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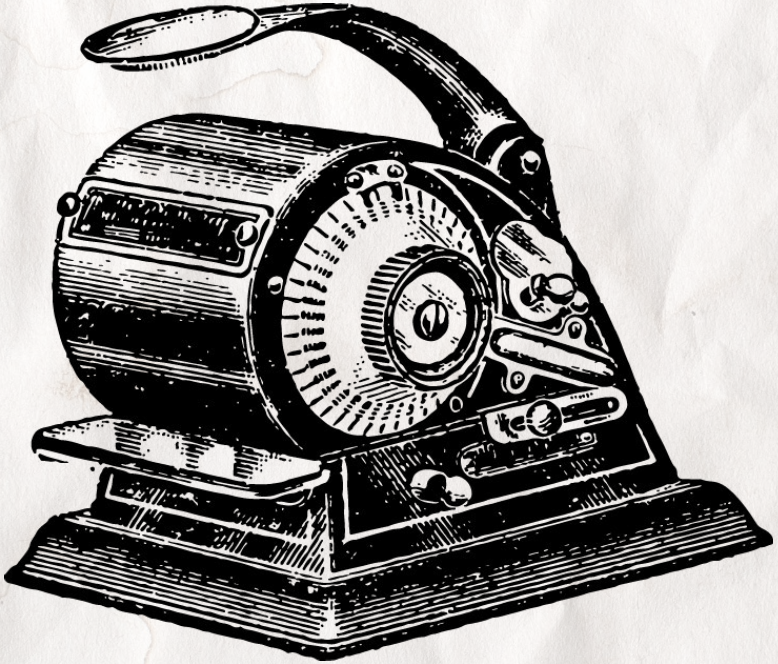

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Data on the move

How household energy data travel and empower

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DASTS is the primary academic association for STS in Denmark. Its purpose is to develop the quality and breadth of STS research within Denmark, while generating and developing national and international collaboration.

Abstract

Even though Science and Technology Studies has highlighted how things and publics participate in energy assemblages, the specific role of big data has received relatively little attention. This paper examines the politics of energy data in relation to residential grid management. Informed by the concept 'data journey', developed by Bates et al. (2016), it proposes an 'energy data journey' approach and focusses on two questions: how are big data of smart homes produced and how do they travel? And who is empowered by this energy data production and movement? The paper addresses these questions in the empirical context of a Dutch-Belgian pilot project that has designed and tested energy management of a smart home. The empirical analysis shows how energy data and household profiles are created and travel through different cyber-physical locations to serve different purposes. The use of specific 'home energy profiles' is crucial and contributes to neoliberal energy management as it focusses on self-monitoring tools and users' responsibility, while empowering commercial tech-companies and high income groups. The final section reflects on the cyber-materiality of energy data and the techno-politics of energy data more broadly. The paper argues that an energy data journey approach is productive for STS researchers when critically reflecting on the agency and politics of energy data.

Keywords: data journey, energy, smart homes, techno-politics, empowerment

Introduction

In recent years, automated home devices have captured the public imagination. Ranging from advertisements for convenient smart products, to dystopic futures in popular series such as Black Mirror, the home is clearly digitizing. Significantly, smart homes have also triggered the interest of energy grid operators, but in the form of grid innovation.

Traditionally, homes without smart technologies ('dumb homes') only entered the radar of grid operators during brown-outs or electricity disturbances. However, as households consume increasing amounts of electricity, and deliver local renewable energy 'back to the grid' (cf. Darby, 2010), grid managers are trying to grapple with bi-directional energy flows and local energy peaks.

Digital energy technologies such as smart meters and energy feedback devices have already allowed households and grid operators to gain relatively detailed information about household energy flows (Strengers, 2013). After the liberalization of the electricity sector in many European countries in the 1990s, commercial energy companies and technology suppliers started playing a key role in the energy system. Grid operators increasingly cooperated with new (often commercial) actors to explore tools to govern electricity grids, including smart meters and smart grids. Another fruit of this development is the smart home. Importantly, not all smart homes are designed to manage or even reduce energy flows (some even lead to greater energy consumption). Specific smart homes that digitally monitor and manage energy flows are considered a promising innovation for grid management. Digital energy data play a key role in smart homes, especially in relation to the management of residential grids.

Energy data and their politics

Data related to smart homes are not self-evident, fact-like entities, with naturally defined boundaries and functions. In the field of Science and Technology Studies (STS), much work has been done to unpack the relational and political character of technologies, including how things and publics participate in energy systems (Strenger, 2013; Throndsen & Ryghaug, 2015). However, the agency and politics of energy-related data have received little attention, and relatively little is known about the techno-politics of energy data (Hess & Sovacool, 2020).
The rise of big data and algorithmic networks in residential grids is especially interesting because household energy use and grids cut

across the public and private spheres (Hess & Coley, 2014; Chandler 2015). What is more, data-driven management is entangled with ethico-political questions about privacy, technocracy, and hackability (Kitchin, 2014). This not only relates to the politics of information flows, but also to the material politics of digital data (Bulkeley, McGuirk & Dowling, 2016; Bates, Lin & Goodale, 2016). Following Von Schnitzler here, I argue that adequately understanding smart homes, and their data, requires examination of "the very design, [as] such technologies are scripted with, and come to reflect, specific ethico-political projects, targets, and expectations" (2013: 672). Focussing on the production and circulation of smart home data in relation to grid management "opens up new understandings of the stickiness of the *status quo*, how unequal relations of power are (re-)accomplished" (Jensen, Cashmore & Späth, 2019: 2).

Focus and outline of the paper

This paper examines the politics of smart home data in relation to grid management, addressing two interrelated questions: How are big data of smart homes *produced* and how do they *travel*? And, who is *empowered* by this data production and movement? It particularly looks at the ways in which a specific type of smart home produces digital knowledge about 'energy peaks', and how this knowledge moves through different sites and intersects with particular techno-political strategies. The notion of politics here does not refer to 'conventional' politics related to public demonstrations or formal policy negotiations. I follow Von Schnitzler, who advocates a 'micropolitical' understanding in which data technology "itself becomes a political terrain for the negotiation of moral-political questions" (2013: 671). The politics of energy data, then, refers to the ways in which energy data are created, as well as specific ways in which these data are employed politically. Energy data, in the context of smart homes, are expected to reassemble socio-material relations between households and grid management.

The paper is structured as follows. First, it briefly discusses the broader technological and societal context of smart homes in relation to grid management. It highlights how energy-managing smart homes integrate smart devices, and emerge as socio-material arrangements with the capacity to monitor residential energy patterns. Second, it examines recent insights from STS and energy research on big data. Informed by the concept of *data journey*, developed by Bates et al. (2016), it then proposes an 'energy data journey' approach as a socio-material (or rather cyber-physical) sensibility of the production and movement of energy data, and their micropolitical dynamics. The proposed analytical approach emphasizes: (1) the production of energy data; (2) their movement and mutability; and (3) the empowerment of specific actors and techno-political strategies. Third, the paper presents the empirical case of a Dutch-Belgian pilot project called Standard Grids, Smart Homes (SGSH) that has designed and tested a particular energy-managing smart home (a Home Energy Management System, or 'HEMS'). The methods used for this case study are presented in the case section. Adopting an energy data journey approach, the case illuminates in detail how smart home energy data are produced and travel. Energy data and household profiles are created and move through different cyber-physical locations: sensory devices, household appliances, bodily practices, computational software, and energy monitors. Specific data profiles are integrated and aggregated, with the strategic aim to monitor 'acceptable' grid parameters semi-automatically. The use of these 'home energy profiles' mostly contributes to neoliberal energy management, empowering high income households with self-monitoring tools, grid operators, and commercial companies that seek to develop smart home products.

Finally, the paper argues that an energy data journey approach contributes to STS, enabling researchers to reflect critically on the agency and politics of energy data as employed in various smart energy projects. As multi-actor projects involving 'smart energy' become omnipresent (smart grids, homes, cities, countries [Strengers, 2013]), such an approach has academic, policy, and social relevance. The final section also reflects on the cyber-materiality of energy data and the techno-politics of energy data more broadly.

Smart homes and grid management

In the last couple of years, smart grids, smart meters, and smart thermostats have offered new ways to manage residential energy. These technologies can be programmed to execute specific semi-automated task, such as monitoring grid peaks loads, visualizing household energy use, and maintaining a comfortable home temperature. For example, smart meters, as adopted in many countries, allow real-time measurements of household electricity (kilowatt-hours) or gas consumption (M3). For grid operators, these measurements provide many more data points than before. As a result, local consumption patterns and peaks are rendered visible in much more detail (Van Dam, 2013). Smart meters are not neutral devices; the levels of detail serve specific techno-political strategies (Von Schnitzler, 2013). Fine-grained residential energy information can, for instance, contribute to better monitoring to safeguard trustworthy and affordable energy for all connected households. Consumers are, supposedly, also able to monitor their own consumption and make more informed choices about their energy use. Data-driven meters enable consumers to reduce 'excessive' electricity use, saving money and electricity, sometimes by as much as 15% (Darby, 2006).

Integrating devices: smart homes and HEMS

Next to smart meters, other devices have been developed that are also able to communicate digital information. The combination of sustainable micro grids and home batteries, for example, allows households to utilize their own solar energy directly (during sun hours) or indirectly (when this energy is captured as stored capacity); grid operators are also interested in local storage capacities, which accommodate decentralized energy infrastructures, reducing residential peak loads. Relevant to energy consumption, digital capacities are incorporated

into household appliances, such as washing machines, tumble dryers, dish washers, and e-boilers. Smart home devices can be remotely controlled with apps, creating a personalized system with self-learning algorithms. All these energy technologies and smart devices have been designed and developed in relatively separate markets.

In recent years, however, energy production technologies and domestic appliances have gained the capacity to 'communicate', including with each other. An important integrative development is the rise of the smart home, or the Home Energy Management System (HEMS). There are many types of HEMS available on the market (Zhou, Li, Chan, Cao, Kuang, Liu & Wang, 2016). They all serve different socio-political purposes, which also depends on the integration of particular devices. Some HEMS optimize heating, for example, by connecting a smart thermostat to an e-boiler and a mobile app via the internet (e.g. Nest Learning Thermostat). This moves away from manual heating to allow semi-automated and personalized heating in order to increase comfort and convenience. Other HEMS optimize lighting and home security (taking over manual lighting) by integrating smart lighting devices, mobile apps, displays, and voice recognition (e.g. BrilliantSmart), while yet others optimize energy efficiency, energy autonomy, and environmental sustainability. In the case of the latter, which is the focus of this paper, using smart meters only 'simply to measure' energy consumption does not suffice. More technologies and software are required in order to monitor and manage other household electricity flows. All these types of 'HEMS data' can then be connected to smart appliances, such as smart white goods and smart e-boilers, and be programmed to utilize 'your own' solar energy. An important part of such HEMS is the computational software that integrates data and provides automated feedback about, for example, off-peak tariffs or the self-produced energy availability. In addition, the role of users and their household routines cannot be isolated from energy monitoring devices and HEMS (Shove, 2014). Even though smart homes are 'automated', the way consumers respond to automated feedback is a crucial part of the broader socio-material arrangement (Verbong, Beemsterboer

& Sengers, 2013; Hargreaves & Wilson, 2017).

The advanced integration of these HEMS have a clear potential for grid management and broader energy transition. As Zhou et al. suggest, it "leads to a fundamental transition for modern energy management systems from traditional centralized infrastructure towards the cyber-physical HEMS" (2016: 31). The term 'cyber-physical' is significant here, as it emphasizes that HEMS data should be understood as embedded in a complex socio-material network, linked to material devices, human conduct, automated data management, and particular socio-technical strategies. Before zooming in on an empirical HEMS case, in which energy data play a crucial role, it is instructive to understand conceptually how energy data are produced and transformed into moveable objects that serve specific techno-political strategies.

Conceptualising energy data and their journeys

Long standing STS and sociology-informed research on energy has suggested that energy technology is socially and culturally embedded (Nye, 1990; Hughes, 1993). Recent scholarly work on smart energy technologies (Schick & Winthereik, 2013; Strenger, 2013; Throndsen, & Ryghaug, 2015), social practices related to energy (Shove & Walker, 2014), and power dynamics of energy regimes (Boyer, 2014), has examined the socio-technical and normative characteristics of smart energy technology (Silvast, Hänninen & Hyysalo, 2013). Yet, while these studies provide useful insights about the social and political entanglements of energy technologies, relatively little attention has been paid to the specific role and use of digital energy data from an STS perspective (Verbong & Loorbach, 2012; Bibri, 2018). Importantly, Hess and Sovalcool (2020) argue that, in the period between 2009 and 2019, STS-informed energy research has approached energy in different ways, identifying four STS perspectives: (1) cultural analysis, concerned with sociotechnical imaginaries and expectations; (2) policy analysis, focussing on risks and standards; (3) public participation, highlighting expert-public relations and mobilized publics; and (4) sociotechnical

systems, including the politics of design and the role of practices and users (Hess & Sovacool, 2020: 7). Nonetheless, although some STS work highlights how things and publics play a role in smart energy networks, the specificity of digital data seems to take a backseat.

An energy data journey approach

This, however, does not mean that energy data should be regarded as separate from energy technologies. In a broader sense, big data as symbolic matter are deeply entwined with physical infrastructures (cf. Dourish & Mazmanian, 2011), while energy-related digital data are expected to play a role in all perspectives, as pointed out by Hess and Sovacool (2020). Energy data are linked to software systems, physical devices and infrastructures, regulatory norms, and cultural practices. Specific uses of energy data, then, can also play an important role reassembling these relations. In this paper, I argue that energy data should be understood as 'cyber-physical' entanglements that have the capacity to make and remake energy infrastructures in particular ways (Zhou et al., 2016). Therefore, to highlight how energy data come into being, how they move, and the strategic work they do, I employ a *data journey approach,* as proposed by Bates, et al. (2016). Even though these scholars do not explicitly refer to 'energy data', their understanding of data movement is instructive for the purpose of this paper.

Bates et al. (2016) present a conceptual understanding of what they call the cyber-physical 'life of data' as they move though time and space. Data, in this sense, transform as they move from their "initial production through to re-use in different contexts" (2016: 2). In fact, knowledge reproduced elsewhere is never duplicated, rather "repetition is concerned with the production of novelty, even in situations where 'things' appear to repeat in the image of the 'Same' or the 'Similar'" (Aroles & McLean, 2016: 538). The metaphor of 'journey', therefore, is significant, as it characterizes moving energy data: an assumed starting moment, the figurative 'luggage' it has while moving (information about energy), and constantly changing socio-material environments. Drawing from the methodological notion of 'journey' as employed in earlier cultural studies (e.g. Sheller & Urry, 2006), a data journey approach puts emphasis on

> [...] diverse social worlds that are interconnected, in part, by the journey of data through and between different sites of data practice, with the intention of illuminating the concrete ways in which evolving socio-cultural values and material factors cohere over time to create the socio-material conditions that frame activities of data production, processing and distribution and resultantly influence the form and use of data and their movement across infrastructures. (Bates et al., 2016: 2)

Importantly, a data journey often does not follow a linear path from A to B, but is altered, blocked, replicated, moulded, and reused in different ways. A data journey, therefore, can be said to consist of smaller and interconnected journeys. Based on meteorological data, Bates et al. (2016) inductively propose a set of analytical dimensions to a data journey approach: (1) the constitution of digital data objects; (2) cyber-physical data friction and shifts in patterns; and (3) the mutability of digital data (Bates et al., 2016: 6). In this paper, the latter two aspects are combined, as I think it is useful to analyse data movement in direct relation to mutability and repurposing of data. This sheds a more comprehensive analytical light on the digital-physical travelling of energy data. Furthermore, since this paper also investigates how energy data is linked to the reassemblage of socio-material relations in terms of power and empowerment, I add the following question: how do data and data travelling *empower* specific actors and techno-political projects? (cf. Von Schnitzler, 2013; Fox & Alldred, 2016). Below, three analytical aspects of an energy data journey approach are presented in the form of guiding questions for empirical examination.

1) **Cyber-physical constitution of energy data**
How are specific energy data points created? What knowledge do these data represent? What are the characteristics of these energy data in terms of accuracy, timing, and measurement?
2) **Cyber-physical data movement and mutability**
How does energy data move through specific physical-cyber settings? What actually enables and restricts the movement of data? How do practitioners repurpose and adapt energy data, as data move between sites? In what way do cyber-phys ical settings force energy data to hold their original shape, or adapt?
3) **Strategies and empowerment of specific actors**
How do energy data and their movement empower particular actors? Which techno-political projects and strategies are mobilized and strengthened by energy data?

These analytical building blocks do not follow a specific sequence. Rather, they shed analytical light on how energy data journeys unfold, and guide the proposed assessment of the empirical smart home project.

Empirical case: energy data journeys in the SGSH project

The sections above presented the societal context in which smart homes and HEMS have emerged. In 2015, Dutch and Belgian electricity grid operators initiated the so-called Standard Grids, Smart Homes project (SGSH) within a Dutch subvention, supported by a Dutch government programme to stimulate energy innovations and economic development. The SGSH project sought to make households more energy autonomous (maximising the use of local production and storage capacity), and less dependent on 'the grid'. As such, the project mainly utilizes smart homes for grid management purposes. As will be elaborated below, this is directly informed by considerations of finding a cost-efficient digital alternative to traditional (costly) public investments in ‘wires and cables’. As well as three grid operators, a technology supplier and two research institutes participated in the project. The rather techno-scientifically driven project has designed and developed its very own type of HEMS. This type utilizes a low capacity household-grid connection (e.g. 6, 8, or 10 ampere instead of 25 or higher), while safeguarding sufficient electricity supply and ‘normal comfort’ by optimizing local production and storage capacity. In this way, the grid serves as a ‘backup system’, and stops being the prime supplier of electricity. The ‘thin’ line between the grid and homes is balanced by a relatively self-sufficient residential energy system. In addition to the technical development of the HEMS technology by technicians and engineers in the laboratory setting (however, without the involvement of actual users), the HEMS was ‘tested’ in actual households in 2017. The project partners and their expertise employed predominantly technical and computational software knowledge about energy infrastructure, power balancing, and data-driven applications. After a period of designing and ‘lab testing’ the HEMS (April-August 2017), they were physically installed in 16 Belgian and Dutch homes for ‘field testing’. HEMS software was programmed and connected to the cloud, so that software developers could monitor the home energy use patterns of participating households.

The selected Dutch and Belgian households are located in three areas associated with the regional span of the three grid operators. The householders can be considered ‘friendly users’ since they already have solar panels and are willing to participate in the pilot project. Some have an electric vehicle or have participated in previous energy pilot projects. All 16 homes are privately owned and located outside densely populated urban areas. In terms of demographic characteristics, the users are between 35 and 66 years old, 65% men, and 70% higher educated. Most householders’ professions are in domains such as consultancy, health care, or education and/or have a technical background (a couple are retired). The main objective of the field test was to assess if households can manage to stay within the limits of a low capacity grid connection (6 - 13 amp.) and rely on the HEMS without losing ‘normal’ levels of energy use, hygiene, convenience, and comfort. This particular HEMS (embedded in the SGSH project), as an actor-network through which energy data are produced and circulate, serves as the empirical case to examine how energy data are produced, and how they travel and empower.

Methods

The SGSH stakeholders were interviewed in a semi-structured way between the fall of 2016 and the summer of 2018 (almost the entire project duration). These direct project actors include the Dutch and Belgian grid operators, technology suppliers, software developers, and professional advisors. In total, I conducted 16 interviews with them, with an average length of about 60 minutes. Some of the interviews were a bit shorter (about 30 minutes), while others had a longer duration (up to 90 minutes). In addition to these interviews, empirical insights were derived from stakeholder workshops, field notes (visiting the lab and the households), as well as aggregated HEMS data. After the 2015 HEMS installation, I also approached the 16 households multiple times for interviews and digital surveys over the course of one year (summer 2017 - summer 2018). Interviewing and surveying the households every three months was useful to assess potential differences in how users adopted the HEMS in different seasons (e.g. temperature differences, number of sun hours for solar energy). Of course, this also enabled mapping any changes in experience and impact of the HEMS over the course of a year. The semi-structured interviews with households (in total 32 interviews, both physical and digital) were sometimes conducted with multiple household members. The interviews with HEMS users had an average duration of 60 minutes (some of which took about 90 minutes). In addition, I offered households a ‘digital diary’ to note down any HEMS-related experience or reflection between interviews and surveys. These (mostly qualitative) empirical materials have been analysed with a coding method (combining axial and *a priori* coding [Saldaña, 2015]), by categorizing empirical materials in accordance with the three analytical building blocks of the energy data journey approach (see above). The analytical dimension of the operational guiding questions enabled the clustering and examination of the empirical materials, and proved flexible enough to allow the inclusion of inductive empirical details, while taking into account the main analytical foundations of the data journey concept.

1. Cyber-physical constitution of HEMS data: creating home energy profiles

Before actual HEMS data points emerge as tangible energy knowledge objects, a process of problematizing peak loads takes place. Significantly, in the SGSH project, challenges associated with the residential energy sector were framed in such a way that Dutch and Belgian physical electrical grids remain 'standard', while homes and households became subject to energy 'smartification'. In a broader sense, the physical energy technology and infrastructures (cables, wires) were put in the ground decades ago, and now needed to incorporate accurate digital data for better grid maintenance and management (interview with advisor on grid management, 1 November 2016). As part of a more general residential grid management concern (see above), this project then needed more detailed information about household energy flows. Often, grid operators mention the analogy of traffic jams and finding ways to avoid them. Peak loads in the residential grid work in a similar way, there are consumption peaks in the morning and in the evening, while there is ample local solar energy available in the afternoon. The mismatch between these consumption and production peaks needs to be resolved from a techno-material grid perspective (by 'shifting' and 'shaving' these peaks). However, the home is still 'dumb', and does not measure or share appropriate energy data. A key epistemic challenge is thus to know consumption and production patterns at the level of individual households, and then try to create an automated solution to allow the households to consume self-produced energy (which often

includes a home battery to store and consume it). Problematizing household energy, then, is a *conditio sine qua non* for the production of energy data points as strategic knowledge objects. Most households are invested in this problematization, as they would like to utilize 'their own' renewable energy as much as possible. However, in the SGSH project, grid operators are the main actors to problematize home energy, and the lack of knowledge about it, for underlying grid management purposes. As one grid management actor put it, "The issue is not the technology, but the data" (interview with grid management actor, 20 September 2016). So, before actual data can be produced, there is a grid management need to produce home energy data.

The digital capturing of home energy flows, then, is done in different ways. The smart meter already provides much more information about energy consumption than just a few measurements a year (interview with advisor on grid management, 1 November 2016). Furthermore, the HEMS measures solar energy production, storage capacity, and the state of charge of the electric vehicle. These additional measurements - often based on an average of 15 minutes - produce huge amounts of data points that are algorithmically plotted to assess what I call 'Home Energy Profiles' (HEPs). Even though the category 'HEP' is not explicitly used in the project (although sometimes the term 'load profiles' is used), energy profiles are part and parcel of the HEMS and the broader SGSH project. HEPs represent particular energy flows associated with home devices or energy technologies. The SGSH project employs a wide range of HEPs. First, there are those associated with the local *production* of energy (from solar panels). In the cases of excessive solar energy production, electricity is injected 'back' into the grid, which then creates problematic production peaks for grid operators. Second, there are HEPs related to *consumption*, such as using a washing machine, dish washer, vacuum cleaner, electric kettle, induction stove, laptop adaptor, and so on. Again, excessive energy consumption can create 'problematic peaks', which may lead to grid disturbances, or brown-outs and black-outs. The smart meter is a crucial monitoring device here, as it captures all household electricity consumption as ‘data’, in terms of kilowatt-hours. And third, HEPs can represent the stored capacity of home batteries. All these flows are measured and processed as specific and identifiable data and profiles. There are multiple HEPs, designed to capture different energy flows, which are anything but static and stable units: they can be linked, integrated, and aggregated so as to provide a more ‘complete picture’ of the energy flows of one or multiple households.

2. Cyber-physical data movement and mutability: travelling energy profiles

The HEPs in the SGSH project are quite dynamic, as they move from one cyber-physical place to another. An important ‘starting point’ is the actual place where data points and HEPs come into being, which can be anywhere in a home and its digital connection to the HEMS: the living room, the rooftop, the kitchen, or an attic. Energy consuming practices, but also energy production and storage, are sensed and captured as relevant data points. Radiant light and heat, and social routines (cooking, cleaning), for example, are translated and digitally represented into ‘15-minute averaged data points’. Then these data points become patterns and turn into particular HEPs (see above). The use of 15-minute averaged measurements is a clear indication of translation from the physical to the digital. In the SGSH pilot project, HEPs are mostly used for grid and technical experts ‘behind the scenes’, that is, for monitoring household energy patterns (even at the level of clicks and duration of observing energy feedback by users). Next to the electronic cables and cyberspaces involved, HEPs travel further, from the households to the buildings and SGSH hardware (of software developers and grid operators), both in the Netherlands and Belgium.

A clear example of a travelling HEP (as mutable object [Law and Mol, 2001]) is the integration of specific HEPs: from singular energy patterns to a composite HEP, exemplified by the ‘storage capacity profile’. Storage capacity, in this profile, refers to the ‘state of charge’ of the home battery. However, in a the smart home configuration, the home battery’s profile is connected to other physical devices and their respective digital profiles (solar panels, the oven, state of charge of the electric vehicle). If, for instance, a consumer uses the oven to make dinner during a local energy peak hour (e.g. 6 pm), in order to avoid using grid energy, the smart home tries to utilize energy from the home battery which was charged by solar energy earlier that day. In other words, the digital storage capacity profile is entangled with different energy devices and socio-material household routines. Interestingly, the (re)charging itself is done by the HEMS algorithms, written by the SGSH project software engineers. The HEMS computational architecture calculates, monitors, and integrates a huge number of energy data points. Such integrated calculations facilitate the automated responses of the HEMS to optimize sustainable and autonomous energy use, linked to the overall SGSH project purpose of respecting low ampere grid limits. An advisor on grid management mentioned that even though information management has been around for years “we now have to help people [grid operators] with identifiable patterns” (interview with grid management actor, 1 November 2016). In this context, an interesting example of repurposing would be in elderly health care, as one stakeholder mentioned. If, for instance, energy consuming routines of an elderly patient are monitored and a daily pattern is interrupted (e.g. an expected electricity peak that represents making morning coffee remains absent), then a smart energy technology could alert a care worker to check on this person (interview with software developer, 9 November, 2017). This potential new data journey in a health care setting illustrates not only the potential reuses of energy data, but also its socio-material situatedness. The same holds for potential journeys in which HEMS data is used in a digital energy-sharing platform.

In the SGSH project, data journeys are neither smooth nor neutral cyber-physical trajectories; there are specific thresholds and limits within which energy flows should be maintained. The design of the software architecture serves grid balancing and management purposes. In the case of the battery profile, for example, the limits set refer to charging and discharging parameters. These limits are programmed, so that the battery does not utilize its full potential, and contains an extra buffer for extraordinary times. The limits can be adjusted according to season, as the winter requires more battery capacity because there is reduced solar energy availability and additional heating requirements. These energy profiles are linked to the algorithms that are programmed to respect grid limits, both injecting electricity into and consuming electricity from the grid, design choices that are entangled with socio-political questions. During the SGSH project, questions emerged about the roles and responsibilities of actors vis-à-vis 'controlling' individual solar panels or battery capacity (interview with grid management actor, 2 November 2016). What if, for instance, there is excessive solar production? Under which conditions can grid operators shut down solar production of individual households to prevent peaks in energy production? Or, can grid operators use individual storage capacities to solve grid problems elsewhere? These questions express the blurring of public/private boundaries associated with smart home data and profiles, situated in the context of increased energy decentralization. Instead of considering the (traditional) energy meter as the boundary between individual home autonomy and grid responsibilities, the HEMS (and its use of smart meters) shifts this boundary 'downstream' to the level of individual devices such as home batteries and smart washing machines. Ultimately, the rise of smart homes and digitalized energy information reframes a range of legal and political concerns about grid responsibilities and privacy.

As suggested earlier, the data journey approach suggests a 'journey', as an ongoing movement from devices inside the home to the aggregated monitoring devices of software developers and grid operators. However, in the SGSH project, energy data also move 'back' to the households. Energy feedback is a crucial aspect of informing and engaging users. HEPs are visualised for HEMS users with the aim of monitoring their own energy flows ('front end'). Most households consider the HEMS feedback an 'assistant' in terms of synchronizing energy supply and demand, thereby enabling them to become more

sustainable and autonomous, although in some instances, it was 'just fun' or 'a game' to play around with the new technology. HEPs 'return' to households in roughly two forms. First of all, there is a more or less intuitive user-friendly feedback system: a so-called 'traffic light'. An ambiance light (designed by Philips) has been modified and installed in all 16 households. It produces three signals; green, red or no light, which represent a simple message, namely, whether or not to change energy consuming routines (e.g. cooking, cleaning), in accordance with available and self-produced green energy. The colour-coded feedback is based on individual HEPs and algorithmic calculations and forecasting, a system that indicates that HEPs travel all the way 'back' to kitchens and living rooms, albeit in a different form. Interestingly, within these households there are all kinds of negotiations taking place vis-à-vis the energy feedback. Householders mention that some energy-consuming practices can be delayed, such as turning on the washing machine. Other routines are considered simply non-negotiable, such as cooking or vacuum cleaning prior to a family visit. As one user mentioned, "When you have guests and cook a lot, using lots of electricity, the red light can turn on. But, obviously, I won't stop cooking when that happens" (interview with householder 31 July 2017). In contrast to this micro-resistance to energy feedback, there are also many users who simply try to conform to the traffic light signals. In some cases this takes the form of moral discipline. As an older user told me, "Sometimes, in the morning … when I turn on the kettle and make some tea, I ask myself, is this actually acceptable? That's a strange feeling" (interview with householder, 19 May 2017). The anxiety this person experiences suggests that the traffic light associations (about being a 'good' or 'bad' energy consumer) can address both morals and emotions, which contributes to changing energy-consuming routines.

In addition to this relatively simple energy feedback, there is a more technical and detailed feedback format, called the 'energy dashboard', which provides information about a number of HEPs on a computer website. For instance, a graph can present 'monthly self-sufficiency', referring to ratio of using electricity from self-produced energy compared to electricity used from the grid. For most households, however, there is a limit regarding the level of detail they can process. As one user explained to me, "You should not constantly bother everyone with information, like, you've now used 1.01 hertz. You are going to need medicine for that" (interview with householder, 18 August 2017). Similarly, a grid management actor mentioned that consumers "just want to watch television at 8 o'clock, they just want to eat when they want to. So, it's not the job of the consumer but of grid operators to offer the same level of comfort and optimize the portfolio of the customer" (interview with grid management actor, 20 September 2016). Feedback in the form of detailed HEPs is thus considered meaningful insofar as it provides tangible and useable information for prosumers.

The energy data that travels back to the household, interestingly, is entangled with social dynamics and negotiations among household members. As one HEMS user mentioned, "If the kids say, I want a grilled cheese sandwich, then I can say, maybe not right now [if the feedback lamp is red]. They might get a different type of sandwich instead [that does not require electric heating]" (interview with householder 3 May 2017). In some instances, traditional household (gender) roles and responsibilities are enacted or reproduced, which was the case in another household where I was told, "It's difficult to convince my wife about this story [using the HEMS]. The big changes will be on her account, as she is a big energy user when she washes, irons, and cooks. She is the one who has to adapt" (interview with householder, 7 June 2017).

3. The strategic use of HEMS data: modes of techno-politics

HEPs do specific cyber-physical work. The overall techno-managerial aim of using energy data in the SGSH project is quite clear. As one grid management actor mentioned, "To give an example, if you have an electric vehicle and you come home in the evening at 7 pm, it would be a nightmare if everyone were to start charging their electric vehicles [creating huge electricity grid demands]" (interview with grid

management actor, 20 September 2016). Using self-produced and self-stored home energy – all measured, calculated and managed by the HEMS – could significantly reduce electricity grid peaks. HEPs are particularly interesting for grid operators, because they allow them to stimulate automation and save significant amounts of public money on traditional investments in physical 'wires and cables' (interview with grid advisor, 2 November 2016). Although most SGSH stakeholders claim that investing in physical energy infrastructures is much more costly than using smart solutions (such as smart homes), a few of them still argue that traditional grid investments could be more trustworthy and efficient (interview with grid management actor, 1 November 2016). Nevertheless, national and local energy policy can benefit from HEMS, as they have the potential to contribute to decarbonizing local electricity networks in the broader sustainable energy transition (Verbong & Loorbach, 2012). The HEPs that have been tested and developed in the SGSH project represent modernist techno-politics that provide cyber-physical 'grip' on an increasingly complex grid. It seems that the rise of such cyber-physical energy infrastructures can extend and fine tune existing physical energy infrastructures, thereby providing novel energy governing strategies (Boyer, 2014). Relatedly, for prosumers and users of such HEMS, it might be clear what is in it for them. Despite the relatively high initial investments of buying solar panels, a home battery, and smart appliances, energy data can empower them as it allows them to save money on their electricity bill and become more environmentally friendly and autonomous in terms of energy consumption (Darby, 2006).

Significantly, the political logic underlying the deployment of HEPs and energy managing smart homes more broadly creates opportunities to steer behaviour. First, the disciplinary work that HEPs seem to do is to allow grids to distinguish 'good' from 'bad' energy situations. HEPs produce very detailed information and graphs about energy flows, and when there is too little or too much consumption and availability. This holds for back-end HEPs monitoring low ampere grid limits (of both individual households and groups), but also for front-end HEPs (energy feedback in the home). Consequently, HEPs transform grid management practices by adding a layer of digital representations of household energy flows, and knowledge about problematic energy moments of injection and consumption peaks. Energy data related to finances and tariffs (e.g. euros saved) are particularly relevant, as has been shown in a different project; as I was told, “The difference between peak and off-peak tariffs has to be five times, in order to make consumers change their behaviour” (interview with grid management actor, 20 September 2016).

New forms of visualizing domestic electricity render knowable the kind of activities that are required to be a good ‘grid-respecting’ prosumer: for instance, moving washing activities to another day or even reducing electricity consumption. Without suggesting that seeing energy feedback automatically leads to different conduct, participating SGSH households do try to become more energy efficient. Ambient lighting and energy dashboards or apps, therefore, can be considered cyber-physical interventions that seek to change everyday energy use routines, including financial incentives that punish and reward. The use of HEMS is also tied to the promise of a low voltage grid connection, which is significantly cheaper for households. Many SGSH stakeholders think that this financial advantage could be interesting for the broader public as well (even through there are many technological, economic, and regulatory uncertainties).

Furthermore, the possible mainstreaming of HEMS resonates with consumer lifestyles that cultivate home comfort and convenience while ‘being green’. As some households suggest, the use of HEMS could even increase standards of living by augmenting the opportunities for households to become slightly more knowledgeable, energy autonomous, sustainable, financially aware, and tech-savvy. As Levenda, Mahmoudi, and Sussman (2015) argue, the rise of smart energy goes hand in hand with the neoliberalization of energy systems and practices, while the techno-commercial use of HEPs sits well with modern information and control systems. As I was told, “If the market received more accurate and detailed data, more than one index per year, it would be more

conscious about possibilities and business models” (interview with grid management actor, 20 September 2016). In other words, smart homes (designed for grid management) can be big business. What is more, in order to make HEMS more interesting to the broader public, they could potentially even receive financial compensation for contributing to solving the problem of grid operators (i.e. reducing and balancing local peaks) (interview with technical researcher, 10 January 2018).

The rise of HEMS data is associated with the development of new smart energy products and services for households, which can be (semi-)public or commercial in character. The public role of grid operators is especially significant as they are keen on safeguarding accessible, reliable, safe, affordable, and sustainable energy for *all* households (energy, or even the HEMS, could become a ‘public good’) (interview with grid management actor, 21 October 2016). As mentioned above, the Dutch government co-funded and supported the SGSH project as part of a broader strategy to stimulate economic development related to energy innovations, although this gives rise to risks associated with defining energy and energy data as commercial goods (e.g. selling energy data to third parties, decreased accountability). Furthermore, specific options are also explored in a ‘community model’ in which a virtual community of HEMS could self-produce and share renewable energy (interview with software developer, 7 December 2017). Such a community is ‘cyber-physical-geographical-legal’, since it is geographically local but also stimulated by European regulations and physical infrastructure, as well as by a HEMS-like digital platform (interview with grid management actor, 15 January 2018). One could argue that this resonates with the notion of energy democracy as a political strategy to empower citizens groups and local energy communities (Szulecki, 2018). For more commercial stakeholders, the SGSH project even works as an R&D innovation project. However, if energy data are produced and travel mostly due to financial incentives, it could become problematic, especially in cases where energy data are designed and controlled by a few or only a single commercial tech company (Kitchin, 2014).

During one of the stakeholder workshops, there was a discussion about whether households could also see more detailed information about their own energy profiles but the back-end energy profiles (this seemed to be the argument at least from professionals) seemed to be considered less relevant and too technical for householders. Yet, if energy data management systems are not transparent and accessible, they might undermine the trustworthiness and public character of grid-related energy data. As an alternative, a more hybrid techno-political strategy is explored in the SGSH project in which grid operators engage in (medium or large scale) contracting, or employ HEMS as part of a broader grid management repertoire to solve local grid problems (at the level of specific streets). In that scenario, only a few "problematic households" could be targeted by grid operators, who could install HEMS in those homes to solve a local grid problem (interview with grid advisor, 2 November 2016).

A final political issue related to the HEPs (in the SGSH project at least) is that they seem to benefit a small group of users. The HEMS are tested and adopted in particular rural areas, in households with higher incomes, higher education, energy-saving awareness, and an interest in energy autonomy. Consequently, an expanding gap might emerge between households that enjoy the financial, environmental, and informational fruits of HEMS and households without them (particular households in particular cities or districts). Most participating households and HEMS developers argue that this energy technology should become interesting for the broader public, highlighting, for instance, its money-saving potential and the need for regulatory standardization for accelerating market development (of whitegoods products and designs). If only frontrunners adopt a HEMS, it could create adverse effects. What if, for instance, only future HEMS users with higher energy capacity have access to lower energy prices on a structural basis than low income groups (interview with grid management actor, 1 November 2016)? This could unfold along the line of digital inequalities, the infamous digital divide, and intersecting socio-economic inequalities (Day, Walker & Simcock, 2016).

Conclusion and discussion

This paper has discussed the cyber-physical life of energy data, in particular in relation to smart homes. Residential energy data are much more than just digital knowledge objects. The empirical case showed that they represent specific and highly dynamic socio-material measurements, updated every 15 minutes, strung together as energy patterns (which I termed 'HEPs'), and individualized yet transmittable. As Aroles and McLean (2016) suggest, the power of HEPs lies in their ability to re-emerge in novel contexts, that is, to be flexibly reconnected and become significant repeatedly. HEPs are standardized objects of knowledge about very particular energy flows, but can be merged, shared, repeated, replicated, and modified.

Although it was developed in relation to meteorological data, the data journey approach presented by Bates et al. (2016) was productive in assessing how HEMS data emerge and move through energy infrastructures. The study showed that during the establishment of data, a process of problematizing household energy peaks is conditional. The approach also showed that HEPs, as standardized yet highly flexible energy representations, fuse two "ontologies of social order" (Strengers, 2013: 8): the 'techno-rational' and the 'messy social'. Thus, energy data should be understood as cyber-socio-physical entanglements. This contribution shows that energy data journeys are cyber-material, and highlights how specific energy data travel between socio-material places (Bates, 2018). HEPs travel via cooking practices, smart meters, washing machines, energy markets, computer hardware, databases, clouds and computational software, laptops in the living room, gender roles, and weekly laundry practices. Importantly, whenever energy data move, they are transformed, as they gain new relevance in different configurations. Energy management and feedback, then, constitute a circular movement of automated energy monitoring, constant digital updating, and shifting energy routines. Importantly, energy data movement re-assembles existing socio-technical energy relations between prosumers, grid managers, and other actors.

The energy data journey approach also proved to be fruitful in highlighting the techno-political strategies associated with their production and movement across places. So, what did the approach offer in terms of considering the smart home and energy data as "political terrain for the negotiation of moral-political questions" (2013: 671)? How are energy profiles used, and who wins and loses? Clearly, the use of big data in residential energy infrastructures is driven by a profound techno-scientific, even anti-political, commitment to managing socio-technical systems (Strengers, 2013; Sadowski & Levenda, 2020). Not only avoiding public discussion, but also steering away from public investments in physical grids by grid operators, the neoliberal approach embedded in the SGSH project focusses on a digital grid, delegating responsibility to energy-shifting households. Most of these households already participate in energy efficient practices (as friendly users), but without playing a significant role in residential grid management. This techno-neoliberal strategy to govern the grid employs energy data in a hybrid public-private network, rendering individual households responsible for investing in costly energy technologies and smart devices. I argue that smart home data empower three groups, all in particular ways: smart home prosumers, grid operators, and commercial energy (tech-)companies. Prosumers gain more decision-making power over their own energy system, while grid operators gain more fine-grained insights, storage capacities, and grid management capacity. In market-driven energy sectors, smart homes allow commercial companies to develop innovative physical and digital energy products. The energy data journeys themselves, and the values they produce during such movement, are geared towards making already powerful actors in the energy regime more powerful (all three groups). Simultaneously, such smart home technologies seem to reproduce societal inequalities, especially disempowering low-income households, and groups with little affinity for technology and sustainable energy.

These journeys and their associated accumulation of power, however, are not entirely fixed. The potentialities of energy data for digital health care services or energy-sharing platforms, as we have seen, point to the techno-political mutability of such data. This results in moral and political questions about energy data ownership, and how individualized energy profiles are related to surveillance, commodification, and hackability (Kitchin, 2014). To be sure, it is rather unclear whether one would still own the data recording one's own energy routines in smart home projects implemented on a large scale. At the same time, the energy data journey does not have a fixed meaning or final location. This means that repurposing household energy data points potentially resonates with more democratic strategies that would democratize renewable energy systems (e.g. community ownership, energy cooperatives). These techno-political aspects of energy data are particularly interesting, as they relate to different political narratives in the broader sustainable energy transition in which, no matter the scenario, the political uses of energy data – such as moving and changing cyber-physical 'objects' - cannot be underestimated, requiring continued scrutiny from researchers, software developers, and policy makers.

The proposed energy data journey approach is particularly fruitful given the world-wide mushrooming of (sustainable) smart energy projects. Energy data are expected to be co-produced and adopted by grid operators, engineers, commercial companies, policy makers, and citizens. An energy data journey approach tailored to (green) energy regimes, as proposed in this study, contributes to STS-informed energy research. STS scholars, in particular, should engage in critical research on the micropolitics of energy data, and the role of big data in the energy transition more broadly.

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