Nichehunting? - Exploring the influence of incumbents on niche dynamics in transitions to sustainability*

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Abstract: Sustainable innovations in the energy system do not seem to have the best preconditions for success. Two bodies of literature, the innovation system tradition and the recently growing literature on socio-technical transitions outline the importance of niches, such as research and demonstration projects, for transforming large technological systems. Yet, it is unclear which role established firms from the energy sector play in this context. While they can contribute with capital and unique technological capabilities, there is the also the risk that they might undermine path breaking developments, which could threaten the established unsustainable system. The analysis of Danish energy grid R&DD project characteristics and the engagement of established firms shows that projects with a more pronounced participation of incumbents are more likely to develop incremental solutions.

1 Introduction

Literature on sustainability transitions outlines the significance of niches for the protection and development of path-breaking technologies in early stages (e.g. Geels, 2002; Hoogma et al., 2004; Geels, 2004). Even though the niche is not an explicit concept within the innovation systems literature, the Technological Innovation Systems (TIS) approach highlights the importance of creating protected spaces to foster market formation and diffusion (Hekkert et al., 2007; Bergek et al., 2008b). The engagement of large incumbent actors in the development of emerging technologies is generally positively perceived. Apart from the direct effect of the engagement. it is likely to have a

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positive signaling effect. Thus, it might contribute positively to the status of the niche, improving financial credibility and triggering interest of other companies (Smith et al., 2005). However, the involvement of incumbents might alter niche dynamics, making technology outcomes more incremental and adapted to the current unsustainable socio-technical regime. The purpose of the present paper is to study the interaction patterns between incumbent actors and innovative technologies / applications, that are nurtured in protective niches, and the effects, which this interaction has on the functional properties of the niches. As empirical base the paper explores the evolution of three broader technology areas within the electricity grid-infrastructure in Denmark.

In order to address the growing challenges imposed by climate change and depleting natural resources - while facing globally growing energy demands - the transformation of the energy sector towards sustainability not only requires a radical decarbonisation of energy production and intensified energy efficiency management, but also a renewal of the grid infrastructure (Farhangi, 2010).

The next generation energy grid will have to handle numerous challenges originating from growing energy demands and various functional developments within the energy system. On the generation side it will have to cope with a growing variety of decentralized and potentially unstable renewable energy sources (Van der Vleuten and Raven, 2006). On the consumption side, it will have to allow for new energy usage patterns including electric mobility and prosumption.

Large technological systems, such as the energy grid, build complex, extremely interwoven technical, economic, institutional and administrative structures (Hughes, 1987). As these systems gain momentum, they also develop effective resistance mechanisms against radical change (e.g. Walker, 2000; Van der Vleuten and Raven, 2006). The co-evolutionary process between the rapid development of new energy sources and the patient upgrading of the grid-infrastructure is yet rather unbalanced.

Theoretically a multi-level perspective evolved (Geels, 2002), aiming at combining and structuring the processes, involved in the technological transitions on the micro, macro and macro levels. The framework builds on insights from evolutionary theory and sociology of technology. It emphasises the importance of niches as temporarily protected spaces on micro level for the development and configuration of path-breaking innovations, which would fail to successfully compete within selection environments of the incumbent regime. The notion of niches entails three functional features: (1) Shielding against selection pressure, (2) nurturing of networks and learning, and (3) empowerment by preparing innovative technologies for the competition in the mainstream market or by modifying the selection environment favourable for the particular innovation (Smith and Raven, 2012).

Raven (2007) distinguishes two niche innovation patterns, *hybridisation* and *niche accumulation*. While the hybridisation pattern aims at linking new technology and knowledge to the existing structure within the current regime, niche accumulation might result in episodes of creative destruction. A challenge for the development of effective niches is understandably the interaction between the niche and incumbent actors.

With 22 % Denmark currently hosts the highest percentage of smart-grid research projects in Europe (Giordano et al., 2011; KEMIN, 2013b). The technology areas in focus are *grid-hardware*, advanced measurement-, communication- and control technology, and software- and system integration. The paper examines the configuration of publically funded smart-grid research projects in the period 1997 until 2013. Companies and projects were identified by exploring membership lists and publications by industrial associations and the Danish energy research database. Corporate websites provided additional information about companies' technological capabilities and their range of activity. Earlier expert interviews supplement and helped interpret the quantitative findings.

Although a slight majority of the analyzed project develops novel technological solutions, the arrangement of research projects, the selection of participants and technologies create doubts about the extent, to which these projects can be seen as protective, nurturing and empowering spaces for the development of path-breaking technologies.

In fact, many of the projects do not target the development of a particular innovation. Rather they aim at generating experience, related to grid stabilization and the combination of several technologies in one system. The need of newly developed technology to interact with the existing grid made the classification of smart-grid related research and demonstration projects (R&DD) into more *accumulative* or more *hybridizing* rather challenging. Projects that would develop a new technology or application and would potentially require some adaptive change of the existing grid infrastructure were classified as accumulative. Applying this distinction, results suggest that niche accumulation trajectories can be seen more often than niche hybridization strategies, while increased engagement by incumbent players is correlated with the development of more add-on type technologies within projects.

2 Theoretical background

2.1 Sustainable innovations and socio-technical transitions

Any technological innovation that is entering a new market will face selection pressure and will need to compete with existing technologies. The innovation has to demonstrate superior qualities as compared to mainstream solutions or address the particular needs of users that are currently not satisfied with the performance of the established technologies (Bower and Christensen, 1995; Christensen, 1997).

In addition to the particular features of the new technology and the competition with established alternatives, the environment into which the innovation is introduced, plays a substantial role. This environment is comprised of physical infrastructures, institutions and routines of producers, markets and users. Systemic alignments and mutual interdependencies on many of the aforementioned socio-technical dimensions generate path dependency. While incremental innovations will seamlessly align, constructively drawing on the existing preconditions, more radical innovations might represent a challenge for the environment (Rosenbloom and Christensen, 1994).

Radical novelties are likely to require changes in this multidimensional environment and will therefore be confronted with resistance. New technologies that do not conform to the existing infrastructure and lack significant superior performance or outstanding functions will eventually not be able to withstand the selection pressure and fail. Diffusion and adaptation can however be achieved if advantages gained from the superior performance of the innovative technology can offset the adaptation efforts. Such processes of innovation diffusion and complementary systemic change are often referred to as 'socio-technical transitions' (Geels, 2005; Smith et al., 2005).

Against this background, sustainable transitions in the energy system do not seem to have the best preconditions for success. Geels (2011) summarizes three classes of peculiarities, where sustainable transitions differ from many other historical transitions and impose a multi-dimensional challenge for the society.
A large share of transitions in history were 'emergent' in a sense that change was often the result of autonomous experimentation and entrepreneurial exploration of market opportunities of new technologies. These processes, motivated by commercial interest, would eventually lead to the emergence of technologies with pervasive impact. Sustainable transitions are 'purposive', meaning that they are oriented towards addressing environmental problems and growing resource scarcity (Smith et al., 2005). The normative concerns that underlie such transitions are related to the production of the collective good, 'sustainability', what limits the incentives for private actors to engage in the development of these technologies.

Sustainable innovations are subject to double externalities (Rennings, 2000). Just as in the case of other technological novelties, developers of sustainable innovations will not be able to appropriate its entire value, due to imitation and spillovers. The other part of the double externality is related to the absence of environmental costs in incumbent technologies, which are however internalized in sustainable technologies. Since sustainability is a common good, most sustainable innovations will not provide obvious user benefits. However, due to the presence of external costs and the novelty of the technologies, sustainable solutions will often score lower on performance/price dimensions then incumbent technologies (Rosenberg, 1972; Geels, 2011).

Finally, many of the industrial areas, which mostly need the introduction of sustainable solutions, are characterized by an industrial composition, which does not particularly favor change. Sectors such as transport, energy generation and supply or agriculture rely on existing tangible and institutional infrastructures (e.g. development and trial systems, supplier and distribution networks, energy transmission grids and other complementary assets). This dependence leads to high entry barriers in aforementioned industries and explains, why key players are likely to be large companies (e.g. electric utilities, car manufacturers, railway operators). This circumstance creates a power and capability imbalance between usually small enterprises that are pioneering the development of sustainable solutions and incumbent actors (Hockerts and Wüstenhagen, 2010). As long as production and distribution processes within existing trajectories are economically favorable, incumbents will not see urgent reasons to make large investments and reorganize existing production structures. On the contrary, they are most likely to defend the system against change (Walker, 2000).

2.2 Theories of technological change

These reflections have received increased attention in the context of sustainability, over the last 10-15 years. Similar empirical phenomena of technological change have been conceptualized and analyzed throughout the past three decades. Early theoretical approaches include i.a. overall evolutionary economic theory (Dosi, 1982; Nelson and Winter, 1982), the notion of large technological systems (Hughes, 1987), social construction of technology (Bijker, 1997) and long-wave theory on techno-economic paradigm shifts (Freeman and Perez, 1988; Freeman and Louçã, 2001). During the second half of the 1980s the concept of the innovation system was formulated, as both, a practical tool to design innovation policy but also as a synthesis of analytical results produced by innovation researchers (Lundvall, 2007). Besides the concept of the national system of innovation (Freeman, 1987; Lundvall, 1992), different sub-orientations such as the regional system of innovation (RIS) (Cooke et al., 1997; Malmberg and Maskell, 2002), sectoral system of innovation and production (SSI) (Breschi and Malerba, 1997; Malerba, 2002) or the technological systems, later technological innovation system (TIS) (Carlsson and Stankiewicz, 1991; Bergek et al., 2008b; Hekkert et al., 2007) were developed for the analysis of innovation and capacity building in various empirical domains and within other system delimitations as the national boundaries. All of the modified versions of the innovation system concept are entrenched in evolutionary economic theorizing, they emphasise the analysis of a systemic interplay between actors, networks and institutions, and acknowledge phenomena such as path dependency, lock-in and non-linearity. Yet, only the national system of innovation and the regional innovation system, address the local character of the system as a consequence of geographical embedideness of tacit knowledge (Lundvall, 2007).

2.3 Technological innovation systems for studying transitions

Despite the dominant role of the national focus in innovation system studies, which is used in half of all innovation system based publications (Carlsson, 2006), sustainable innovations do not represent a prominent empirical application. RIS and SSI approaches appear conductive for the research of sustainable innovation, but most of the studies with this empirical focus are rooted in the TIS tradition. Here, recent publication use the notion of sustainable transitions rather then addressing the diffusion of sustainable innovations, to underline the far reaching socio-technical scope of the changes in domains such as energy, transport or agriculture. The technology specific sub-orientation of the innovation system approach is conductive for the analysis of emergent industries on the basis of radically innovative technologies and the institutional and organizational changes that accompany the technological development (Truffer et al., 2012). Early studies applying the TIS approach focused on systemic interplay of actors along the whole value chain, networks and institutions, connected to the development, distribution and use of particular novel technologies. They experimented with varying system delineations that referred to knowledge fields, specific materials, single products or groups, and finally whole sectors. While system delineation, particularly the set-up of the TIS in relation to geographical and sectoral embededness, still remains under dispute, the concept did experience a major conceptual refinement, shifting the analytic emphasis from system composition towards a key functions assessment for the determination of system performance (Bergek et al., 2008b). System functions are seen as intermediate variables between the structure of the system and its performance, emerging out of the interplay between actors and institutions (Jacobsson and Bergek, 2011). This perspective was developed to facilitate the junction between technology-specific and more general industrial dynamics. Thus, the TIS is by definition tied to higher system levels (e.g. SSI or NIS) (Jacobsson and Johnson, 2000).

The framework distinguishes two central segments of development (Jacobsson and Bergek, 2004): An extended 'formative stage', characterized by long periods of technology and market development, uncertainty at various levels, poor price/performance levels and lack of system stabilization (Bergek et al., 2008b). It is followed by a 'growth phase', during which technologies experience up-scaling and transition towards larger markets.

Core contributions within the TIS literature identify seven key functions: (i) Market formation, (ii) Entrepreneurial experimentation, (iii) Influence of the direction of search, (iv) Resource mobilization, (v) Knowledge development and (vi) Legitimation.

Especially in respect to the development and diffusion of radical innovations, two of the seven identified key processes within technological innovation systems play a major role. On the one hand the ability of the system to drive entrepreneurial experimentation and thereby foster technological variation, on the other, the systems contribution to the formation and maintenance of markets for emerging technologies. Even though the more aggregated notion of niches, which closely relates to both processes, is not an explicit central element of the concept, key authors within the TIS stream acknowledge niches, as highly important structural elements, which support these two core functions. The creation of protected spaces for new technologies is essential for their development

(Hekkert et al., 2007) and is situated at the heart of the formation process of the TIS (Jacobsson and Bergek, 2004). In addition, the creation and nurturing of niches is likely to contribute to knowledge formation (v) and guiding of (re)search (iii). While the formative stage is undoubtedly in the focus of most TIS based studies, the growth stage has received relatively less attention.

2.4 Multi-level perspective

In the recent decade, a second stream of literature that proposes a conceptual framework for the analysis of particularly sustainable transitions, gained considerable attention. Technological transitions are explained by the interplay of three systemic concepts. The landscape on the macro-, the socio-technical regime on the meso- and niches on the micro level respectively (Geels, 2002, 2005). The key concept of this multi level perspective is the socio-technical regime, which represents a coherent, stabile structure at the meso-level, combining established products, technologies and institutions (routines, norms, practices). Refering to work by Arie Rip and René Kemp, Hoogma (2002) defines the regime as: "the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, institutions and infrastructures". The regime is characterized by a high level of 'structuration' (Coenen and Díaz López, 2010), stable and well articulated rules, and hence path-dependency and mechanisms for self-stabilization. It corresponds in many respects to the selection environment in terms of evolutionary economic theory and generates entry barriers for innovative technologies.

The landscape summarizes exogenous factors, such as energy prices, environmental catastrophes or public debate, which can have an effect on the stability of the regime. A recent example would be the nuclear meltdown in Fukushima, which (without having any physical impact) amplified risk awareness and mobilized anti-nuclear-energy protests in Germany. This alternation in the national energy system's landscape level generated enough pressure to trigger a policy turnaround. The Bundestag took back the operation extension of nuclear plans, which was decided in autumn 2010 and by

June 2011 it passed a roadmap for the stepwise shut down of all German nuclear power plans by 2022.

Niches are conceptualized as spaces for protection and development of path-breaking technologies in early stages (Hoogma et al., 2004). The texture of the niche is in many respects similar to the regime level, however niches differ in terms of size and stability (Schot and Geels, 2007).

The concept grounds on insights from literature on strategic niche management (e.g. Kemp et al., 2001) and represents the gateway through which innovation can be introduced into the regime. The character and intensity of the interplay between the three levels define the paths, which a socio-technical transition might take. Determinant factors are here the initial origin of the change process, the affiliation of the agents that stand behind the novelty and the extent to which the innovation is radical and would lead to episodes of creative destruction (Schumpeter, 1942; Geels and Schot, 2007).

2.5 Niche dynamics

Looking at the niche level in a more isolated way Raven (2007) identifies two patterns of transformation that can occur during interaction with established technologies, *hybridisation* and *niche accumulation*.

The former strategy relates to the development of radically different technologies in niche markets by relatively small and new actors. Here innovations can grow, enhance their performance and obtain competitiveness in a protected environment outside the selection pressure of the regime. The notion of accumulation refers to this process of shielded technology learning and improvement. Mainstream markets represent an obvious long-term target for these technologies, however they might be rather difficult to reach, since innovations that are accumulated in this kind of niches, have to compete with established solutions. While the accumulation path is a great strategy of developing radically new technologies, there are several potential pitfalls, which might result in stagnation of development and confinement in small niche markets. Limited resource endowment and lack of complementary capabilities of agents that stand behind path breaking innovations might prevent the generation of momentum for a persistent stimulation and development of the niche technology. It is likely that these kinds of niches do not benefit from dense networks and knowledge sharing mechanisms to the same extent as in the case of established technologies and industries. Achieved results and insights might therefore remain in the particular niche environment without diffusing into the wider network.

The latter of the two emerging strategies locates innovation activity close to the established regime technology. Incumbent actors participate in niche activities and resulting innovations usually display a symbiotic add-on character to established technologies, which are targeting mainstream markets. The advantage of such a strategy results from the easy integration of the developed innovations into the regime technology. Especially in the case of infrastructure related innovations this innovation pattern is likely to generate rapid and applicable outcomes. Yet, compatibility with the existing regime might come at the price of getting stuck in the trajectories and routines of the established regime.

2.6 Niche functions and features

Niches usually have been conceptualized as spaces, which would shield path-breaking innovations from mainstream selection pressure (Schot, 1992). Thereby allowing for a higher pace of development as compared to the mainstream market (Levinthal, 1998). Yet, the concept of protection itself has not received much attention, in terms of a thorough interrogation of niche functions and interdependencies. Niche trajectories were conceptualized as a result of technology characteristics and interaction with the established technology set-up. To understand, how niche dynamics compete and eventually transform established regimes, it is essential to have a conceptual insight into the processes within niches. Smith and Raven (2012) suggest to assess niche dynamics, using three essential niche functions: shielding, nurturing and empowerment. The authors propose an analytical distinction between passive and active niche spaces. Passive spaces are generic in a way that they preexist the active mobilization by innovation advocates. Selection pressure of mainstream markets is reduced by natural or preceding institutional distance or barriers. A widely quoted example is the development and usage of solar cells in space in the 1960s. Broad availability of mobile phones Sub-Saharan Africa and relatively higher trust into the wireless telecommunication system then into the conventional banking system generated a favorable setup for the development of mobile banking applications in the recent decade. In contrast to the natural shielding, provided by passive niches, the artificial construction of protective spaces for technology development is informed by a strategic niche management approach (Kemp et al., 1998). These artificial or active niches are for example research and demonstration (R&DD) projects.

Shielding strategies include technology policies on the supply and demand sides but also interventions by non-policy actors through for instance establishment of incubator units beyond the boundaries the firm. In this context, selecting the appropriate level of protection and upholding a continuous assessment might be crucial, in order to prevent protection of poor innovations (Hommels et al., 2007).

Nurturing of innovations within the niche is the second functional level that basically encapsulates the functions of the TIS approach. In contrast to the strategic management framework, the empirical focus of the TIS approach reaches beyond experimental projects and is therefore seen as the more elaborated framework for the analysis of nurturing processes (Markard and Truffer, 2008).

The last functional dimension, proposed by Smith and Raven (2012) is the empowering of path-breaking technologies. Innovations that are shielded against the established selection environment within the niche, will eventually develop, improve on price/performance levels and be able to compete in the mainstream markets (Christensen and Bower, 1996). In this case the protection can be removed and the innovation will potentially diffuse beyond its boundaries. There it will integrate into the unchanged established regime. This process is referred to as fit and conform empowerment and reminds of the hybridization trajectory. Yet, the effect is due to the performance of the protective space, rather than the technological features of the niche and the *inter-*

operability with the regime. Just as in the case of hybridization, the fit and conform empowerment strategy will be more likely to reach at alignments between the niche and regime levels. This might however come at the expense of path-breaking features of the niche technology. Alternatively to the molding of the niche into a fit with the regime, niche agents can execute a stretch and transform empowerment strategy, aiming at alternating the regime by institutionalizing niche practices within a transformed regime.

2.7 A common framework?

Considering the above-sketched dynamics, commonalities between the TIS approach and the niche conceptualization within the MLP become obvious. Although the two frameworks are often categorized as belonging to different streams of literature (Fagerberg, 2005), it has been proposed to identify and draw on the complementarities of the two bodies of literature (Markard and Truffer, 2008; Coenen and Díaz López, 2010). Both frameworks share a systemic understanding of innovation and acknowledge evolutionary phenomena such as path-dependency, lock-in, nonlinearity or mutual interdependency. However, there is arguably one significant difference between the frameworks: The TIS approach has been criticized for being 'inward looking' (Markard and Truffer, 2008), in a way that it underplays the potential tension between path-breaking innovations and established technologies, or more broadly the selection environment. The success of the developed technology is primarily explained by the performance of the system and not by the interplay of the emerging technology and the established socio-technological environment. Although one of the functions of the TIS during the *formative stage* relates to promotion of entrepreneurial experimentation, protection against selection pressure and the need for shielding are not mentioned explicitly. In fact, entrepreneurs in the TIS terminology can be new entrants but also incumbent, who diversify their business strategy, targeting new developments (Hekkert et al., 2007). However, organized incumbents, who protect their investments, market shares and the alignment between institutions and established technologies are seen as external blocking mechanisms (Bergek et al., 2008a). Transition-literature is even more skeptical in regard to the eagerness of incumbent players to support path-breaking innovations. Even though, it is acknowledged that incumbents can, given a strategic reorientation, accelerate the breakthrough of niche innovations if they supported the development with their complementary assets and capabilities, these actors are assumed to defend existing systems and regimes (Geels, 2011).

The multi level framework and the innovation system approach have been applied to study radical innovation and socio-technical transformation processes. Strategic niche management insights and concepts stemming from the TIS approach contributed to the design of industrial policy, aiming at fostering innovation, particularly in relation to sustainable technologies. The disagreement of the two frameworks in regard to the particular role of incumbent actors and the according protection levels of respectively niches or emerging TIS against selection pressure calls for empirical interrogation.

Assuming that incumbent actors are interested in the protection of their investments, assets and markets, innovative technologies will be perceived as a threat, whenever they have the potential to evolve as substitutes for established technologies or make existing assets obsolete. Novelties, introduced by newcomers, who intend to update regime technologies by adding new features that would not compete with existing structures, are likely to receive support or even originate from incumbent actors. This is in line with Anderson and Tushman (1990), who claim that competence-destroying innovations are initiated by newcomers, while competence-enhancing breakthroughs are pioneered by incumbents. In the historical study on the cement, glass and minicomputer industries they find that both, newcomers and incumbents, were actually involved in the development of these competence-destroying breakthroughs. Given the result of the study, they speculate – in a Schumpeterian tradition - that the initiation of competence-destroying innovations requires a first move by newcomer actors. In the aftermath of the radical change, incumbent actors might contribute to building up a technical order (Anderson and Tushman, 1990).

Hence, innovation paths that are compatible with regime technologies are attractive

for established firms. Resulting innovations can address some of the existing problems on the regime level without compromising existing socio-technical structures. Established firms are therefore likely to initiate or engage in niche activities, such as R&DD projects, which investigate such applications.
On the contrary, they will probably not support the early development of path-breaking innovations, particularly of those that might replace existing physical structures.

2.8 Technological background and energy grid policy in Denmark

To reach a better understanding of the structure of Danish R&DD projects, this section will introduce a brief description of the technologies and actors that are involved in the development of the smart grid. It is also aimed at providing an overview over the Danish policy ambitions and commitments, which are closely bound to the set-up of R&DD activities.

The existing electrical grid infrastructure

The traditional architecture of the electricity grid was developed to enable a unidirectional flow of electricity from centralized generation plants to consumers (Farhangi, 2010). On its way to industrial, business and residential customers, it would pass the transmission and the distribution grids, with stepwise decreasing voltage. Production levels are constantly adjusted to the estimated consumption, which fluctuates in the course of a day and throughout the year. Communication and automatized exchange of information between the different segments is relatively limited, since the regulation options do not go far beyond the up- and downregulation thermal power plants and international connections.
It is obvious that the present grid architecture has to develop in order to address the changes, which are evolving in the energy generation and consumption patterns in future. There is a constantly increasing share and growing diversity of renewable energy sources, which (apart from biogas) are intermittent and unstable regarding the energy output. Since there is no way to regulate generation levels in renewable sources directly,

the harmonization between generation and consumption has to happen in the grid or on the consumption side.

Large-scale renewable energy generation is limited to areas, which yield an efficient production of energy and these usually cannot be closely located to the consumers. Generation is therefore becoming increasingly decentralized and the produced energy has to be transported to the consumers via a new grid-structure. On the consumption side of the system, there is an apparent attempt of integrating the transport- and heating sector into the electric energy system. Lund et al. (2012) argue therefore that it is more appropriate to talk about a smart energy rather then a smart grid system. The ongoing electrification of energy consumption will include the introduction of electric vehicles (EVs) and heat pumps, demanding larger amounts of energy in the middle- and low voltage distribution grid, which are more sensitive and limited in their capacity as compared to the transmission systems. Flexible consumption will become particularly important for the optimal utilization of the distribution networks. To postpone or prevent costly investments in reinforcement of the distribution grid infrastructure, energy consumers will be encouraged to make their flexible consumption available to the system, while relocating energy usage to off-peak times (KEMIN, 2013a). Rooftop mounted solar photovoltaic modules, heat pumps, EVs, micro combined heat and power systems and other imminent technologies are already today altering the role of the energy consumers, who gradually become so-called *prosumers*. It is likely that their involvement in the operating of the electricity grid will grow even more rapidly in future. In practice their new tasks will include energy production, storage and thus participation in the decentralized stabilization of the energy grid.

To accommodate numerous technological developments on the production and the consumption side of the energy system, a smart or intelligent energy grid system has to be shaped. This next generation energy grid has to combine old and new technologies from different areas: The *smartening* of the grid requires contributions from the wide area of energy engineering, such as innovative energy storage and -transportation.

Furthermore, measuring, information and communication technologies have to be included in order to monitor and manage the growing complexity and number of the applications.

Hence, the transformation of the energy grid system requires both, new solutions within the electric hardware domain but also the inclusion of a superstructure of information and communication technology, sometimes referred to as the *layer of intelligence.*

Smart energy research in Denmark

Denmark is the country in Europe with the largest amount of R&DD projects in the smart energy area Giordano:2011fv. The recently announced national Smart Grid Strategy follows the tradition of making Denmark a European laboratory for innovative energy solutions (KEMIN, 2013a). The main driver for this strong engagement is the expansion of the wind power capacity. The set goal is to cover half of the electricity consumption with wind power by 2020 (KEMIN, 2013b). One of the milestones in the promotion of the Danish smart grid development was the set up of a Smart Grid Network, consisting of key research institutions, industrial organizations and the national transmission system operator (TSO) *Energinet.dk*. The network defines the publically funded R&DD agenda by providing analyses and giving recommendations to authorities on the design of the research infrastructure. Public energy research funding is mainly conducted through 6 programs, which support projects in all stages from basic research to market introduction (Forskningsnetværket, Smart Grid, 2013). Even though being very advanced and ambitious, the national strategy reveals a path dependency component. Strong emphasis is put on the role, which the current consumers are intended to play with regard to the stabilization of the distribution grid. Optimal usage of the distribution networks is primarily to be reached by deploying flexible consumption capacity of energy users and the shift of consumption to off-peak times. Thus, the intention is to minimize and postpone the amount of costly investments in additional or stronger grid infrastructure. This strategy is also likely to strengthen the position of add-on type technologies, such as remotely-read hourly meters, which would allow promoting and incentivizing the flexible consumption.

Project composition and innovation paths in Danish smart grid R&DD

Applied to the development of the smart grid in Denmark the theoretical propositions formulated in the theory section would translate as follows:

Grid R&DD projects with a higher share of incumbent participants are/become less path breaking.

Projects that are initiated by incumbents are less path breaking than project, initiated by new entrants or research institutions.

The effect should be stronger for projects that focus on hardware development.

3 Data and Methods

The framework is applied empirically relying on the Danish database of publically funded energy R&DD projects.[1] The constantly updated register contains in 2013 information about 2040 projects that have been granted public funding under 10 funding programs since 1989. The projects are divided up into 8 classes: *biomass and waste, hydrogen and fuel cells, energy efficiency, wind, sun, wave energy, smart grid and systems, and others.*

For the current analysis records from the *smart grid and systems* category were exported containing information on 102 projects, which were granted public support in the years 1997 – 2013. Only projects that targeted the development, demonstration, simulation or testing of a technological application were selected. Policy analysis projects or those that funded the establishment of a research institution but not a

[1] available at www.energiforskning.dk

particular target oriented process were dropped from the sample. The final dataset contains detailed information on 84 R&DD projects, including the time period and the year in which the grant was given, the funding program, the budget, a project description and a result description for finished projects. It lists participants and the leader, the financial contribution to the budget, the amount of public support that each participant and the entire project were granted.

3.1 Variables

Outcome variable:

The intention with this research is to explore the participation effect of incumbent players on the project configuration and determination, and hence the ability of project to shield, nurture and empower path-breaking grid technologies (Smith and Raven, 2012). The cross-section data does not allow for a dynamic analysis on project level. To proxy the ability of a project to protect an innovative technology, a keyword analysis of the project descriptions - and whenever applicable result descriptions - was conducted. The binary outcome variable `NicheType` takes the value 1, for projects that develop or test a novel technology or application. Novelty was seen relative to established technology in the existing grid infrastructure. Projects that worked with established technologies or solutions in new configurations or new technologies that would make incumbent structures more efficient by connecting to them, were classified as hybridizing or add-on projects (`NicheType=0`). The limitation of this approach stems from the design process of research projects. It is legitimate to assume that projects' trajectories can get altered over time as suggested by the niche dynamics literature. Yet, projects can also have an *ex ante* break trough or add-on character, and participants might self-select into the projects, which most fit their technological development agenda.

Independent variables:

Participants were classified as *incumbents* – mature companies in the energy sector, their subsidiaries and utilities, *new entrants* – small companies, which entered around 2000 and are not a subsidiary of an incumbent - or *research institutions* and participation numbers were recalculated into shares within the particular projects. Mature players from sectors, which traditionally have not been related to energy, represented a particular challenge. Corporate websites and firm databases [2] were used to provide more information for a more precise classification. These adjacent players were categorized as new entrants, if their core markets were others than energy and participation in the project could be seen as part of a diversification strategy. `ShareInc`, `ShareNew` and `ShareRes` measure the relative shares of the respective groups of project participants per project. The variables `IncumbLead`, `NewLead` and `ResLead`, indicate the type of the project leader.

Control variables:

Size of the project is approximated by the project budget relative to the number of participants (`BudgetRel`). The variable `Support` measures the percentage of public funding in the project budget. It is assumed that projects with a higher share of public funding are more likely to have a higher involvement of public research institutions that are by definition closer to basic research of more breakthrough technologies.

Based on the project descriptions projects were categorized into to 3 broad technological dimensions of grid infrastructure hardware (including system stabilization and to a minor extent energy storage technologies) `Tec_HWare`, grid related ITC technology `Tec_Comm`, and finally software and analytical applications `Tec_SoftAnl`.

Furthermore 4 classifications have been made for the position of the elaborated applications in the grid infrastructure, covering projects related to integration of produced energy, transmission and overall grid management `Appl_Intgr`, applications related to changes in the traditional energy consumption `Appl_Consm`, energy storage `Appl_Storg`

[2] Navne og Numre for Danish firms and Amadeus for international

and finally electricity based mobility concepts `Appl_Mob`. The latter classification is interesting in a descriptive context for providing an overview over the different application dimensions of the research projects. Its greatest limitation lies however in the systemic and highly intertwined nature of the energy grid infrastructure. Any change in consumption patterns will have an effect on the degree to which the grid has to be stabilized. Integration of new energy sources call for changes in consumption and for storage solutions, which will automatically evolve with the growth of electric mobility.

The projects in the sample were run under 4 program. Approximately 73 percent were funded by *ForskEL*. This program was established in the aftermath of the split up of the Danish energy sector into generation, transport and sale and is run by the national TSO (Transmission System Operator). The overall focus of the yearly-renewed program lies on the development of renewable energy technologies and grid integration. 6 percent of the projects are funded by the Energy Technology Development and Demonstration Programme (*EUDP*) under the Danish Energy Agency, which targets similar technologies as ForskEL but emphasizes the importance of interoperability with existing systems. Nearly 12 percent of the projects were co-financed by the predecessor of *EUDP*, the *EFP* program. 9.5 percent of the projects were funded by the Danish Council for strategic research (*DSF*).

Finally year dummies, derived from the starting years of the projects, were introduced. A first wave of research projects in the field starts, as shown in Figure 1, in 2004 peaks in 2006 and ends in 2008. A second wave starts with strong increase of new research projects in 2009 and continues until today.

Table 1 reports the descriptive statistics for the dependent and explanatory variables.

Slightly more projects (55 percent) were classified as following a path breaking *niche accumulation* path. Incumbents and new entrants have on average equal participation shares in projects, highest participation rates are reached by research institutions. These are also first, when it comes to project leadership. Research institutions lead over half of all projects. With 27 percent, new entrant leaders are ahead of incumbent players. Project budgets were on average around 10.8 million Danish Kroner (1.448.960

Table 1: Summary statistics

Variable	N	Mean	Std. Dev.	Min	Max
NicheType	84	0.56	0.50	0	1
ShareInc	84	0.28	0.32	0	1
ShareNew	84	0.29	0.36	0	1
ShareResinst	84	0.43	0.39	0	1
IncumbLead	84	0.20	0.40	0	1
NewLead	84	0.27	0.45	0	1
ResLead	84	0.52	0.50	0	1
ProjectSize	84	3.81	4.07	1	29
Budget	84	10.79	18.52	0.08	120.86
BudgetRel	84	3.32	3.43	0.08	18.57
Support	84	63.63	22.22	0.71	140
Tec_Comm	84	0.06	0.24	0	1
Tec_Hware	84	0.27	0.45	0	1
Tec_SoftAnl	84	0.67	0.47	0	1
Appl_Consm	84	0.19	0.40	0	1
Appl_Intgr	84	0.61	0.49	0	1
Appl_Mob	84	0.07	0.26	0	1
Appl_Storg	84	0.13	0.34	0	1
DSF	84	0.10	0.30	0	1
EFP	84	0.12	0.33	0	1
EUDP	84	0.06	0.24	0	1
ForskEL	84	0.73	0.45	0	1

Notes: Summary statistics on project level. *Budget* measured in mil. DKK.

Eur) and received public funding of approximately 64 percent. The distribution across different technologies is rather uneven. Two thirds of projects are related to simulation and analysis new scenarios and compositions of existing technologies. In 27 percent of the cases, new technologies were developed. Only 6 percent of the projects experimented with a novel communication technology. While over 60 percent of the projects dealt with the integration of decentralized energy sources and overall stabilization of the grid, approximately 20 percent looked at the consumption side (often related to stabilization potentials) and 13 percent with new energy storage solutions.

The pairwise correlation matrix in Table 2 reports the results of a bivariate analysis. Neither the share of incumbent players in research projects nor their role as project leaders shows an impact on the likelihood of the research project being more path breaking. However, it seems that projects related to grid hardware development are more likely to deal with more path breaking technologies, while projects that are related

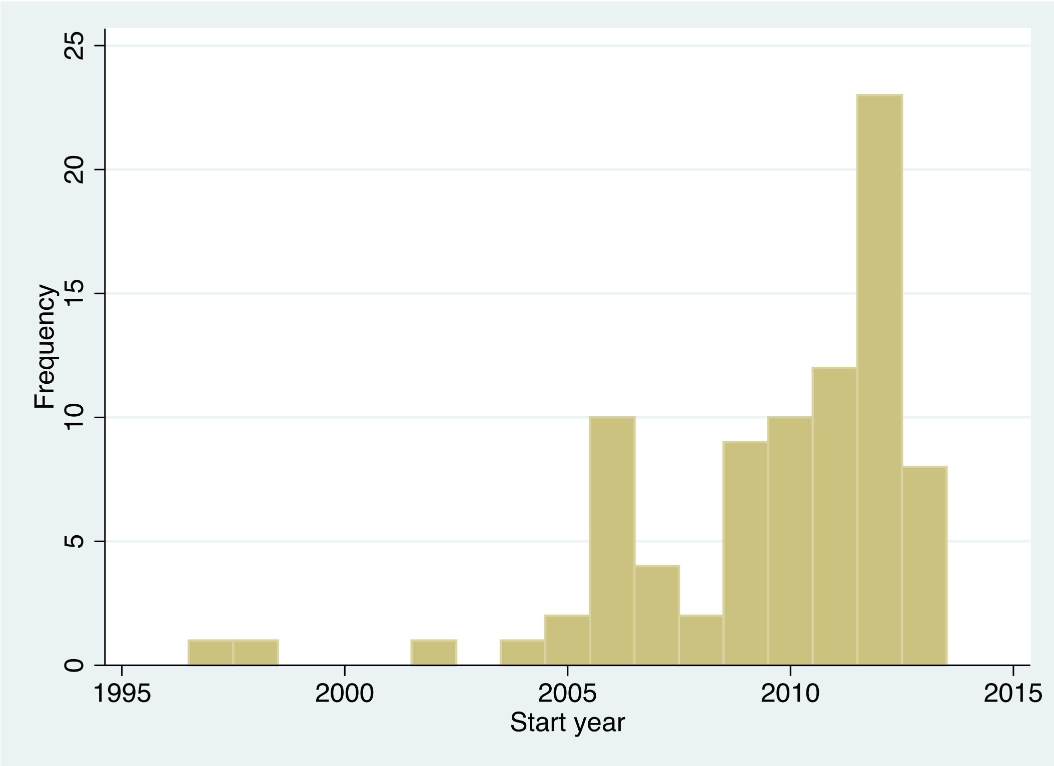

Figure 1: Smart grid R&DD projects by starting year

to software development or analytical tools have higher chances to develop add-on character technologies. These indications are not surprising but rather logical given the characteristics of the technologies. Projects with a higher share of incumbent players are likely to receive lower levels of public funding. Projects with a higher share of or being led by research institutions are on the contrary receiving higher levels of public funding while their overall budgets are larger on average. Levels of public support seem to be however lower for grid related hardware technology development in general. Other significant results regarding the relationships between participation shares and leadership are trivial.

3.2 Methods

Based on the above presented data the empirical analysis examines the ability or intention of R&DD projects to be protective spaces, given different levels of project engagement of incumbent players. I apply a binary logit maximum likelihood estimation

Table 2: Correlation matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1)	NicheType	1.00											
(2)	ShareInc	−0.15	1.00										
(3)	ShareNew	−0.03	−0.33*	1.00									
(4)	ShareResinst	0.14	−0.51*	−0.65*	1.00								
(5)	BudgetRel	0.13	−0.17	−0.15	0.28*	1.00							
(6)	Support	−0.06	−0.25*	−0.06	0.26*	−0.15	1.00						
(7)	Tec_Comm	−0.18	−0.16	0.09	0.05	0.03	0.09	1.00					
(8)	Tec_Hware	0.33*	0.18	−0.00	−0.14	0.03	−0.26*	−0.15	1.00				
(9)	Tec_SoftAnl	−0.22*	−0.08	−0.05	0.11	−0.04	0.20	−0.36*	−0.87*	1.00			
(10)	IncumbLead	−0.15	0.56*	−0.23*	−0.24*	−0.09	−0.18	−0.13	0.16	−0.08	1.00		
(11)	NewLead	0.06	−0.20	0.80*	−0.57*	−0.12	−0.14	0.07	0.04	−0.08	−0.31*	1.00	
(12)	ResLead	0.07	−0.27*	−0.53*	0.70*	0.18	0.26*	0.04	−0.16	0.13	−0.53*	−0.64*	1.00

* $p < 0.05$, two-tailed Pearson correlation

method, to estimate the relation between project participant composition and leadership, and the probability of the project to work towards a path breaking or add-on technology.

4 Results

Table 3 presents the results of the logit estimations, reporting coefficients and marginal effects. The first three models explore the relationship between project composition and the `NicheType`. The latter 3 models focus on the project leadership by an incumbent player and the `NicheType`. Model 1 and 4 contain dummies for different funding programs, model 2 and 5 add dummies for different application of the projects, model 3 and 6 include year dummies but drop the application dummies.

The results suggest that higher shares of incumbent players `ShareInc` in energy grid R&DD projects might come at the expense of projects' ability to shield novel technologies from established industrial trajectories. As the share of these players grows, projects are more likely to target the development of add-on type technologies. Introducing year dummies in model 3 reduces the levels of significance, what might indicate an over time development of the effect. The effect is particularly pronounced for projects related to hardware development. This is in line with the results of the bivariate analysis, which suggested only a significant relationship between hardware development and projects following a niche accumulation trajectory, which are conductive for the development of path breaking technologies.

Model 4, 5 and 6 document similar results for the project leadership effect of incumbent players. This might be partly related to the correlation between leadership and participation, which can be seen in the correlation matrix (Table 2). Introducing year dummies in model 6 intensifies the effect however, rather then decreasing it, as shown in model 3.

5 Discussion

The current paper is an attempt to study the impact, which the participation of incumbent players has on the character of R&DD projects in the wider energy grid field. Theoretical frameworks that aim at explaining how innovation happens in technological systems, refer to generic and artificial niches that serve as protected spaces, in which novel technologies can be nurtured, shielded from the selection environment of the mainstream markets. While passive or generic niches have to be found and optimally exploited, often the active creation ond management of niches is required. Publically financed research and demonstration projects are typical examples of such artificial

Table 3: Logit models

	(1)		(2)		(3)		(4)		(5)		(6)	
	NicheType		NicheType		NicheType		NicheType		NicheType		NicheType	
	β / SE	Mfx	β / SE	Mfx	β / SE	Mfx	β / SE	Mfx	β / SE	Mfx	β / SE	Mfx
ShareInc	-2.197**	-0.538**	-2.482**	-0.606**	-2.052*	-0.512*						
	(0.966)		(1.062)		(1.204)							
IncumbLead							-1.347*	-0.329*	-1.551**	-0.375**	-2.771**	-0.692**
							(0.712)		(0.771)		(1.183)	
BudgRel	0.061	0.015	0.055	0.013	-0.004	-0.001	0.081	0.020	0.077	0.019	-0.024	-0.006
	(0.087)		(0.092)		(0.127)		(0.082)		(0.088)		(0.124)	
Support	-0.002	-0.001	-0.003	-0.001	-0.015	-0.004	0.001	0.000	0.000	0.000	-0.018	-0.004
	(0.012)		(0.012)		(0.017)		(0.012)		(0.012)		(0.017)	
Tec_Comm	-1.524	-0.373	-1.109	-0.271	-0.923	-0.230	-1.278	-0.312	-0.867	-0.210	-0.582	-0.145
	(1.290)		(1.308)		(1.492)		(1.271)		(1.291)		(1.495)	
Tec_Hware	2.312***	0.566***	2.369***	0.579***	2.620***	0.654***	2.248***	0.549***	2.379***	0.575***	3.237***	0.808***
	(0.773)		(0.826)		(0.876)		(0.773)		(0.848)		(1.067)	
Application dummies	No		Yes		No		No		Yes		No	
Research programs	Yes		Yes		Yes		Yes		Yes		Yes	
Year dummies	No		No		Yes		No		No		Yes	
Observations	84		84		76		84		84		76	
Pseudo R^2	0.225		0.262		0.295		0.210		0.246		0.340	
LR chi^2	25.979		30.165		30.996		24.174		28.365		35.731	
Prob chi^2	0.001		0.001		0.009		0.002		0.003		0.002	
Baseline predicted probability	0.560		0.560		0.526		0.560		0.560		0.526	

Notes: Computing the variance inflation factor, $VIF(j) = 1/(1 - R(j)^2)$, where $R(j)$ is the multiple correlation coefficient between variable j and the other independent variables, indicated no collinearity problems. Not reported control variables: *Funding programs:* `DSF`, `EFP`, `EUDP`, `ForskEL`; *Starting years:* 1997-2013 and *Applications:* `Appl_Consm`, `Appl_Intgr`, `Appl_Mob`, `Appl_Storg`.

niches.

Two streams of literature were briefly presented, the innovation system approach, particularly TIS (Bergek et al., 2008a; Hekkert et al., 2007) and literature on socio technological transitions (Geels, 2004, 2005). Both outline the importance of niches but seem to have a different understanding of the incumbent players' role in this context. The technological innovation system is rather in favor of relating to established firms, since they are likely to be able to contribute with capital and competences, while signalizing legitimacy of a new technology. The pitfall here is that incumbents might employ defensive strategies to protect the current system. This idea is even more pronounced in the transition literature.

Participation patterns and leadership in Danish energy grid R&DD projects were examined to study the impact of incumbents' engagement on the characteristics of projects. The results suggest that higher shares of incumbent players in projects and to an even higher degree the leadership of projects by incumbents is linked to the development of technologies and applications that are compatible with the established system. One of the most salient features of large technological systems is that they are not that easy to change or even replace (Hughes, 1987; Unruh, 2000). These add-on technologies are therefore likely to make the current system more efficient and can take on a bridging function on the way to a new sustainable grid system. On the other hand one could also argue that they contribute to the legitimacy and stabilization of an unsustainable system. Traditionally theory has argued that new entrants pioneer innovative development, while established firms often ignore the novel products and technologies and are seriously threatened once innovations gain momentum (e.g. Christensen, 1997). This view was recently challenged by (Bergek et al., 2013), who find that incumbent firms master episodes of radical change by quick active absorption and adaptation of new technologies. Participation in R&DD projects might be therefore part of such a strategy.

Being static the conducted analysis does not provide insights into the development of niches and the roles or strategies of different players. An approach using evolutionary social network analysis might be a fruitful avenue for further research.

The results suggest also that R&DD projects are often not capable or not intended to provide shielding from technological path dependencies. To develop these, more attention might be put on the exploration of generic niches, such as rural areas in less developed countries, that have very week or non-existent energy grid systems.

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