Keeping Systems at Work:
Electricity Infrastructure from Control Rooms to Household Practices

Antti Silvast and Mikko J Virtanen

This article discusses the reliability of electricity supply and the management of its uncertainties from a systems theoretical point of view. We begin by outlining recent Science and Technology Studies (STS) literature about energy systems, infrastructures and practices concerning their use and argue that many current discussions hold promise in two directions: one concerns the brittleness and uncertainty of the electricity system that is seen as an ongoing achievement, the other is about broader structuring factors and contexts that should also be acknowledged when researching such systems. With an aim of developing this two-part focus, the paper advances systems theoretical considerations about the electricity infrastructure and proposes an analysis tool to study the necessary reductions of complexity of the infrastructure in two emblematic settings. The sites are infrastructure control rooms on the one hand and households on the other hand. The article concludes by discussing the different reductions of complexity by electricity users and electricity experts through using the theoretical point of view presented in the article.

Keywords: actor-network-theory, ethnography, systems theory

Introduction

Systems are a classical concern of STS research on energy issues, starting from the historian Thomas P. Hughes's (1983; 1989) work on electrification and the invention and expansion of *large technological systems*. A *system*, according to Hughes (1983: 5), "is constituted of related parts or components [...] connected by a network or structure". Parts and components in an electricity system include physical artifacts like lines and transformers as well as organizations, scientific works, legislation and natural resources (Hughes, 1989: 51). While some are "social" and some "technical", the key to their inclusion in the system is control: when the parts are "under control" (often centralized), they belong to the system, when they are not they are merely in its *environment* (Hughes, 1989: 66). According to previous research on organizations that manage these systems, large technical systems are marked by institutional inertia and resistance to change especially when it is unanticipated (see e.g. Silvast et al., 2013: 5; Fuchs, 2014).

Recent scholarship has expanded these considerations about relatively closed systems in several ways, as summarized in a review essay by researcher Erik van der Vleuten (2004, 401-406). As he notes, scholars have drawn more attention to how large systems are attached with cultural symbolic meanings, to societies becoming increasingly dependent on such systems, to the growing complexity of the systems and the issuing systemic risks and vulnerabilities, to interrelations between other processes like nation-state building and urbanization and large system growth and to "second-order" systems that are systems of several "first-order" large systems. While these discussions are heterogeneous, they seem to agree that large-scale electricity systems are not as closed from outside contexts as originally foreseen.

Starting from systems as relative closures and ending with how these systems figure and change in society, many current STS works about energy systems and infrastructures indeed seem to hold promise in two directions. The first is to stress that infrastructures like electricity are fragile, uncertain and practical achievements; the second concerns wider systemic, cultural, and societal contexts that are viewed as highly important though not always manifest in concrete situations and their practices. STS scholar Susan Leigh Star's (1999: 381) ideas on how infrastructure "both shapes and is shaped by the conventions of community of practice" offers an example of the first direction, as do recent openings about the complex ways in which household practices are intertwined with infrastructures like energy and water (Shove, 2003; 2010; Wilhite, 2008). Some commentators have framed the entire electricity network as a "brittle assemblage" (Bennett, 2005: 446) and a "precarious achievement" (Graham, 2009: 11). Lea Schick and Brit Ross Winthereik (2013: 84) summarize by describing emerging, "smarter" electricity infrastructures as "always rich and complicated entanglements of humans and technologies, discourse and materiality, nature and politics".

Others – inspired by actor-network-theory (see Callon, 1986) – expand such a premise to the functioning and risks of energy systems in general: the systems do not hold together by themselves as their breakdowns aptly demonstrate (Bennett, 2005; Graham, 2009). Current energy policy, too, leans on similar ideas in many occasions. The European Commission (2011: 2) vies for "smarter" electricity grids because they can "cost-efficiently integrate the behavior and actions of all users connected to it". Similarly, reports on major electric power failures have repeatedly stressed that human operator errors, failing coordination, and consumers' "wasteful energy practices" pose risks to the systems and their reliable functioning (OECD & IEA, 2005; 2011).

These observations on activities, actors, habits, and decisions as building blocks of systems are important. They also have resonance in political and societal arenas beyond particular failures and breakdowns: accordingly, the long-term sustainability of energy systems may be significantly improved by shifting the attitudes, behavior, and choices of energy producers and users (see Shove, 2010). However, different kind of actors, not necessarily as "flat" as the ones outlined above, might be as important for the discussions. Leigh Star (1999: 381) draws on this notion when she argues that infrastructures are embedded in "other structures, social arrangements, and technologies". Infrastructure researcher Paul N. Edwards (2003: 197), while acknowledging the "user heuristics" of infrastructures, has paid a great deal of attention to the part that political economies, governments, and enduring institutions play in shaping these technologies. A similar point is made by energy scholars Harold Wilhite and Elizabeth Shove, respectively: while interested in situated household practices of energy use, they position these practices along "changing socio-cultural contexts of everyday life" for Wilhite (2008: 125) and "clusters of practice" and "organizing principles and engrained habits" for Shove (2003: 408).

A summary of these arguments is relatively straightforward: both wider systemic issues and their practical manifestations are relevant and interesting for STS scholarship on energy systems. A broader way to say this is that the uncertainty of the systems holding together and more durable factors should not be seen as contradictory perspectives or as each other's alternatives. Motivated by these considerations, this article advances an interest in the structuring of those activities that constitute the continuous management and the use of infrastructures. We develop terminology and a set of operationalizations as an analysis tool to elaborate a conceptual vantage point on large infrastructures and demonstrate their use by presenting a study about electricity system management and use in Finland.

The research objective comprises two closely related ends. The first objective is theoretical-conceptual and develops a perspective on electricity infrastructures and their societal embeddedness from a systems theoretical point of view. In so doing, we aim at establishing a conceptual approach that enables us to explore both electricity experts and energy-using lay persons by means of the same theoretical framework. Our theoretical objective is consequently to conjoin these perspectives in our conceptual work: on the one hand, the possibility of observing infrastructures' system-likeness and their manifold connectedness to their environment and, on the other, the focus on concrete practices in which the infrastructures are continuously produced and maintained as well as consumed.

The second part of our research objective is based on an analysis of diverse empirical material. We start by inquiring into the ways in which electricity technicians manage the electricity infrastructure continuously and in real-time in special infrastructure control rooms. We then analyze the concrete effects and experiences of electricity reliability at the consumer level. The analysis uses the conceptual approach that was developed in the first part of the article. We pay particular attention to the necessary maneuvers, which we term as reductions of complexity, that actors make in their own contexts: electricity experts are responsible for a reliable critical electricity supply, while the end users experience a functioning electricity supply as an indispensable part of everyday life. The research question is: *what kinds of stableness emerge by studying an electricity infrastructure from the vantage point of its situated reductions of complexity?*

The structure of the remaining article is as follows. The next section outlines our theoretical-conceptual approach, and the subsequent section of the article contains the methodology and the materials. The analysis is in three different sections, divided to the empirical sites. The article concludes with a discussion section, where we tie together the conceptual and the empirical parts of the article.

Uncertain Infrastructures: Contours for a Systems-Theoretical Methodology

It is uncertain that assemblages such as modern infrastructures hold together and function appropriately. The ever-present uncertainty is due to their complexity. This underlying train of thought, which constitutes our vantage point to understand infrastructures, comes from the German sociologist Niklas Luhmann. Luhmann's (1993: 87) proposal for a generic definition of *technology* as "a functioning simplification in the medium of causality" bears implicitly the general idea of uncertainty. The uncertainty has to be actively tamed. In other words, the simplification has to be produced and continuously maintained: technology is a result of an active and successful process of *technicalization* (Luhmann, 1993: 87-88). This view goes close to the philosophical concept of a *machine* (e.g. Deacon, 2011: 90). A machine has been designed to attain a particular function, it has a specific design, and to reach this end in a predictable manner, its controlled closure must be actively maintained. The causal effects that are relevant to a technological system or a machine are therefore first identified as accurately as possible and are then made subject to control. Those effects that are not identified and those that are identified as problematic and non-controllable are in turn excluded and kept outside the system, if this is possible.

The perspective can be presented through the functioning of a simple electric engine. When an engine is working accurately and predictably, its input current and the functioning of its internal parts, like magnets, coil, and coal rods are subject to control, as is the internal temperature of the engine. However, managing even such a simple system requires a number of continuous and relatively complex duties, such as providing a standard level of electric current, excluding unwanted environmental factors like moisture and maintaining the parts of the engine. Considering the generic definition of technology above, one soon notes how a causal closure is only a relatively momentary achievement: in fact, all factors affecting the functioning of the system on different timescales can never be exclusively controlled. A degree of uncertainty is inherent in the functioning of all technologies.

Assemblages that are considerably more complex, large-scale, and societally interconnected, such as the electricity network, can likewise be considered as systems based on a relative closure. Bearing this in mind, we define the electricity network *as a causal (relative) closure, which is built on continuous management and permits the distribution of electricity in a controlled and predictable manner.* The adequate functioning of the network, the distribution of electricity, and the maintenance of its equipment, together with the system's manifold environmental effects, continuously shape the network and its parts. The potential, constant change creates conditions in which causal effects can slide beyond control and this in turn requires persistent management of the processes that may have an impact on the network's functioning. The network holds together because it is actively and unceasingly held together.

These are not new considerations within STS. For example, that the electricity network requires continuous performing to stay afloat is almost the same point that Bruno Latour has made about the focus of sociology: accordingly social scientists study "associations that have to be constantly reshuffled in order to gather once more a collective that is threatened by irrelevance" (Latour, 2005: 160). Inspired by Latour, political theorist Jane Bennett has explored the electricity network as a brittle "assemblage" of "actants" that "produce effects, or even initiate action" (Bennett, 2005: 446) – ranging from electron streams and economic theory to energy consumption lifestyles, legislation, and beyond. Furthermore, she stresses that the specific assemblage of the electricity network's actants that "will be actualized at any given moment is not predictable with confidence" (Bennett, 2005: 457). Urbanist Stephen Graham (2009: 11) endorses Bennett's view of electricity networks as uncertain assemblages: "Such a perspective underlines that any coherence that the electrical assemblage achieves as an infrastructure must never be assumed or taken as permanent and inviolable. [...] [T]he grid is always precarious achievement ready to untangle at a moment's notice through a myriad of possible causes."

It is clearly the case that such an *assemblage* (Bennett, 2005) or a *collectiv*e (Latour, 2005) can only become durable through constant effort and coordination among human and non-human. Though focused on history of large systems and their expansion more than their maintenance, Thomas Hughes's classical work on electrification offers similar examples. For instance, the builders of early electricity systems strove "to increase the size of the system under their control and reduce the size of the environment that is not" (Hughes, 1989: 66) and attained this by "absorbing" new equipment as well as organizations into the system whose boundaries were marked by control.

So far so good, the relative closure of an infrastructure, a collective or an assemblage has to be actively maintained. But are all the components of these compositions, encompassing everything from electrons to electricity market, to be investigated as mutually symmetrical as the *credo* of actor-network-theory (see Callon, 1986) goes? This is where our paths diverge slightly. Latour's (2002: 125) methodological emphasis on "flat concept of society" as a microscopic starting point is to be geared towards freeing empirical research from any aprioristic (and normative) presumptions of social structures, order, change, strata, and so forth (cf. Lash, 2009). We do not postulate any of these big classical categories as a priori starting points for our study at hand either. But we do our bests to tune up our observation to see also grades of stableness, durations, repetitiveness and thicknesses in our research topics and materials. We would thus like to add to Latour's (2005: 165-172) advice that instead of considering societal structures, contexts and dimensions "we have to try to keep the *social domain* completely *flat*" (Latour, 2005: 171), that *to start with the flatness doesn't have to end with one*. Some stableness and duration in ways of conduct, in techniques of using artifacts and even in the functioning of artifacts themselves might emerge. In other words, the ever-present complexity of societal occurring does become somehow tamed, and thus some structuredness is constantly created and also dissolved. How this actually happens in particular settings is, nevertheless, a matter of empirical study.

We aim at combining these general sociological ideas with our conceptualization of the electricity network as an uncertain infrastructure. Our conceptual framework describing these phenomena draws on Luhmannian systems theory, but in a rather unorthodox manner. We utilize a systems theory informed starting point to approach and conceptualize the various ways of structuration as *continuous reductions of complexity* (Luhmann, 1989: 12). In this regard, two clarifications of our interpretation of systems theory have to be made. Firstly, and in concord with Latour's view, neither systems nor institutions or structures are taken as pre-empirical a priori entities, nor are they thematized as static and binding. Furthermore, they are not grasped as extra-empirical entities deduced from Luhmann's conceptual apparatus either. Entity-centeredness is replaced by a relation-scheme: "A system [...] is the result of interactions of its parts, not the other way round" (Nassehi, 2005: 180). In other words, systems are not investigated as, and through, static pigeon-holes (*Setzkasten*) out there to which empirical phenomena more or less comprehensively fit. Instead, a topology of incessant connections and disconnections is put to use: systems are observed as constantly evolving "real-time machines" (*Echtzeitmaschinen*) to use a metaphor of one of Luhmann's successors (see Nassehi, 2003: 159-187).

Secondly, our notion of a system as constantly maintained reduction of complexity is not compatible with an idea of systems constituting on some a priori "levels". Rather, the infrastructure holds together only via constant mundane tasks in concrete settings where different logics merge: in control rooms and electricity stock exchanges as well as at the homes of end-users. Put methodologically, instead of focusing on the maintaining of only one structure, electricity network as an "infra-structure" in our case, we try to pinpoint local and subtle structurednesses created and maintained in constant practice, and manifoldly intertwined with keeping up the large-scale infrastructure, the electricity network. These concrete ways of complexity reduction, which are not necessarily empirically "flat" but possibly also embedded and contextually bounded, is the main target of our "systems theory informed qualitative social research" (Nassehi & Saake, 2002: 81).

Materials and Methodology

The rest of our article is based on multi-sited empirical work carried out among Finnish electricity consumers and experts.[1] On this point, we interpret the materials by building on the theoretical premises laid above. Starting with the observation that the electricity infrastructure both consists of and combines multiple actors, logics and components only some of which can ever be included by a *technicalization* at the same time, the analysis focuses on different, concrete ways of complexity reduction found in the materials. However, this general starting point has to be calibrated towards a more subtle methodological apparatus for observing localized practices. In this regard, and to get soundly on grips with different logics and the richness of ways and variations of complexity reductions, empirically merged in concrete practice, we fine-grain our conceptual approach. This is done by analytically dimensionalizing the idea of reduction of complexity. We utilize Luhmann's (1995: 75-81) original tripartition to factual, temporal, and social dimensions as a background and source of inspiration. As we are focusing on concrete empirical practice of real people and artifacts, observed mainly semi-ethnographically, instead of focusing on circulation of communication in different types of systems in strict Luhmannian sense, we experiment to stretch this divide a bit. The focus is on the feasibility of the methodological concepts in relation to our empirical data consisting of control room workers and lay people. A preliminary reading of the data has also affected our conceptual choice at this point. Consequently, we split our observation of empirically interwoven practices, during which complexity gets constantly reduced, to *structural, temporal* and *personal dimensions.*

On the *structural dimension*, the focus is on matters of fact, on concrete topics which have to take care about and reacted upon. Hence binding structuredness with features of duration and externalness come to the fore. This "structural exposure" is done by asking questions of *what* and *why*: what is concretely at hand; what is out there that can't be easily changed, and upon which has to be reacted? The why-questions are actually questions about the relatedness of the tasks at hand to other tasks and demands, and can thus be formulated as questions of why is the task at hand to be done (now)? On the *temporal dimension*, our focus is on the time structuring of the practices. By asking *when*-questions, we observe the temporal structuredness of complexity reduction: (different) time frames, postponing as well as repetitiveness and successiveness of different tasks. Lastly, in regard of the *personal dimension*, the persons in question with their unique knowledge and experience are of our interest as well as attributions of tasks and responsibilities to different persons and groups. We start by asking *who*-questions to find out how complexity gets reduced in relation to the persons in question: who takes care of certain tasks, how different roles are related to each other and how distinctive identities are constructed. Furthermore, we also ask *how*-questions: how do the persons manage to take care of the tasks concretely? Attention is paid to the relevance of personal (tacit) knowledge, experience and skill as well. Also variations in the ways of taking care of concrete tasks and concrete mundane practice vis-à-vis technological devices, manuals and other scripts are of interest in this regard.

Two main actors and sites were identified for the study based on their important role in earlier scholarship on electricity infrastructures and reliability: first, electricity *control rooms* where electricity systems and energy markets are managed in more or less real-time allowing "interaction, communication, and coordination across organizations through various technologies and methods (e.g., computers, markets, telephone calls, meetings)" (De Bruijne, 2006: 89; see also Roe & Schulman, 2008); and second, going further than a focus on market trading and technical maintenance, *households* whose expectations, interests, routines, habits, and energy-using practices have been recently raised a key issue of energy systems by many STS scholars (e.g. Shove, 2003, 2010; Wilhite, 2008; Rohracher, 2008). At the same time, comparisons of these two actors have not been that common and our generic framework presents one possible new vantage point for a comparative analysis. The following presents the main themes which were found in the data by analyzing the structural, temporal, and personal dimensions of those practices that the research subjects put into effect.

Electricity Reliability and Systems – Multiple Viewpoints

On the Energy Trading Floor

The field work and the expert interviews for the first part of the article happened in restricted sites, two electricity control rooms in a Finnish city. In one of these rooms, energy stock brokers operated in the free energy stock exchange 24 hours a day, 7 days a week. In the other, the technical operation of the local electricity network was taken care of by monitoring, adjusting, and if necessary maintaining the various components of the network. We start our analysis with the market room.

Structural Dimension

The duty of the market control room was to participate in the Nordic common energy market, *Nord Pool*, whose headquarters is in Norway and which combines energy market players in Finland, Sweden, Norway, Denmark, Estonia and parts of Germany. The *pool*, as the electricity industry characterizes it, "is a kind of a stock exchange that gathers daily the sale offers from electricity providers for each half an hour and determines the system's market price" (SENER, 2000: 10). The example concerns the UK and the granularity of the stock exchange is one hour in the Nordic countries, but the idea is similar. The pool is a wholesale market of electricity where companies that generate electricity once a day place bids and offers for each hour of the day. Based on how these bids and offers play out, the owner of the stock exchange then calculates for each hour of the day a "system price" that determines the price that these actors pay for electric energy (Nord Pool Spot, 2009).

The seven brokers in the control room, working in shifts around the day, were responsible for making these transactions happen with the city's electric energy. In practice, they balanced energy levels on two electricity markets. Firstly, they used the *Elspot* market for managing the supply and demand of the days ahead (Nord Pool Spot, 2013a). This market is accessed through already mentioned techniques called bidding and offering: communications about how much energy in megawatt hours the company is willing to buy or sell for a certain wholesale price.

A second energy market that was founded a decade ago and has gained more importance over the years is called Elbas (Nord Pool Spot, 2013b). Rather than concerning the day ahead like Elspot, Elbas is a real-time, hour-ahead market place that has operated in Finland and Sweden since 1999, Germany since 2006, Denmark since 2007 and Norway since 2009. The market works through bids and offers like Elspot.

These markets provide an important structuring dimension to electricity control room work. Based on interviewing the workers of the energy market control room and observing their work, it appears that the key characteristic of Nord Pool trading on the screen is its discipline. Bidding and offering on the Nord Pool obliges workers to follow a number of routines: completing electronic forms on computer monitors and submitting them by a certain hour, as well as following the Nordic market situation on a minute by minute, if not a second by second basis. One of the operators stressed how energy trading used to be "much more casual" over the phone. He continued that the "work has become much more exact" after the introduction of Nord Pool and others agreed: they were not as financially accountable prior to today's market (Silvast, 2011). What is important here for the present argument is that the market appears as simply being "out there" to these workers, a durable entity whose rules, routines, and disciplining techniques like bids and offers need to be followed all the time. There is more routine than there are attempts to think about them in detail: in practice, the reflection of the market tools would only provide minimal input to the work that is all about fulfilling the bids and offers on time each and every day.

As a practical matter, the energy markets are accessed through software visible on several control room computer screens. Like one of the authors has argued elsewhere (Silvast, 2011), this software assumes that all energy traders are anonymous and rational economic decision makers; and perhaps then a reality is created where the control room workers become these non-human actors at least when they "screen" electricity through market bids and offers. On another note, it also seems that computer monitors, computer software, and market bids and offers can extend or "distribute" (MacKenzie, 2008: 16-19) the cognitive capabilities of the control room workers. For each hour of the day, two numbers (quantity and price) is adequate to make sense of a large distributed electricity network and a market that comprised hundreds of companies from tens of different countries. Such market provides an original and specific structure to the control room work, although more intuitive human skills and capabilities also remain important, as we shall see soon.

Temporal Dimension

The markets, as indicated, produced their own temporal dimensions too. To start with the spot orders, they were made to the energy stock exchange once per day, at 13:00 Finnish time (12:00 Norwegian time due to the time difference). One of the workers explained the day-ahead Elspot bid and offer as follows:

> In the morning shift we make the next day's prognosis, where the power plant's generation power is defined based on the weather situation and from there the electricity. From there on we also send to Norway (to the energy stock exchange) the order, which has for each hour the information on which price we are willing to sell and buy (energy).

At 13:00 each day, the company then sends their "order" to the Nord Pool stock exchange: the prices for which it is willing to sell and buy energy during each hour of the following day. However much skill this required, the necessity to do the order at a specific time was instituted by the energy markets.

Another relevant temporality of the work was shaped by the real-time market, Elbas. As Nord Pool Spot (2010, 2013b) the operator of the Nordic stock exchange has noted, the more or less real-time trading of energy fulfills several functions: not only can economic agents engage in just-in-time trading that increases their revenues, but the real-time market may also help manage "incidents" such as shutdowns at nuclear power plants and fluctuations of the wind power.

Similarly, all the operators in our study emphasized the ever-changing contexts of day-to-day practice and the real-time market certainly seemed to raise this intensity. Even if not much happens but the worker's main task is to *stay alert*. One of the workers aptly summed energy trading as watching a camp fire: "You have to be constantly keeping up a small flame. That is, you mustn't fall behind the energy stock exchanges." Here, again, the energy market creates the conditions of possibility – and a specific kind of compressed timeframe – for actors to manage electricity and its always-on reliable provision.

Personal Dimension

The operators were titled as technicians and most of them were trained in energy generation technology, which is a vocational degree. About half of them, in correspondence with their new duties, received a brief course as brokers after the energy market was liberalized. The work seems clear enough based on its designations: the workers observe monitors and use them in accordance with the requirements of the respective room.

However, when interviewed, the informants made it clear that the work is not merely about following computer monitors and interacting with them in hourly and daily rhythms. Instead, the working required special skills and capabilities. Both ordering energy for the day ahead and adjusting it hour-by-hour provide useful examples. The ordering, for its part, is shaped by the difficulties of predicting the weather, requiring the finding of a "comparison day" that has had similar temperature and consumption patterns as the coming day. The same days of the week are preferred: working days tend to have slightly different energy consumption than the weekend. But only part of this process of ordering could even be reflected. Instead, as one of the experienced workers reported, he could draw on his "gut feeling" to foresee the energy demand on any one day of the week:

> Tuesday, Wednesday, Thursday, they could be similar to each other in the middle of the week, then you have Friday, Saturday, Sunday, even Monday, they are little bit different. But that starts from your guts in a sense, that you somehow suspect that they have some small difference.

Hunches and intuitive moves were it seems as important for the real-time trading, which invoked images of what one of the workers termed as managing a "living infrastructure":

> The process is alive all the time. And we try to keep up with the district heating network and as a counterweight to it. It's alive all the time. When we make some guess about the temperature and what could be the consumption, it's a living process even though there have been similar temperatures in the past. It's alive and production is alive too.

He is referring to the weather here, which impacts people's demand of heat which then impacts the local power production: the Nordic weather might suddenly become colder and alter the level of power and heat co-production in the city's own plant by increasing the demand of heat. Or the city's street lights could come on, which creates a marked shift in the required level of electricity production. Hence for another worker, "this work is always about making adjustments, there is no crystal ball. You cannot do the electricity stock exchanges beforehand so that it goes dead-on. This work changes from moment to moment." Such ever-present shifts keep the skills and experience of a worker important, even as, at the same time, many structural dimensions and temporal dimensions of the work are instituted by the international free energy markets.

Technical Maintenance Room

A further structural dimension of the management of electricity infrastructure was suggested by architecture on the field. As mentioned, there were two control rooms in place of one in the studied company, mostly with different workers that had received differing training following the liberalization of the energy market. To better understand this arrangement, we have to briefly visit the concept of infrastructural *unbundling* before accounting for the control room working practices.

Structural Dimension

Urbanists Stephen Graham and Simon Marvin (2002: 141) provide the following general definition of unbundling: "Central to the notion of unbundled networks is the concept of `segmenting' integrated infrastructures into different network elements and service packages. Segmentation involves detaching activities and functions that were previously integrated within monopolies and opening them to different forms of competition." In other words, unbundling means the separation of monopolistic provisions from market-based provisions in order to support competition that is seen as "fair". One main issue behind this practice is called *vertical integration*: if utilities like electricity are vertically integrated – that is, if the same company manages several steps of the energy supply chain from production to distribution as is typical in a monopoly – the result may be that this company has an "incentive" to "discriminate against competitors as regards network access and investment" (European Parliament & European Council, 2009: 10). To mitigate such suggested "discrimination", many bodies including the European Parliament and European Council (2009) have proposed mechanisms of unbundling: setting up legally, functionally, or organizationally separate entities to manage the systems of electricity supply and those of electricity production. Nord Pool Spot (2009: 4) explains the two distinct responsibilities that are created by unbundling like this:

> The commercial players are not and cannot be responsible for the security of supply. If a South Swedish retailer, for example, has bought electricity from a North Swedish producer, the North Swedish producer cannot guarantee that there will be electricity in the plug at the retailer's customers. What the commercial players deliver to each other and the end users are only the prices (and the bills). Hence, the commercial players deliver financial services only. The commercial players work in the domain which is changed when the electricity market is liberalized: the financial domain.

Hence, the actors on energy markets are not responsible for dealing with risks and security. However, there is a "non-commercial" side of electric energy as the stock exchange calls it (Nord Pool Spot, 2009: 3). This "non-commercial" operator transmits and distributes the electricity from one region to another from the producers to the retail customers.

In the case of the control rooms, the aspirations for unbundling – which had only existed briefly at the time of the study in 2008 – had already created highly specialized working tasks for the two control room workers. The two control rooms were neighboring and only separated by a wall. According to the principle of unbundling, the operators were not supposed to "know" about each other's activities. In practice, they could have easily talked with each other through an open door or in the kitchen that they shared.

The operators had the same title and a similar training, as already mentioned above; they were also of similar age and had worked in the same control room prior to the energy market restructuring of the 1990s. At the time of the study, however, only one worker still operated both the control rooms as a broker and a technician. For the others, the tasks were separated according to the room.

In practice, the technical control room work involved a number of main recurring tasks. First, continuous monitoring of the voltage, current and temperature of the components of the electricity network was carried out on several computer screens. Second, when new components like lines, transformers or power stations were installed, the control room operators needed to change the switching of the network. Third, the management of a repair team might have been required when a component failed and triggered an alarm. The structural matters that this rooms deals with are then much to do with the electricity network itself: its frequencies, voltages, and components that need to be continuously watched and maintained in order to stay always on. The difference that this creates in relation to the market room is also that of temporality.

Temporal Dimension

Each of the above control room tasks shows a slight variation of a similar rhythm. The first task above is about routines of monitoring that continue all the time. However, the second task was also seen similarly because, as one of the operators noted, the remote testing of newly installed components was "most typical routine in a working day". The temporality of the third task, the response to an alarm, is seemingly different and most obviously concerns on-the-spot responses.

But even the third case was not a clear-cut non-routine, disruptive event to these workers. One operator had not counted how many alarms there had been in a single day, but an event list on a computer screens showed 36 pages of events for that particular day. Not all of these events set off an alarm as some are "invisibly" solved by automatic fail-safe devices. When an alarm occurs, the task is to first report the details of the fault to a computer system, then determine whether a maintenance team is needed and if it is, to send the team into the field and coordinate the field work in relation to the information on the control room computer screens.

A factor that considerably structures these on-the-spot behaviors is working rules and protocols. The steps taken are discussed in the following:

> Interviewer: Are there many rules that are followed even though situations change?
>
> Operator: Well, of course there are security and other sets of rules about what should be done. You have to go according to them. And every operator has to have the same point of view about those things. That doesn't change according to who sits here.

Thus, the working practice of the room follows strict sequences of actions when "security" is considered. The time frame, duration, and pace of the work and its rules and decisions get standardized through such standards.

Personal Dimension

The worker who compared the market room to "keeping watch of a camp fire" was able to work in both of the control rooms. The distribution control room, in turn, he said, "is like being a tin soldier. Things don't happen all the time, but when someone calls you have to be ready on the spot." What he saw hence was a market place that has to be constantly "made" by economic actors. The electricity grid, in its turn, was managed primarily through reactive monitoring and maintenance tasks.

The previous examples demonstrate the matters dealt with in the maintenance room and their relatively straightforward character. The control room work is to do with the distribution of electricity through reliable components, not the price of this electric energy as that was dealt within the other control room. To this end, the room has setup highly structured routines and protocols that are followed to attain "security", as the workers termed it. In addition, as the energy industry is liberalized and competitive, the network maintenance was outsourced and hence workers get billed for the maintenance work. Considering personal dimension, however, it would seem that personification is not seminal for the work of this room. What is at stake is that the billing for the work should be fair and transparent and deviations from the safety protocol are against the norm.

Nonetheless, the informants still emphasized how skills and in some cases even improvisations may be necessary, as a purely practical matter. As one of them told:

> In principle electricity work is usually highly standardized. If everyone follows the standard, then it is highly structured. There is a problem, however, that when you go to a work site, the situation might vary greatly. And then comes

> your own adaptation about how you want to do things.

So the actual work site introduces uncertainty that requires special skills. Another broader source of uncertainty is given by the complexity of the managed systems and the difficulty of finding which many possible processes had led to their failure.

A participant observation of practical fixing of a fault showed that only some activities involved a standardized control of risks and uncertainty. The observations also uncovered independent decisions, team work, skills, help from computer systems, practical rules of thumb and knowledge of the local region. Indeed, even the problem that was identified and anticipated by the technician shifted gradually as the situations unfolded: a customer's blinking lights becomes a possible dangerous ground fault to the control room worker, requires maintenance that could cause power failures to other customers, but is finally discovered to be a sagging line and not a ground fault. In another case written to a fault report, a blackout occurs and a loud bang has been reported from a near-by construction site but a careful investigation on the field reveals that the problem that caused the failure was a twig and the bang was unrelated to this problem. Such logic deals with incidents little by little by adjusting working habits. Formalized prevention of hazards then receives significant assistance from working experience and localized experience.

Households

The previous sections were concerned with the operations of two control rooms in formal energy organizations. The question about finding structural and temporal dimensions was relatively straightforward in these cases: organizations have to deal with markets of various temporalities and follow set rules, routines, and protocols. However, the theory outlined in this paper is more general and can be applied to other sites, including households that are viewed as central in many STS energy discussions (e.g. Shove, 2003; Wilhite, 2008). We also apply the framework to homes during the remainder of this article.

Structural Dimension

When considering households, the identification of structural dimensions almost immediately starts to seem like a complex task. Part of this is because households are not formal organizations as we discuss below, but another matter is wider-ranging. To draw on scholarship on infrastructure and energy uses and practices (Star, 1999; Shove, 2003; 2010; Wilhite; 2008), the electricity infrastructure is "structured" for homes in various manners. It is structured, first of all, by being embedded in and utilized by other household technologies like lighting, cooking, media, and computing, by everyday habits with their long durability, and by clusters of practice such as using electricity to do other things like typing on a computer during the night. More broadly speaking, patterns of electricity consumption also receive structures from cultures of using electricity in the cold Nordic countries and Finland in our case. Finally, the traits of these patterns are affected by more durable institutions and arrangements such as the regularity and resolution of household energy billing, prohibitions to cut electricity for example during very cold months, and compensations from electricity supply failures in homes.

When reflected, the number and scope of such matters can indeed easily become overwhelming. However, it is also important to stress that the households that were interviewed and surveyed did not seem to think about such issues all the time or even that often, not even in the context of failing electricity that was the original research problem of the study. Rather, most of them shared the idea that a capable person manages to be without electricity, at least for a short while, as long as this person acts responsibly and has prepared for a blackout.

For example, an interviewee, a retired woman, told about the wood stove that heats her old house and emphasized that she would have "no worries" during a blackout:

> Personally I have no worries, there is a wood stove here as this is such an old house. But then the neighbor's house doesn't have wood heating, so they started to complain [during a long blackout] that it was starting to be a bit chilly.

This woman did not suffer from a crisis during a blackout. Rather, she managed to continue key everyday habits – at least those that require heating – even though the electricity supply was interrupted. She knew from repeated experience that the wood stove would keep the house reasonably warm. Indeed, almost no interviewees were particularly concerned about blackouts. Instead, they explicitly stated that not all blackouts were harmful events. One interviewee said that blackouts have not caused her any harm personally, while another might even accept one further blackout a year.

On some level, it seems that everyday practices were simply allowed to stop during an electricity blackout. A similar positive view of a "primitive" non-electrified moment was shown by a 35-year-old woman female interviewee:

> Of course the blackout offers a possibility to light the candles and spend a kind of primitive moment without computers and televisions. You're forced to sit on the couch with people and talk.

A blackout therefore encourages a positive attitude to doing things differently.

The respondents of the survey had similar thoughts as they thought they could cope for many days without using electricity for appliances (Table 1). We can see, for example, that the lack of credit cards, washing machines, dishwashers, cleaning, computers, the Internet, summer heating, saunas, housekeeping, and gardening only started to significantly worry these people after one week.

Another indication of the low "visibility" of the electricity infrastructure as a structure is provided by dimensions of the network that a power cut revealed to the subjects. When asked about what a blackout indicates to them (Table 2), most people considered general society-wide impacts of electricity failures, the opening of the market and the pricing of electricity, the imagined causes of blackouts, and their own preparedness and consumption. Countering the notion

Table 1. How many days households (N=115) thought they could cope without different electricity-using appliances or functions.

Days	Appliance or function
1-3	fridge, freezer, toilet, heating in the winter, all water (warm and cold)
4-6	cooking, media appliances, lights
7-9	batteries (e.g. mobile phone), credit cards, washing machine, cleaning
10-12	computer, dishwasher, Internet, heating in the summer, electric sauna
12-	housekeeping and gardening

that a technological failure highlights what caused it – thus opening the “black box” – the experiencing of a blackout in a year made explanations concerning the causes of blackouts seem less important to the subjects. At the same time, a blackout made explanations concerning the open electricity markets and their pricing more relevant, even if according to idea of unbundling (see above) the competitive energy and security of supply are separate issues managed by different organization. Finally, whether having experienced a blackout or not, many key factors on the structural dimension like politics, legislation, and the structure of the electricity network appear in the bottom of the list in Table 2. This too is understandable: one cannot stop using electricity after the power comes back on, so it would not always make a difference to think about structural issues in depth in everyday life contexts.

Temporal Dimension

The people that were studied did not underestimate the effects of all electricity blackouts. But in order to raise concern the electricity failure had to have a significant effect, for example, frozen foods melting, water in pipes freezing, or the contents of the hard disk drive disappearing. These situations can be usefully framed as issues of temporality. First, a blackout should not interrupt everyday habits on a very regular basis. Second, a blackout should not occur at a time when people have planned to do something that really requires functioning electricity. And third, a blackout should not impact on tangible objects which are the result of time and investment – such as the contents of the freezer or a computer’s hard disk drive.

We can consider the deep freezer as an example: a blackout may destroy the contents of the freezer and, hence, very suddenly undo the investment of gathering the contents in the first place. Other practices need to occur at a certain time and place and can be vastly affected by blackouts: for example, as remarked by a women in her 30s, she would not want to have a blackout when she needs to hand in her thesis or, more mundanely, to go to a party or watch a television series.

One interviewee had even more persistent problems with electricity blackouts. Practically all the appliances of

Table 2. What blackouts uncovered to households (N=115).

% of respondents	had blackout in a year	no blackout in a year
societal impacts of blackouts	79	75
electricity market opening	74	59
own electricity consumption	70	52
electricity price	67	69
own preparedness	65	44
causes of blackouts	63	72
damages to your home	59	47
utility customer service	58	46
own electricity contract	55	54
the number of blackouts in different regions	51	54
the structure of the electricity network	38	35
energy politics and legislation	30	35

this woman in her 40s were electric, from regular appliances to air conditioning, water fountains and unusually for 2005, an electric car. Altogether she had almost 150 separate appliances that required electricity, which she counted when she was interviewed over the phone.

The problem was that this consumer lived in a rural area, as classified by the electricity utility. In comparison to cities, according to this classification, such areas have relatively more open-air electric cables. These open-air components are particularly subject to weather, trees, and animals which damage overhead cables and transformers and cause short, but frequent blackouts. This was precisely the issue in the woman's house.

The interviewee stressed that blackouts cause multiple actual harms and not only infrequently but on a day-to-day basis. Such constant harms often cannot be understood by people who do not "live surrounded by the latest contemporary technology". She remarked that such people may talk about the way in which blackouts symbolize a halt. Infrequent blackouts may be acceptable and even have positive aspects, but as frequent occurrences, blackouts can become unbearable:

> For us a blackout is not just an interruption. Instead, it is difficult to cope with a situation where every morning the phones may start ringing at five in the morning, so that the whole family wakes up. Because this is a new house, everything is automated. And if there's a blackout and for some reason a program is erased, then certainly it's a nuisance that you have to spend an hour entering the data again. For a person who doesn't have this equipment it's just a matter of resetting the digital clock. But we live in a house where everything works with electricity and modern technology is complex.

Blackouts were thus a major inconvenience to this person and her family. It was taxing to constantly think about blackouts and she wanted her technology simply to work without having to reset it every morning. In regular use, electricity does not structure the time of everyday life into separate events: with always-on electricity, the idea precisely is that lights and appliances can be used all the time without giving electricity that much consideration. It is the breakage to this durable temporal logic that proved particularly worrying to this subject.

Personal Dimension

Both of the above sections have already hinted at the importance of personal factors in people's assessments of electricity distribution failures. However, this did not necessarily mean reflective decision-making like obtaining new energy-efficient purchases or willingness to postpone consumption for the sake of the electricity network reliability. Indeed, most respondents tended to emphasize that a blackout does not cause marked damage or harm. People coped with blackouts rather than being highly reflective about them. One thing that signified this was an emphasis on simple mundane skills like finding the switch board, candles, and a flash light. A woman in her 30s, a kindergarten teacher, noted that she coped with blackouts well while children might not cope. A retired woman already quoted above emphasized she would have "no worries" during a blackout, but that her neighbors would. A similar emphasis is apparent in the survey (Table 2) where a blackout, most often, signified to people the importance of own consumption and own forms of preparedness as well as damages to their own home.

The personal dimension is also visible in the ways in which households explained blackouts in interviews. The subjects were not unaware of the catastrophic potential of blackouts. One interviewee thought about what would happen if the temperature was minus 25 degree Celsius in the winter, whereas another thought that a blackout "makes you observe the whole system's vulnerability and you start to feel sort of stupid, as you are so dependent on electricity". However, these types of catastrophic effects were not mentioned in connection with any blackout that the interviewees had personally experienced. Catastrophic considerations of infrastructures, it seems, are simply not very tangible when making sense of actual harms. This also made preparing for blackouts difficult for a woman in her 40s:

> Somewhere in the back of your head you have these fallbacks, like what if. And you think about buying an emergency heating system and about whether you should get one. But then when the electricity starts up again and is not interrupted, it's easy to forget about it.

The reflective, active, and thorough consideration of one's own energy use seems to be the exception rather than the rule. When asked about what causes a blackout, nearly all interviewees concurred: in addition to natural acts, the most common perceived reasons were the liberalization of the energy markets, trees growing next to electricity lines, and the downsizing of energy network maintenance. Even if electricity supply disturbances revealed a material network that is normally hidden from view, it seems that people consider the causes of failures to be "scapegoats" that are easy to comprehend. Rather than seeing how the systems work, people considered whether the institutions that deliver electricity are trustworthy.

The blackout – originally, a complex system-level failure of an infrastructure – was hence reduced to more mundane and comprehensible explanations in the everyday frame. Such explanations kept the electricity infrastructures hidden rather than opening up their functioning to debate.

Discussion

This paper advanced an interest in different dimensions of the electricity infrastructure and the management of its reliability. The paper acknowledged the importance of starting the analysis of an infrastructure with a Latourian "flat" concept of social domain. However, and importantly, the paper also tried to demonstrate how such an analysis that "follows the actors" does not necessarily have to end with flatness. Rather, the purpose of the paper was to tune our sociological observations to see grades of stableness, durations, receptiveness, and thicknesses from the situated, practical vantage point.

To this aim, to find structuredness among flatness, we drew upon systems theoretical considerations inspired from the work of the sociologist Niklas Luhmann and his colleagues and successors. This theory was utilized from a specific, rather unorthodox premise: the concern was not directly with themes popularized by Luhmann such as subsystems of society, their interrelations, and their "autopoietic" ("self-creating") communications. Rather, the systems theoretical vantage point was calibrated into a research methodology about how people engage with the electricity infrastructure and manage its complexity and uncertainties in workplaces and homes.

Our key sensitizing concept was that of *locally contextualized, embedded reduction of complexity*. Three such reduction dimensions were operationalized for the analysis: the *structural dimension* of factors external to the situations at hand; the *temporal dimension* of varying time frames; and the *personal dimension* of experience, local knowledge, and skills as well as roles and identities. The difference between the categories is relative and they overlap in practice: for example, different structural dimensional factors, like market places, have their own temporal variations. Cases about special electricity infrastructure control rooms and homes – both important in recent discussions in STS and organization and workplace studies – were analyzed to demonstrate the framework and its use.

The results from the analysis of these sites and their concrete practices show important outcomes for a comparison of different sites. In the electricity control room whose workers trade electric energy in an open energy market, the Nordic energy market posits important external factors on the structural dimension that discipline the control room work and create certain binding temporal dimensional time frames like once-per-day ordering and once-per-hour trading. Nonetheless, it seems that the control room workers' personal skills, experience, and local knowledge remain important (see also de Bruijne, 2006; Roe & Schulman, 2008). This is because they managed what they saw as an ever-changing "living" infrastructure and matched various temporalities from day-ahead prognoses to a more or less real-time trading.

In the second control room that deals with technical distribution of electricity, the electricity network technology creates various external constraints to the work as do safety protocols and both trigger special kinds of maintenance and monitoring routines. But it was also clear that the systems maintained would not hold together would it not be for the local experience of the control room workers and their skillful adjustments in ever-changing work conditions.

At the same time, households are a key concern for many recent STS discussions on energy systems and infrastructures and provide a critical addition to our analysis and interpretations. The structuring factors in an organization like an electricity utility are relatively clear to an analyst, often also to practitioners themselves: in many instances, such factors have even been engrained in job descriptions, professional roles, and wider rules like those concerning "unbundling" some specific "interests" of infrastructure provision from different "interests". The time frames shaped by these factors – like those triggered by markets whose trading emerges every even hour or once per day – seem likewise typically apparent to an organization and its members dealing with them on a routine basis.

However, energy-using households seldom have similar organizational frames nor is expertise typically at-hand to domesticate issues created by markets, failures, or other matters. To lay people, the majority of the structural dimensional factors of electricity seem not to be reflected and remain simply "out there", and this stays accurate even when the electric power goes out, according to the analysis in this paper. Power failures were seen as temporal matters as was shown: through their regularity, their time of occurrence, and their impact on time use. Yet, it is plausible that other temporal dimensional occurrences of energy systems remained hidden – the key temporality of electricity simply being that it flows continuously to home. The use of electricity and the reduction of the complexity of a failure then becomes by and large a personal matter to members of households. It involves issues like their skills, installed electric equipment, situated preparedness, and explanations that hide the electricity infrastructure rather than opening up its functioning to debate.

The observations on households are important not only for showing what knowledge was gathered in this analysis. They also contribute to perspectives on current strivings for creating more rational electricity consumption and informed energy consumers. The active consideration of electricity and its reliability, which experts do continuously in their organizations, seems to be the exception rather than the rule in households. In other words the demand for rational electricity consumption seems to increase the complexity of everyday life, which is something people would rather avoid.

The organizations that keep systems at work, studied in this paper, offer one way to elaborate this result concerning households further. First of all, the notion that a reliable system would not hold together without continuous maintenance is certainly accurate in the control rooms based on the analysis (Bennett, 2005; Graham, 2009). But the rooms also show that for work practices to become effective reductions of complexity, they need to involve some structuring factors and time frames. Not everything was and maybe even can be "flat" for people that manage a large-scale electricity network. Indeed, one part played by the energy markets and security standards, though their effects and functions could be discussed and even critiqued from various other angles (e.g. de Bruijne 2006; Roe & Schulman, 2008), is that they offer specific structure and a temporality to what seems like highly demanding working practice.

This conclusion may shed some new light on energy consumption practices, too. Many commentators have drawn attention to personal dimensions of energy use and to how the practices of energy consumers' or even citizens' might be shaped and altered: for example by energy rationing, price signals, and information campaigns concerning more rational energy use. While such measures are important, one could pose another follow-up question based on the framework in this article. What are the structural dimensions and temporalities for lay persons to manage challenging energy issues and what kind of institutions would be needed in their support? Various arrangements are doubtless possible, but they could serve two functions in daily life. The arrangements could reduce the uncertainties of electricity distribution and at the same time, also buffer lay-people from constantly thinking about these uncertainties.

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Notes

1 The materials include interviews with two Finnish electricity control room operators (12 interviews) and households (9 interviews), participant observation in the two electricity control rooms, and an electricity consumer survey (115 respondents, response rate 21 percent). The control room informants were found through the other author's field work in the Finnish electricity sector, particularly through personal contact with the managers of the workers. The questions posed in the control room interviews concerned the anticipation of electricity blackouts and the management of their damages as risks, and were divided into sub-themes

about working practice, free energy markets, and security in the control rooms. The control room operators worked for one electricity company in Finland and were male in their 50s or 60s with the exception of one younger female worker. The questions for the households concerned experienced blackouts and imagined blackouts in homes. The household interviews were found through various means including a housing association, personal contacts, and "snowballing" new respondents from those subjects that had already replied. Both female (7) and male (2) respondents were included in the household interviews from the greater Helsinki region. The household survey was posted to the customers of two electricity companies in Finland, one a city and other a rural region. The structure of the survey included four sections: the household impacts of electricity blackouts, the preparedness against electricity blackouts, lessons from electricity interruptions, and attitude questions. The survey responses covered all adult age groups and both men and women were represented – however, the majority was male, more than half were over 60, and most lived in an electrically heated detached house.

Antti Silvast
University of Helsinki, Department of Social Research
antti.silvast@iki.fi

Mikko J. Virtanen
University of Helsinki, Department of Social Research
mikko.jz.virtanen@helsinki.fi