Solving Infrastructural Concerns Through a Market Reorganization

A Case Study of a Danish Smart Grid Demonstration

Pallesen, Trine; Holm Jacobsen, Peter

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Solving infrastructural concerns through a market reorganization: A case study of a Danish smart grid demonstration

Trine Pallesen*, Peter Holm Jacobsen

Department of Organization, Copenhagen Business School, Kilen, Kilevej 14A, 4., 2000 Frederiksberg, Denmark

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ABSTRACT

Following the rapid growth of wind power in Denmark in the past 20 years, energy infrastructure has become increasingly politicized. Fluctuating renewables not only contest the dominant 'logic' of operating the system, namely 'supply-follows-demand', but it also introduces new actors like aggregators and reconfigures existing market actors. In this paper, we study a case, EcoGrid 2.0 on the Danish island Bornholm, as a case of a 'marketized' solution to the infrastructural concerns emerging from the large share of fluctuating wind power in the system. The market design involves transforming 'flexible consumption' into an exchangeable good, as well as a transformation of households into 'distributed energy resources', making it possible to capitalize on the existing infrastructure in new ways. We end the paper with a discussion of the implications for infrastructure; when households become balancing entities and a digital and smart infrastructure is made indispensable to the operation of the system, the infrastructure grows significantly in terms of scope and complexity eventually introducing yet new challenges.

1. Introduction

Against all odds, wind power in Denmark has developed into a massive success. The integration of wind power into the electricity system has grown from constituting 10% of total national electricity consumption in 2000, to 42,1% in 2015 [1]. This success can be traced back to the 1970s [2], where the oil crises exposed Denmark's critical dependence on oil producing states. For the first time energy became a political matter [3]. Partly as a consequence of the oil crises, wind power gained increasing interest as a means of suspending the dependence on foreign states [3], and in these early years, the role of wind power was intimately connected to concerns of security of energy supply. During the 1980s, the dominant political concern associated with energy shifted towards the environmental effects of energy production. Gradually, wind power became requalified as 'clean', 'renewable' and a solution to the environmental effects of industrialization. In the 1990s, this agenda was reinforced. Politically, wind power was increasingly backed, yet large parts of the industry remained critical: wind power was argued to be an expensive, intermittent energy that threatened the stable operation of the electricity infrastructure [3]. In sum, wind power which was initially framed as part of the solution to security of supply, experienced substantial development rates as part of an ambition to decarbonize energy production and ended up becoming a challenge to the stable operation of the system.

Today, almost 20 years later, the stable operation of an electricity system with high shares of fluctuating renewables has been practically achieved. Yet, the political ambition of further radical increases in wind power problematizes the future operation of the infrastructure. Smart grids and flexible consumption are seen as representing the "best socio-economic method for handling the future challenges inherent in using large volumes of wind power" [4] and a key element in becoming a carbon neutral nation by 2050 [5]. Such a transformation of the energy system, from the historical regime of supply-follows-demand to demand-follows-supply [6], through the idea of flexible consumption, in turn grants a new role to the consumer (e.g. [7]). As an example, consumers are imagined to adjust their consumption to the intermittent generation of wind power or other renewables. In fact, protagonists of smart grid technologies envision consumers as new and central constituents to the stable operation of the system—and thus the future security of energy supply [8].

In this paper, we study a large scale demonstration of flexible consumption, namely EcoGrid 2.0, as it seeks to produce flexible consumption by means of markets. Based on observations, interviews and document analysis of this Danish smart grid demonstration, we describe how the infrastructural challenge of security of supply in a wind power dominated system is pursued through a market design. Drawing on New Economic Sociology and Science and Technology Studies, we discuss and problematize the politics of this type of market solution to public

* Corresponding author.
E-mail addresses: tp.ioa@cbs.dk (T. Pallesen), phj.ioa@cbs.dk (P.H. Jacobsen).

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concerns [9] as a particular redistribution of roles and responsibilities vis-à-vis the electricity infrastructure. We end by a discussion of the implications for the boundaries of infrastructure; a new digital infrastructure is introduced and households are made active and controllable elements in the balancing of the system, which eventually challenges the distinction between (public) infrastructure and private homes.

2. The case of EcoGrid 2.0

The object of this study is EcoGrid 2.0, an ongoing large-scale smart grid demonstration on the Danish island Bornholm. The ambition of EcoGrid 2.0 is to demonstrate the possibility of realizing flexible power consumption through the design and implementation of a new market platform. The demonstration is publicly funded, and is constituted by nine partners, including two Danish universities, the local utility of Bornholm, software developers, and behavioral designers. The project involves app. 1000 households on the island, and provides each participating household with a smart meter and automated devices.[1] As part of the demonstration, two so-called aggregators control the households' heat pumps and electrical heating (within predefined temperature intervals or set points depending on the type of equipment). Aggregators can, through their control of the individual households' heat pumps and electric radiators, 'aggregate' flexibility across a larger subset of houses, allowing them to offer larger pools of flexibility in the so-called flexibility market (see Fig. 1[2]). Developing interoperability in the flexibility market is a crucial part of the demonstration in order to set the conditions for future competition between aggregators. In other words, consumers should be able to shift, by simple means, between competing aggregators.

As the *2.0* in the name indicates, EcoGrid 2.0 succeeds a previous project called EcoGrid EU. EcoGrid EU was an EU funded project, running from 2011 to 2015 and comprised largely the same participants at Bornholm as the current project. EcoGrid EU involved the design and development of a so-called real-time market, introducing variable electricity prices at five-minute intervals to retail consumers [10]. Consumers' responses to real-time price signals were partly manual, and partly automated. Based on the experiences of the first project, EcoGrid 2.0 does not include variable prices, but instead adds a new flexibility market and aggregators to the previous arrangement. A relatively new player in a Danish context, aggregators are to offer new products and services, making consumers willing to grant the aggregator external control of their heat pumps and electric radiators (e.g. see [11]). Aggregators are to compete for consumers, and these will be able to choose freely between aggregators and their services. 'Choice' and 'competition', in other words, are among the main novelties characterizing the current EcoGrid 2.0 setup.

Bornholm, which hosts the demonstration, is located in the easternmost part of Denmark. The island is considered particularly well-suited for demonstration projects like EcoGrid 2.0, amongst others because of the configuration of the electricity grid; the island is largely representative of the Danish grid, and has only one sea cable connecting the island to mainland Sweden. This implies that the local system can be, and sometimes is, operated in island mode [12]. Finally, the island has clear ambitions in terms of reducing the island's greenhouse gas emissions, "...Bornholm wants its future to be 100% green; a carbon-neutral community based on sustainable, renewable energy" ([13], p. 1). Since early 2017, electricity produced by the local utility is – under normal operation – based entirely on wind, sun and biomass.

[1] The equipment installed in the participants' homes are either Greenwave or Siemens.

[2] The abbreviations mentioned in the figure are TSO: Transmission System Operator, DSO: Distribution System Operator; BRP: Balance Responsible Parties; AGG: Aggregator.

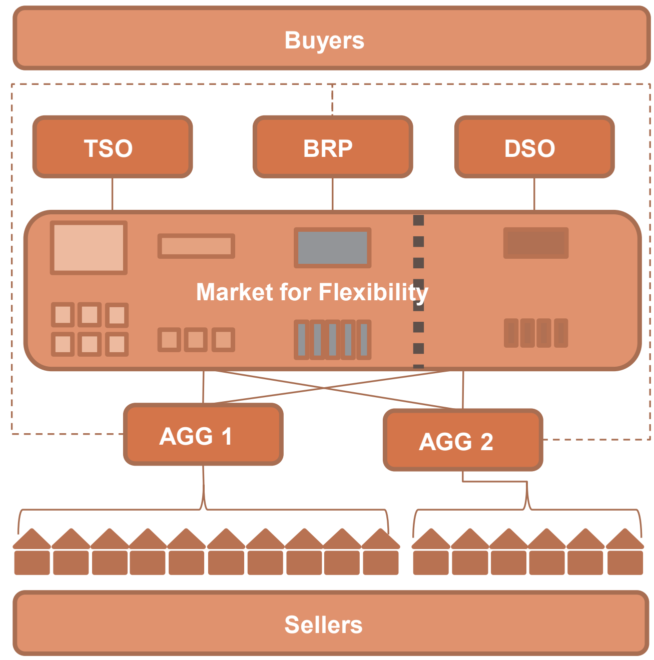

Fig. 1. EcoGrid 2.0 outline.
Source: EcoGrid 2.0 [52].

3. Market solutions, agencies and commodities

This paper is concerned with the design and deployment of marketized solutions to infrastructural challenges. Energy infrastructures are usually portrayed as co-evolving with institutions, organizations, technologies, raw materials, social norms etc. (e.g. [14–16]), something which is often used to explain their inertia against change [17,18]. In these studies, markets and economics have traditionally been viewed as co-constituents of infrastructure, but only rarely as the principal 'change agents'. More recently, however, a number of studies have pursued a particular interest in the role of economics in reorganizing energy infrastructures ([19–21]; see also [22]). Here, economics and market design are not just 'simple' tools for optimizing the existing infrastructure, but also shape infrastructures concretely, and society more broadly.

To study markets as solutions to complex societal challenges, such as climate change or security of supply, we draw on a more recent turn within the 'New Economic Sociology' [23]. This strand of research has studied the diverse array of agents and devices involved in making 'market encounters' possible, situations characterized by calculative agents and calculable goods [24–26]. Among the most important contributions made to the new economic sociology is the illustration of the elaborate organization of the sociomaterial infrastructure making calculations by agents possible, regarding the value of well-defined goods [27,28]. Where economics usually assume agents to be calculative a priori, and markets to somehow spontaneously emerge or pre-exist [29], social studies of markets have demonstrated how agents must be equipped to become calculative, and goods must be stabilized and framed in order to make exchange possible [24,26]. Economics as a discipline is itself portrayed as a central constituent in achieving such outcomes, however, not as a passive observer, but by performing the (abstract) models of their textbook [30,31]. The main claim advanced by these authors is that markets and calculative agents are outcomes – outcomes that should be made objects of analysis in their own right [32,23].

A number of case studies, notably of the energy sector, have described the entanglements of processes of politicization and economization in markets [33,34]. In parallel, scholars have started documenting how markets are also devised as policy instruments. Studies of diverse areas such as carbon trade [35,28], electronic waste [36], social housing [37], health insurance [38], kidney exchange [39] and security of energy supply [19,40], provide descriptions of markets carefully designed and organized to solve distinct societal challenges by designing and introducing markets as policy instruments. Such markets share the fact that they are designed by technical experts to achieve political objectives. In other words, these markets are engineered [40] and may be seen as closely associated with the advent of the new economic discipline *market design*, with the most prominent exponent being Alvin Roth [41,42]. The study of markets devised to solve *collective concerns* [9] produces an important shift in attention: from studying the devices and technologies that make market exchange possible, to studying markets as devices or technologies designed to achieve specific outcomes. In other words, from this perspective, the market itself becomes a policy instrument [43] designed to solve a societal problem.

In this paper, we study both the market *as* device and the devices *of* the market: on the one hand, we describe how EcoGrid 2.0 is designed and deployed as a means for solving infrastructural challenges in the future. And as such, EcoGrid 2.0 can be viewed as an example of a market for collective concern. However, in order to elucidate how such a market is achieved, we describe and discuss the particular ways in which commodities and agencies are designed and organized to accomplish a solution to the concern at hand.

The introduction of markets as solutions to social problems may be seen as a distinct neoliberal characteristic, as claimed by some authors;

> "The market (suitably reengineered and promoted) can always provide solutions to problems seemingly caused by the market in the first place… Any problem [to the neoliberal], economic or otherwise, has a market solution, given sufficient ingenuity" ([44], p. 64–65)

We do not deny this more obvious political legacy (e.g. see [81; 82]). Yet, what we want to pursue in the this study is slightly different: with market design, markets can no longer be claimed to be like the *spontaneous order* proposed by Hayek, but instead resemble the *made order* used to characterize organizations [45]. Accordingly, we may use the design of this 'made order' as an occasion for addressing the micro politics involved in developing a market for a collective concern, and thus to move beyond the broader (macro political) neoliberal characterization. In other words, we are interested in the specific ways in which EcoGrid 2.0 is practically organized to solve a concrete challenge.

4. Data collection

This paper draws on qualitative data from interviews and observations across multiple sites [46] to explore the case of EcoGrid 2.0. The data can be split into two somewhat broad categories: data concerning the design of the market reorganization, and data concerning the deployment and operation of the market. The sites for these two types of work differ substantially; the design of the reorganized markets is largely performed by the technical expertise of the involved partners in Copenhagen, Zurich, Lyngby, Svendborg, Horsens and Risø. The deployment, on the other hand, to a large extent takes place on Bornholm, involving consumers, technicians and support staff from the local utility.

The design of the new market platform as well as the test and demonstration of making consumers willing to provide flexibility is largely a process taking place in the cross-disciplinary work packages amongst the project partners. Data concerning the work of designing the market, developing the so-called interoperability layers, the services and tools of aggregators etc. take the form of observations from meetings, minutes from meetings and workshops. Amongst these meetings are steering group meetings, work package leader meetings, weekly meetings in the individual work packages, workshops across work packages, observations of tests and their subsequent evaluations. All in all we have more than 250 h of observations of engineers, behavioral designers, ICT experts and their work of defining services. Also, reports produced regarding the specific design of the flexibility market as well as the tests are part of our empirical material. In particular, a 100-page internal report documenting the design of the flexibility market is a central source of data in our description of the distinct market design. The report is produced as part of the second work package, and defines bidding and activation procedures as they are expected to take place in the market design tested. Also, we draw on documents such as templates produced by the aggregators, reports written by the respective partners, and minutes in general. Together, these data allow us to describe the design, as well as the potential controversies regarding the scope of the demonstration.

A large part of our fieldwork has taken place on the island of Bornholm, following the local electricians as they visited consumers to install and repair the smart technologies in the households – or simply get the home 'back online'. We observed electricians performing their tasks, and interviewed consumers about their use of the equipment. We conducted more than 30 interviews with consumers, and 80+ hours of observations of electricians repairing, instructing and training consumers in the use of their equipment. Interviews were semi-structured and primarily focused on consumers' use of their equipment, their consumption practices and their perspectives on flexible consumption. This part of the fieldwork allowed an appreciation of the practical achievement of the smart system, as well as its challenges. Many consumers taking part in EcoGrid 2.0 may not have the skills – or simply a computer to setup the system – and thus become more challenging parts in the smart grid setup. Many have no real interest in the content of the demonstration, and therefore hardly know what they are expected to do. Others react strongly to the external control when it fails to respect their comfort levels. These many practical challenges emerging as a consequence of the current system are thus also part of our fieldwork.

Our data are concerned with the design and reorganization of the market as a sociomaterial infrastructure, and our first visits to the field involved carefully describing this arrangement. The data analysed in this paper was collected in the first half of the demonstration project. Therefore, certain issues such as the definition and development of services to retail consumers were still being debated. The fact that we cannot describe the full scope of the demonstration, however, does not affect the ambitions of the present study, namely to study a case of designing a market solution to an infrastructural problem. In fact, the different sites of our data collection together allow us to describe and analyse the overall design of a market reorganization as a specific solution to the most salient contemporary infrastructural challenges. Just as importantly, following the ongoing debates and controversies unfolding in the demonstration, we are able to use EcoGrid 2.0 as an entry point to study the politics of both the existing system, as well as the new trajectories suggested with the demonstration.

5. Wind power as an infrastructural challenge

Liberalization of the Danish electricity sector, initiated in 1999, fundamentally changed the operation of the electricity system. Most prominently, it involved a change from planning electricity generation from thermal power plants based on prognosis of consumption, to balancing production and consumption through a series of auctions and pricing arrangements in the Nordic wholesale electricity market [47]. Alongside liberalization, the Danish electricity sector has also experienced a substantial increase in the proportion of wind power in the electricity system, now exceeding 40% of total national electricity consumption [1]. Replacing thermal power with wind power has been a central feature of the decarbonization of the Danish electricity sector; however, wind power, in contrast to various forms of fossil fuel-based thermal power plants, cannot be made to generate electricity at will.

Therefore, this rising percentage of fluctuating electricity generation has led to concerns of both power shortages and critical excess electricity [48]. As a consequence, the decision to decarbonize the electricity sector has produced a new challenge altogether, namely to manage the electricity infrastructure:

> "In recent years the debate on security of supply has shifted focus from undergrounding of overhead power lines to ensuring a reliable electricity supply in a green transition" ([49], p. 3).

The ambition is to further increase wind power's share to 50% by 2030 and 100% renewables by 2050 [50]. The steady increase of wind power in the system leaves less room for thermal generation, and at the same time, a substantial share of the thermal power plants are approaching the end of their technical lifespan and face shutdown [48]. This leaves system managers and governing bodies in a moment where the conditions for the security of electricity supply for the future have to be defined. Analytically, such moments of 'imagined futures' [51] lent themselves to inquiries of the politics at stake: they are openings to the controversies and negotiations regarding the organization of the energy system of the future. We see EcoGrid 2.0 as the attempt to demonstrate a possible future solution to the challenges produced by the decarbonisation strategy pursued over the past decades.

The analysis proceeds as follows: we start by briefly illustrating how EcoGrid 2.0 suggests to solve a collective concern through the introduction of a new market. From this description, we point out the three central components of the solution: the making of a new commodity, a platform in which it can be priced and valued, and the reconfiguration of actors taking part in the market.

5.1. Market design as solution

EcoGrid 2.0 suggests solving infrastructural challenges produced from the increases in wind power through the design of a market for flexibility [52]. The design of the flexibility market is undertaken by technical scientists and industry experts, of which several were also involved in the design of the real-time market of the previous EcoGrid demonstration.[3] They are, so to speak, experienced market designers. The fact that electricity system experts have become market designers can no doubt be seen, at least partly, as an effect of liberalization; new initiatives and solutions must be compliant with a liberalized electricity system. Accordingly, the governance of so-called 'public goods' in the energy sector, e.g. security of supply, the climate and infrastructure [53], are partly organized through the market – a responsibility which has traditionally resided within state agencies. This does not suggest that market actors and market calculations have not been an integrated part of operating the energy infrastructures from its earliest days [15,20]. But since the liberalization of the Danish electricity sector, the balancing of the electricity system has increasingly taken on a market form [47]. For example, as adjacent markets to the spot market, the intraday market and the regulating power market allow for upwards and downwards regulating power to be exchanged as the moment of dispatch is approaching. The flexibility market introduced with EcoGrid 2.0 should be seen as a supplement to these markets – eventually to be merged with the existing markets, as it is stated in the description of the market (internal report, 2016).

One of the most salient features of the market reorganization suggested with EcoGrid 2.0 is the specific way in which it builds a chain of problems and solutions; climate change—wind power—intermittent generation—security of supply—flexible consumption—marketization. The distinct solution involves a new mode of 'capitalization' [54] of the existing infrastructure: EcoGrid 2.0, as many other smart grids, represents a 'smart' alternative to traditional investments in 'more' infrastructure in terms of cables and transformer stations. As stressed by EcoGrid's project manager, smart grids such as EcoGrid 2.0 "are not the only solution to the current challenges, but a *smarter* solution than drawing new and costly cables" (meeting, 2016). According to calculations by the Danish Transmission System Operators (TSO), Energinet.dk, benefits for more than 6 billion DKK are expected to be derived from smart grid solutions, compared to traditional infrastructure reinforcements [55]. Included in these benefits are new types of balancing services as well as new services for consumers.

As an example of a market designed and deployed to deal with broad public concerns, EcoGrid 2.0 is not unique. The most prominent example preceding EcoGrid 2.0 is the carbon emissions markets [56,35,28]. The design of carbon markets draw on the ideas of Ronald Coase, University of Chicago economist and father of pollution trading [57]. Their purpose is to reduce climate change. One of the main achievements of carbon markets is the transformation of emission allowances into a valuable commodity [28], and the creation of the conditions through which companies can exchange these commodities. As such, carbon markets and EcoGrid 2.0 have in common that they are designed by experts to address societal problems. And both market solutions approach this task by framing a new commodity. Furthermore, such market designs, be it carbon markets or the flexibility market of EcoGrid 2.0, not only involve the creation of new commodities, but just as importantly, they (re)define roles and responsibilities of various market actors. They designate a desired state of affairs, and define the strategy for its achievement.

In sum, the design of EcoGrid 2.0 entails framing commodities, agencies, and the conditions of exchange [25]. In other words, the market solution consists of a meticulous design involving 1) a delineation of the entity to be exchanged, 2) the creation of a platform in which it can be priced and valued, and 3) the equipment of actors taking part in the market. In both carbon markets and the flexibility market studied here, the designs are expected to bring about changes in behavior allowing specific non-market ambitions such as reducing climate change to be achieved. In the case of EcoGrid 2.0, these changes target the retail consumer who is ultimately to adapt consumption to the fluctuations in electricity generation. It is towards the definition of commodities and agents that we now turn.

5.2. Commoditization of flexibility and its exchange

One central task of system operators faced with increasing proportions of wind power is to balance supply and demand whilst production gets increasingly uncontrollable and unpredictable. The solution suggested with EcoGrid 2.0 entails, as already described, adjusting consumption to production. Doing so involves the introduction of a new market for the exchange of flexibility in order to make the 'commercialization of flexibility' possible (internal report, 2016). The actual design of the flexibility market is one of the early milestones achieved in EcoGrid 2.0 [52]. The market provides a platform on which consumer flexibility can be exchanged and thus be made valuable. So far, flexibility derived from so-called distributed energy resources, such as small heat pumps, has not been exchangeable, and therefore has not been valuable for market actors [52]. According to the design, the value of flexibility is determined as the outcome of the bids made by Balance Responsible Parties (BRP) and aggregators [52]. Whereas BRPs usually trade in both Elspot (day-ahead market), Elbas (intra-day market) and the regulating power market, the flexibility market adds yet another platform from which BRPs may ensure their balancing requirements. To briefly summarize the trading procedure in the flexibility market, the procedure begins by TSO and BRPs placing request for services. Aggregators then place bids [52] followed by market clearance, leaving the aggregator with the cheapest bid to deliver the upwards or downwards regulating service. It is thus the demand for services and the aggregators' bids that will allow a price for flexibility to be settled, and consumer flexibility to emerge as a valuable commodity.

[3] For a detailed description of the real-time market designed in EcoGrid EU see Jenle and Pallesen [40].

Whereas the traditional supply chain in the electricity industry runs from large power plants to consumers, the introduction of flexible consumption seems to reverse this supply chain; flexibility is produced in the homes of consumers, it is pooled by aggregators and eventually it is exchanged in the newly designed market. Despite the intangible nature of flexibility, its production requires "the implementation of specific socio-technical arrangements" ([58], p. 7). In EcoGrid 2.0, this socio-technical arrangement entails the external control by aggregators of the consumers' heat pumps and electric radiators. The automation of the households' heat pumps and electric radiators are made possible through smart devices installed in the households that can then be controlled, i.e. turned on and off, by aggregators. Consumers are instructed to define comfort levels in their home, and aggregators may then control consumers' heating in respect of predefined levels (such as an interval, e.g. 18–22°). This reversal of the supply chain can be illustrated by one of the aggregators' product definitions, in which an algorithm is described as tying together household flexibility and the market:

> "The intention is that the control algorithm for a single household always respects the comfort of the participant…. The energetic flexibility of the households will be calculated from the 5-minute smart meter data and the outdoor temperature…. This energetic flexibility model is then used in the aggregator to calculate an optimal bid strategy for the aggregator bids into the market and for optimal control of the households to fulfil the accepted bids and ensure participants comfort" (Template for aggregator A's product description, internal document, 2017).

Providing the market as well as the institutional setup for this valuation process to emerge – under the pressure of competing aggregators – is in itself expected to deliver a large part of the desired solution. Making consumer flexibility valuable is expected to create incentives for new and existing actors to develop innovative services to consumers, granting the aggregators access to control appliances of retail consumers. In other words, by simply providing the market and the system for control, market forces are expected to do the rest. But for flexibility to become exchangeable it must be 'disentangled' [59] from the household from which it is realized. In other words, it must be 'subtracted' from the everyday life of consumers as they pursue their daily routines. Here, the aggregator is envisioned to play the role of the crucial orchestrator. Aggregators are not only to control heat pumps and electric radiators to eventually pool them into aggregated bids in the market, but just as importantly, to do so they must convince consumers to grant them control of their homes.

5.3. Reconfiguring economic agencies

The reorganization introduced with EcoGrid 2.0 involves reconfiguring a number of actors. In the present study, we will focus on two groups of actors, namely aggregators and retail consumers. As already mentioned, aggregators are a novelty in a Danish context[4]; their role and the range of services they are to provide remain somewhat open. The aggregators are to provide services to retail consumers that will allow them to get external control of heat pumps or electrical heating. The aggregator pools the flexibility from households and exchanges the flexibility as service in the flexibility market. Currently, the two aggregators in EcoGrid 2.0 test different strategies for engaging with consumers: one strategy seeks to 'bypass' the consumer in what is referred to as 'hands-of' strategy, whereas the second aggregator tests a strategy where consumers are informed, warned of changes in weather, and sometimes advised through text messages, e.g. messages saying: "You may experience a temperature drop. Consider putting on a sweater" (suggestion made by behavioral designers, 2017).

Since liberalization of the Danish electricity market in 2003, consumers can freely choose their supplier. However, the mobility of Danish consumers remain low compared to other European countries [60]. Historically, consumers have in fact been pictured as passive entities in the electricity system [7,61]. Recently, however, the gradual realization that consumers and their behavior may somehow be crucial to the future of the energy system has emerged (e.g. [62]). The advent of smart grid technologies places the consumer in a central position vis-à-vis the constant balancing of the system, in contrast to the consumer position of the past [63]. This creates a challenging position for the designers of the new system: on the one hand, consumers are perceived as the 'black-box' of the electricity system, as it was polemically put by a system designer during our fieldwork, because historically, consumer practices have been of little importance to system operators and the industry in general. On the other hand, the transition towards smart electricity systems appears to require a somewhat controllable and predictable consumer, suggesting that the black-box has to be opened and integrated into the wider system operation. Meanwhile, for a number of reasons, the active and responsive consumer often portrayed by proponents of smart grids is increasingly perceived as a fiction [7].

The different roles attributed to consumers in EcoGrid EU and EcoGrid 2.0 respectively are illustrative hereof. Whereas the first EcoGrid project involved testing manual response to variable prices [63], EcoGrid 2.0 is limited to include automated response from heat pumps and electric radiators, and "have the consumer interact as little as possible with the smart grid interface", as insisted by one of the aggregators. This choice is partly motivated by the experiences from the first project, most notable the limited effect in terms of flexibility derived from the manual response group. The 'ideal' consumer of EcoGrid 2.0 is one who delegates control to an aggregator, who can then turn off the household's heat pump, for example, during times of grid congestions. In many ways, the user is practically treated as 'demand specification of the technological solution' [64] a sort of sociotechnical residue of the past [80]. To get EcoGrid 2.0 consumers interested, they are provided with a web portal displaying different sources of data. The web-portal is designed by behavioral designers with the intent of "nudging consumers towards the right choice… or make the right choice look more attractive", (behavioral designer, meeting 2017).

First and foremost, the consumer can access consumption data. Smart grid proponents often stress smart technology as a means for informing the consumer, creating awareness of consumption and changes in behavior [66].[5] The web portal is also the platform on which consumers are to set temperatures for their homes, either as temperature intervals or predefined settings such as comfort, pre-comfort or economy. This is usually done within a number of zones of the household, e.g. living room, bed rooms, kitchen etc. These zones have been defined by technicians during installation of the hardware. Also, the web portal allows consumers to communicate if they are away for a period, and thus allowing aggregators increased external control for the distinct period. In addition, the web portal grants aggregators the possibility to give consumers feedback regarding their flexibility, either in the form of smileys or by ranking the individual consumer against other consumers from the island.

Multiple studies have documented that the transition from a consumer acting as 'load' in the system, simply operating the household in accordance with daily practices, weather and house conditions, to an active component in the balancing of the system, is not straightforward [67–71]. The way demand response is envisioned in EcoGrid 2.0, i.e. through automation, the somewhat challenging task of enrolling the consumer is faced by the two aggregators. These must offer services or products that persuade consumers to grant aggregators control over

[4] The aggregator of the pilot study analysed by Hansen and Hauge [11] is identical to one of the two aggregators of the EcoGrid 2.0 demonstration.

[5] To our knowledge, no studies have documented at least long term effects of such visualizations of electricity consumption [65,66].

their heat pumps and electric radiators. Defining such products has been a considerable challenge; in the first instance, even picturing what a product *could* be has been difficult:

> "When the idea of products was introduced, there was a lot of confusion! What is a product really? Is a graph over household consumption a product?" (Software developer during workshop).

Whereas some scholars foresee possible new services as a sort of 'funwashing'; i.e. bundling 'boring' management products with more attractive properties [72], the results from EcoGrid 2.0 currently point to more 'conventional' product definitions such as 'economic' and 'green/environmental'. Interestingly, it has so far been difficult for aggregators to distinguish between system needs, i.e. flexibility, and consumer needs, usually related to their everyday life. To illustrate, early product suggestions were defined as e.g. 'Flex plus services', with the expectation that consumers would both understand the need for flexibility and their role in providing this. During the process of working with product definitions, the real concern became the question of what to offer consumers: "It is something else we'll have to offer them to get the flexibility. This is the real challenge in this", (aggregator, workshop 2017). In turn, consumers generally have difficulties understanding the new role associated with the aggregator and tend to see these as a form of "electricity broker making money off my energy consumption", as suggested by one consumer during a meeting organized by the local utility at Bornholm in order to involve consumers in product development.

6. Discussion: a reorganized infrastructure

Smart grids, such as EcoGrid 2.0, are framed as possible solutions to infrastructural challenges involving both volatility and capacity [70]. Overall smart grid designers suggest that better use can be made of the *existing* infrastructure, e.g. by making consumption adjustable to fluctuating production, and to replace the traditional approach involving costly investments in more cables, transformer stations and additional production capacity. In other words, proponents argue that smart grids are, in terms of socio-economics, an optimal solution to future challenges—and thus, it is presupposed, to the benefit of us all [4]. Thus far, however, attempts to make consumers recognize their stakes in this challenge have not been very successful. And partly because of the failed attempts to interest consumers, some industry experts are less convinced of the promises of smart grids and instead favour e.g. integration across heat-, transport- and electricity systems [73]. In the following, we discuss the effects of marketizing flexible consumption and how it radically alters the infrastructure in at least two important ways; first by including private households to the infrastructure, and second by adding a 'digital infrastructure' at the very centre of operating the new market.

Energy infrastructure allows generation and demand to be joined almost instantaneously. It includes transmission and distribution systems, as well as the careful management and operation of these. Accordingly, a conventional understanding of the electricity infrastructure stops at the consumer's meter. And equally so does the responsibility for its management and operation; what happens 'after' the meter, i.e. in private homes, is largely seen as the consumer's responsibility. Many smart grids like EcoGrid 2.0 seem to radically change this: consumption, and thus what happens after the meter, becomes a central component in the overall balancing of the system. Heat pumps and electric radiators become "distributed energy resources" at the disposal of the system, as defined by the technical experts of the project. Seen this way, the nature of the infrastructure is dramatically extended. This extension does not take the form of new cables or transformer stations, but instead it extends infrastructure with the automated households which are enrolled in the balancing of the system.

A few participants in EcoGrid 2.0 understand and accept this to be the premise of the smart grid. To 'put your home at the disposal of the system', is one description met among some consumers. As one EcoGrid 2.0 consumer put it:

> "Running the washing machine at night that is *not* for me [referring to the real-time prices of EcoGrid EU]… Time is too short for that. Instead, my approach is that I can make a resource available [to the system] in the form of my house that fulfils some criteria in the heat pump area…" (EcoGrid 2.0 participant, 2016).

Private homes are no longer simply entities of load, but instead active resources that can be activated at the request of aggregators and system operators. However, the majority of the participants are less willing—and sometimes able—to understand and accept the suggested setup, which challenges the extent to which aggregators can actually control the households.

Whereas protagonists of smart grid solutions often highlight the empowerment of consumers as a possible benefit [67,74,70], one concern emerging from the EcoGrid 2.0 project is the challenge of ensuring predictability and controllability of consumer flexibility. Aggregators winning bids in the flexibility market must live up to their obligations, or risk to be penalized. Accordingly, they need consumers to comply. However, numerous smart grid experiments and demonstrations have repeatedly demonstrated the difficulties in making consumers change behavioural patterns (e.g. [7,71,75]). The debates amongst aggregators and market designers in this study appear to be more concerned with the 'disempowerment' of consumers, than their empowerment. Rather than stressing consumers' learning and understanding of consumption practices or supporting their transition towards 'prosumers', EcoGrid 2.0 is concerned with producing controllable and predictable consumers who accept the aggregators' control of their heat pumps and electric radiators.

Moreover, the infrastructure of EcoGrid 2.0 also involves a second important extension. To be able to control heat pumps and radiators of private households, aggregators need a digital infrastructure built around the households' smart meters. Accessing and managing data are crucial to the aggregators operations and to the transformation of flexibility into an exchangeable commodity. But this 'new' infrastructure itself requires substantial amounts of 'invisible work' [76]. Interoperability between aggregators, households and flexibility market is judged one of the most important elements of the demonstration, but the everyday maintenance of the digital infrastructure is no less tedious. Maintenance is partly delegated to technicians of the local utility who keep the households 'online' for aggregators to communicate with the smart meters, and this involves daily home visits to households that register as 'offline'. At times, more than 30% of the consumers would be offline and thus not available for activation by aggregators. The work of maintaining the infrastructure makes mundane tasks such as changing batteries (e.g. of smart devices) a major concern for project partners (meeting memos). As such, EcoGrid 2.0 not only suggests we see the infrastructure as enlarged by households and their appliances, but also by adding a new layer of digital infrastructure indispensable for the operation of the market. This suggests that we must study the governance of ecologies of energy infrastructure [77], which will radically increase the complexity of future infrastructural transitions.

What seems remarkable with the infrastructural management introduced with EcoGrid 2.0 is the 'faith' in choice and competition. As mentioned, choice and competition are no doubt an exigence born out of the liberalized electricity market in Denmark, but they come to play a central role in the constitution of a consumer who is both controllable *and* predictable. The designers ultimately delegate the development of the mechanisms for 'attaching' this consumer to 'the market'. Following from transformation of end consumer flexibility into a valuable entity together with the establishment of a market place in which it may be exchanged, system designers appear to assume that new types of services are likely to emerge and allow consumers to maximize their utility all the while contributing to the balance of the grid.

7. Conclusion and implications

Current infrastructure management faces important challenges. Particular to the Danish context is the importance of managing the increasing share of fluctuating renewables. As these challenges are debated and transformed into concrete solutions by experts and policy makers, both infrastructural politics of the past and the future become accessible for scrutiny. The introduction of EcoGrid 2.0 as an example of a marketized solution to a collective concern could simply be understood as part of a bigger neoliberal movement. This would, however, miss an important occasion for studying the politics of the very details of this type of governance through markets. System operators and energy experts alike operate within a liberalized electricity system and any solution needs to fit a liberalized system. The solution put forward with the EcoGrid demonstration is a carefully designed market, organized to realize and harvest consumer flexibility and to make demand response an active component in the balancing of a system increasingly dominated by wind power. The design also entails a transformation of consumer flexibility into a valuable and exchangeable commodity. Finally, the introduction of the flexibility market carves out the new roles of aggregators and reconfigured electricity consumers. Together with choice and competition, making consumer flexibility an exchangeable and valuable good is expected to drive the development of new innovative services, and thus grant aggregators' access to the flexibility reserves sourced from consumers' everyday lives.

Whereas smart grid solutions seem to suggest to make 'smarter' use of the existing infrastructure involving new forms of capitalization, the enrolment of household appliances as distributed energy resources transforms the infrastructure. Not by adding cables, but instead by adding private households. As such, the transformed electricity infrastructure is one which invites retail consumers into the machinery of running the system. Similarly, the digital infrastructure developed, notably in the form of an interoperability layer allowing aggregators to control and exchange flexibility, implies a new infrastructure. This adds both complexity and uncertainty to the operation of the electricity system of the future. These two extensions or transformations of the infrastructure may eliminate the need for radical reinvestments in infrastructure in a more traditional sense, i.e. cables and transformer stations, but are likely to infer other types and sources for reinvestments, such as investments in house-specific appliances and their maintenance, data security etc.

We wish to point out two early implications of initiatives such as EcoGrid 2.0. The first has to do with models of the consumer, the second with the suggested remaking of boundaries between public and private responsibilities. First, the new role of the consumer, now turned an active component for the management of the system, may require new and more sophisticated models of the consumer and consumption practices, something which has not historically been well-developed amongst energy system experts in Denmark. As an example, consider the first lines of an abstract in a recent article by some of the designers of the EcoGrid EU demonstration:

> "Understanding electricity consumers participating in new demand response schemes is important for investment decisions and the design and operation of electricity markets. Important metrics include peak response, time to peak response, energy delivered, ramping, and how the response changes with respect to external conditions" ([10], p. 75)

To many experts of the electricity system, the consumer is translated into—or even reduced to—metrics such as 'peak response' or 'ramping'. This 'simplification' of consumption practices and households may constitute part of the explanation for the difficulties of creating manageable subjects that can eventually become the reliable components in the system. Whereas anthropologists and sociologists are increasingly invited to take part in research projects, contributing with ethnographic accounts of the electricity consumers, the situated and detailed accounts of consumer practices that are often produced in these studies are doubtlessly adding to the understanding of consumption, but they are unlikely in themselves to be a good replacement of the engineers' simplifications. In fact, the detailed empirical descriptions of consumer practices produced in EcoGrid 2.0. were often read by aggregators as discouraging and pushing them towards design solutions circumventing the consumer to the largest possible degree. As long as 'consumer-centric' strategies are pursued, we see a need for new models and understandings of the consumer to inform the making of demand response systems.

The second implication relates to the costs of the 'smart' infrastructure. Whereas the smart grid advocates to make better use of the existing infrastructure, we have pointed out that the involvement of private households instead transforms the infrastructure. This extension is not without costs. Smart meters and devices that allow the external control of heat pumps and electric radiators have to be installed and maintained. Just as importantly, the further development and maintenance of the digital infrastructure that allows surveillance and control of households are costly. The households of EcoGrid 2.0 were equipped through the previous demonstration project, but only a few years later, the equipment was considered outdated by many consumers and experts. The question of who is to undertake the (re)investments in smart devices and digitalization remains unresolved. And finally, making a digital infrastructure indispensable to the operation of the system creates new possible challenges to the security of supply as well as data security.

To end, a brief reflection on the role of EcoGrid 2.0 beyond providing market-solutions to infrastructure problems is warranted. EcoGrid 2.0 is a demonstration project; yet what it demonstrates – and to whom – differs across the project's multiple stakeholders. As this article has illustrated, EcoGrid 2.0 provides the project partners with a 'playing field' in which they may design, develop and test a practical solution to a societal problem, each demonstrating their distinct competences. The purpose of the funding provider, administered by the Danish Energy Agency, is to support the achievement of the defined energy policy objectives, as well as to increase employment, sales and exports [78]. Accordingly, funding EcoGrid 2.0 is one among numerous—sometimes competing—initiatives that support the ambitions characterizing Denmark's official green brand, 'State of Green'. State of Green promotes an array of green solutions and works towards the ambition of becoming the world's first green state, i.e. being fossil free by 2050 [79]. Having successfully developed and integrated large shares of wind power in the Danish electricity system over the past decades, attention has now shifted to providing solutions for handling even further increases as well as operating the system efficiently.

Thus far, the Danish electricity system has, in its own right, acted as a large scale demonstration of the possible realization of radical wind penetration in a 'conventional' energy system. To reinforce this position, experiments and demonstrations of solutions to infrastructural challenges are currently taking place across the country. Here EcoGrid 2.0 represents one type of solution. However, to the island hosting the demonstration, demonstrating the island's suitability for conducting large scale tests of green technologies is just as important. Under the brand, 'Bright Green Test Island', the island offers a living laboratory in which new and green energy technologies may be tested and demonstrated in a 'real-world' setting. Whereas this may reinforce the national green brand, it is also a local initiative devised to counteract depopulation and local economic decline. Along a similar vein, a large share of the users participating in the demonstration have little knowledge, let alone interest, in the ambitions being tested. Instead, they support the local utility in their quest to attract high-profile research and demonstration projects to the island. As such, EcoGrid 2.0 is a frame in which multiple interests are being pursued, many of which are not directly related to the very concrete solution developed and tested—rather, it provides a middle ground from which such different interests can coexist.

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