviews to qualify the findings.

Company lists were enriched with information on size, age, financial performance, research project participation and industrial affiliation.

Corporate online publications, newspapers, research project descriptions and other sources were used to gather information about the firms' activity within the sector.

5 (Preliminary) Results

Entry into the sector

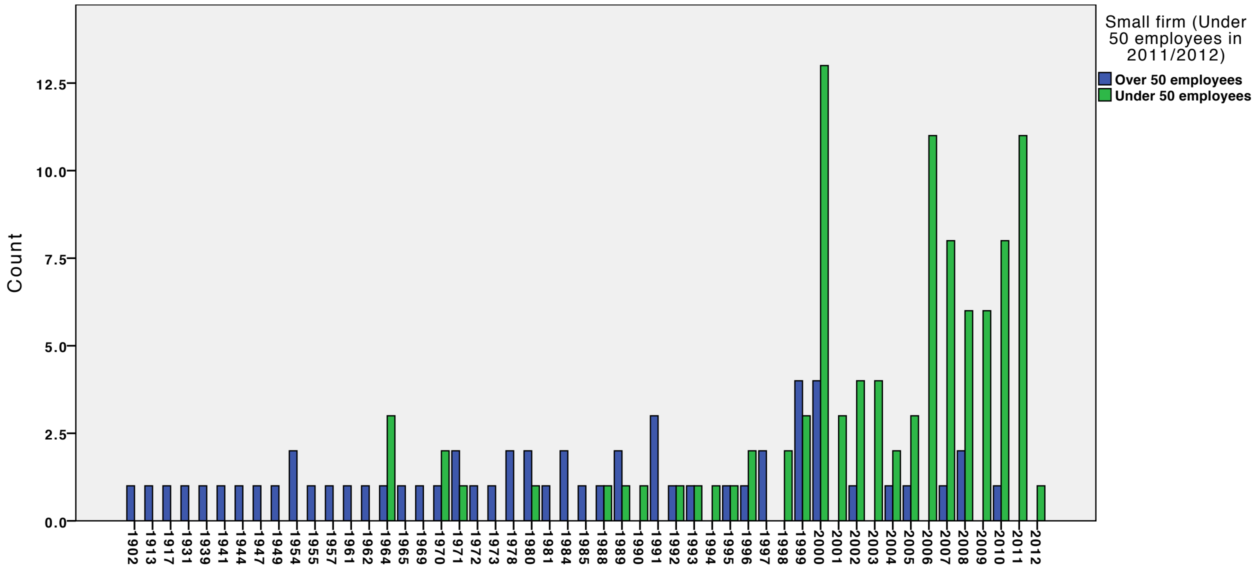

Figure 5.1: Years of establishment of companies in the 'smart grid sector' by size

The analysis of firm establishment dates shows that a large number of companies, particularly the up today smaller firms with less than 50 employees, were founded in or after 2000. At first glance, this findings would support the assumption that the technological development of "the smart grid" facilitates the entry of new entrepreneurial (and eventually innovative) players.

One limitation of such an analysis is that the company founding dates for the period from 2000 onwards are regarded as an approximation for entry into the sector. Yet, the companies might have started their operations in the smart grid field first later. Another related limitation is potential overestimation of the smart grid technology's role as a driver for entry. The presence of the firms in the database is based on some identified affiliation with smart grid development or commercialization. However, these activities might be peripheral for the particular companies and the firm's establishment not related to the dynamics in the smart grid field.

The observation that there is an affiliation between the listed firms and activities in the smart grid area, indicate on the other hand that they succeeded overcoming the entry barriers in the sector.

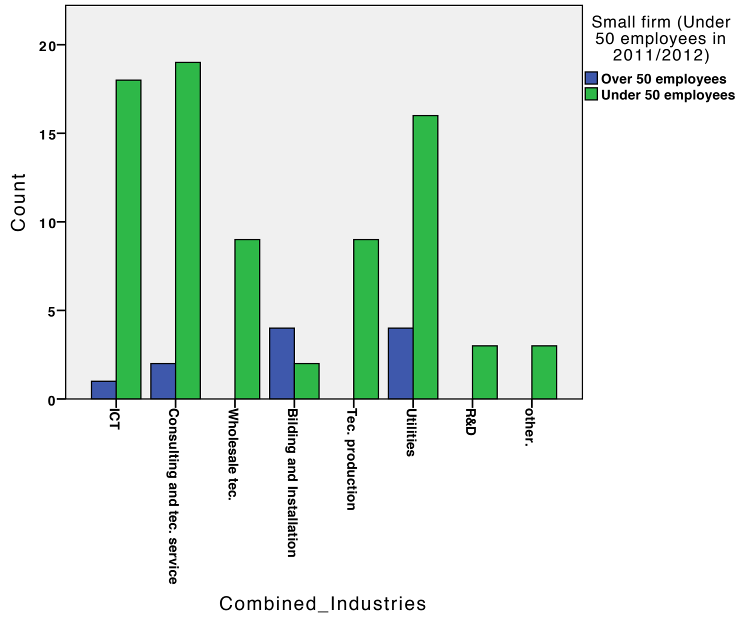

Figure 5.2: Number of companies by industry and size with activity in the 'smart grid sector'

An industry spilt up of companies, which entered in or after 2000, shows that most companies remained small until today. Among those entrants there are many utility companies, which are not start-ups but in many cases changed their legal form probably due to unbundling regulations. As "wholesale" classified actors are often sales-subsidiaries of large multinational production companies. The highest entry numbers can be seen in ICT and among technical consulting and analysis firms. Only 9 companies of all that entered since 2000, can be categorized as technology producers.

This observation suggests that entry barriers in this evolving smart grid field are not equally getting lower across industries. While ICT and technical consulting companies, from industries that are adjacent to the energy sector, seem to be successful at entering the smart grid field. Grid technology producers have obviously less incentives, and opportunities to enter the evolving smart grid sector.

One possible explanation could be that there are two types of change, which the electricity grid system is experiencing today. To make the grid smart, a large share of its units have to be able to exchange, analyze and implement information automatically. To do so, the grid has to be upgraded by adding a significant

amount of ICT, both hard- and software. This type of technology is new to the electricity sector and its fabrication is traditionally not among the competencies of large incumbent firms. Entering ICT firms are therefore less likely to compete with incumbent firms or face restricting regulations.
In contrast to this “additive” change, grid technology manufacturers are aiming at creating technology, which would replace existing apparatus or closely connect to it. Entry barriers in these areas are apparently still very high. Incumbent technology manufacturers might be unwilling to give up business opportunities to start-ups. Additionally it is likely that regulation in this technological area is very rigid and the development and testing of new equipment would be related with prohibitive costs for start-up firms. Especially in a situation with a high amount of uncertainty regarding the future technological development, small firms will be reluctant to invest in the development of technology.

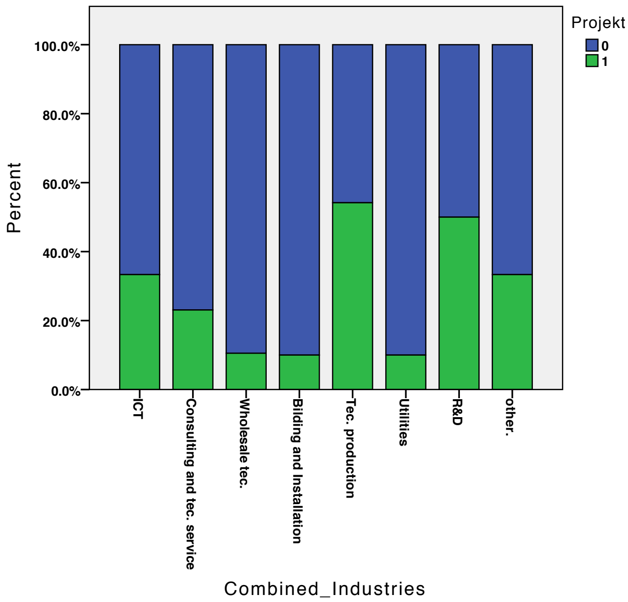

Figure 5.3: Participation of companies in (publically funded) smart grid research projects, by industry affiliation, 1=yes, 0=no

A brief analysis of the industrial distribution of firms participating in publicly funded smart grid research projects (all firms in the sample) backs up the above argumentation: Although ICT and consulting firms represented a large majority among start-ups since 2000, their share within smart grid research project remains relatively low. Technology manufacturers on the other hand - overall few in number - are highly engaged in those projects. This is true for both incumbent firms and start-ups.

This result can have various interpretations: Many IT and consulting/analysis companies might not have products or services, that would require intensive testing in projects. In the case of software, for instance, the firms will supply solutions to hardware producers, which then in turn will test their components along with the software. Hardware component producers, on the other hand, might require the environment and financial support, which is provided within research projects, to assess the performance of their equipment in a setup, where the apparatus has to interact in a complex system. For smaller companies engagement in research and test project might be one of the view opportunities to interact with other players, to acquire a profile in the industry and to learn.

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